WIRELESS ENERGY TRANSFER SYSTEMS

CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] This application claims the benefit of the following U.S. patent applications, each of which is hereby incorporated by reference in its entirety:

[0002] U.S. App. No. 61/100,721 filed September 27,2008; U.S. App. No. 61/108,743 filed October 27, 2008; U.S. App. No. 61/147,386 filed January 26, 2009; U.S. App. No. 61/152,086 filed February 12, 2009; U.S. App. No. 61/178,508 filed May 15, 2009; U.S. App. No. 61/182,768 filed June 1, 2009; U.S. App. No. 61/121,159 filed December 9, 2008; U.S. App. No. 61/142,977 filed January 7, 2009; U.S. App. No. 61/142,885 filed January 6, 2009; U.S. App. No. 61/142,796 filed January 6, 2009; U.S. App. No. 61/142,889 filed January 6, 2009; U.S. App. No. 61/142,880 filed January 6, 2009; U.S. App. No. 61/142,818 filed January 6, 2009; U.S. App. No. 61/142,887 filed January 6, 2009; U.S. App. No. 61/156,764 filed March 2, 2009; U.S. App. No. 61/143,058 filed January 7, 2009; U.S. App. No. 61/152,390 filed February 13, 2009; U.S. App. No. 61/163,695 filed March 26, 2009; U.S. App. No. 61/172,633 filed April 24, 2009; U.S. App. No. 61/169,240 filed April 14, 2009, and U.S. App. No. 61/173,747 filed April 29, 2009.

BACKGROUND

[0003] Field:

[0004] This disclosure relates to wireless energy transfer, also referred to as wireless power transmission.

[0005] Description of the Related Art:

[0006] Energy or power may be transferred wirelessly using a variety of known radiative, or far-field, and non-radiative, or near-field, techniques. For example, radiative wireless information transfer using low-directionality antennas, such as those used in radio and cellular communications systems and home computer networks, may be considered wireless energy transfer. However, this type of radiative transfer is very inefficient because only a tiny portion of the supplied or radiated power, namely, that portion in the direction of, and

InductEV, Inc.
Exhibit 1002
Page 001

overlapping with, the receiver is picked up. The vast majority of the power is radiated away in all the other directions and lost in free space. Such inefficient power transfer may be acceptable for data transmission, but is not practical for transferring useful amounts of electrical energy for the purpose of doing work, such as for powering or charging electrical devices. One way to improve the transfer efficiency of some radiative energy transfer schemes is to use directional antennas to confine and preferentially direct the radiated energy towards a receiver. However, these directed radiation schemes may require an uninterruptible line-of-sight and potentially complicated tracking and steering mechanisms in the case of mobile transmitters and/or receivers. In addition, such schemes may pose hazards to objects or people that cross or intersect the beam when modest to high amounts of power are being transmitted. A known non-radiative, or near-field, wireless energy transfer scheme, often referred to as either induction or traditional induction, does not (intentionally) radiate power, but uses an oscillating current passing through a primary coil, to generate an oscillating magnetic near-field that induces currents in a near-by receiving or secondary coil. Traditional induction schemes have demonstrated the transmission of modest to large amounts of power, however only over very short distances, and with very small offset tolerances between the primary power supply unit and the secondary receiver unit. Electric transformers and proximity chargers are examples of devices that utilize this known short range, near-field energy transfer scheme.

[0007] Therefore a need exists for a wireless power transfer scheme that is capable of transferring useful amounts of electrical power over mid-range distances or alignment offsets. Such a wireless power transfer scheme should enable useful energy transfer over greater distances and alignment offsets than those realized with traditional induction schemes, but without the limitations and risks inherent in radiative transmission schemes.

SUMMARY

[0008] There is disclosed herein a non-radiative or near-field wireless energy transfer scheme that is capable of transmitting useful amounts of power over mid-range distances and alignment offsets. This inventive technique uses coupled electromagnetic resonators with long-lived oscillatory resonant modes to transfer power from a power supply to a power drain. The technique is general and may be applied to a wide range of resonators, even where the specific examples disclosed herein relate to electromagnetic resonators. If the resonators are designed

InductEV, Inc.
Exhibit 1002
Page 002

such that the energy stored by the electric field is primarily confined within the structure and that the energy stored by the magnetic field is primarily in the region surrounding the resonator. Then, the energy exchange is mediated primarily by the resonant magnetic near-field. These types of resonators may be referred to as magnetic resonators. If the resonators are designed such that the energy stored by the magnetic field is primarily confined within the structure and that the energy stored by the electric field is primarily in the region surrounding the resonator. Then, the energy exchange is mediated primarily by the resonant electric near-field. These types of resonators may be referred to as electric resonators. Either type of resonator may also be referred to as an electromagnetic resonator. Both types of resonators are disclosed herein.

[0009] The omni-directional but stationary (non-lossy) nature of the near-fields of the resonators we disclose enables efficient wireless energy transfer over mid-range distances, over a wide range of directions and resonator orientations, suitable for charging, powering, or simultaneously powering and charging a variety of electronic devices. As a result, a system may have a wide variety of possible applications where a first resonator, connected to a power source, is in one location, and a second resonator, potentially connected to electrical/electronic devices, batteries, powering or charging circuits, and the like, is at a second location, and where the distance from the first resonator to the second resonator is on the order of centimeters to meters. For example, a first resonator connected to the wired electricity grid could be placed on the ceiling of a room, while other resonators connected to devices, such as robots, vehicles, computers, communication devices, medical devices, and the like, move about within the room, and where these devices are constantly or intermittently receiving power wirelessly from the source resonator. From this one example, one can imagine many applications where the systems and methods disclosed herein could provide wireless power across mid-range distances, including consumer electronics, industrial applications, infrastructure power and lighting, transportation vehicles, electronic games, military applications, and the like.

[0010] Energy exchange between two electromagnetic resonators can be optimized when the resonators are tuned to substantially the same frequency and when the losses in the system are minimal. Wireless energy transfer systems may be designed so that the “coupling-time” between resonators is much shorter than the resonators’ “loss-times”. Therefore, the systems and methods described herein may utilize high quality factor (high-Q) resonators with low intrinsic-loss rates. In addition, the systems and methods described herein may use sub-

InductEV, Inc.
Exhibit 1002
Page 003

wavelength resonators with near-fields that extend significantly longer than the characteristic sizes of the resonators, so that the near-fields of the resonators that exchange energy overlap at mid-range distances. This is a regime of operation that has not been practiced before and that differs significantly from traditional induction designs.

[0011] It is important to appreciate the difference between the high-Q magnetic resonator scheme disclosed here and the known close-range or proximity inductive schemes, namely, that those known schemes do not conventionally utilize high-Q resonators. Using coupled-mode theory (CMT), (see, for example, *Waves and Fields in Optoelectronics*, H.A. Haus, Prentice Hall, 1984), one may show that a high-Q resonator-coupling mechanism can enable orders of magnitude more efficient power delivery between resonators spaced by mid-range distances than is enabled by traditional inductive schemes. Coupled high-Q resonators have demonstrated efficient energy transfer over mid-range distances and improved efficiencies and offset tolerances in short range energy transfer applications.

[0012] The systems and methods described herein may provide for near-field wireless energy transfer via strongly coupled high-Q resonators, a technique with the potential to transfer power levels from picowatts to kilowatts, safely, and over distances much larger than have been achieved using traditional induction techniques. Efficient energy transfer may be realized for a variety of general systems of strongly coupled resonators, such as systems of strongly coupled acoustic resonators, nuclear resonators, mechanical resonators, and the like, as originally described by researchers at M.I.T. in their publications, "Efficient wireless non-radiative mid-range energy transfer", *Annals of Physics*, vol. 323, Issue 1, p. 34 (2008) and "Wireless Power Transfer via Strongly Coupled Magnetic Resonances", *Science*, vol. 317, no. 5834, p. 83, (2007). Disclosed herein are electromagnetic resonators and systems of coupled electromagnetic resonators, also referred to more specifically as coupled magnetic resonators and coupled electric resonators, with operating frequencies below 10 GHz.

[0013] This disclosure describes wireless energy transfer technologies, also referred to as wireless power transmission technologies. Throughout this disclosure, we may use the terms wireless energy transfer, wireless power transfer, wireless power transmission, and the like, interchangeably. We may refer to supplying energy or power from a source, an AC or DC source, a battery, a source resonator, a power supply, a generator, a solar panel, and thermal collector, and the like, to a device, a remote device, to multiple remote devices, to a device

InductEV, Inc.
Exhibit 1002
Page 004

resonator or resonators, and the like. We may describe intermediate resonators that extend the range of the wireless energy transfer system by allowing energy to hop, transfer through, be temporarily stored, be partially dissipated, or for the transfer to be mediated in any way, from a source resonator to any combination of other device and intermediate resonators, so that energy transfer networks, or strings, or extended paths may be realized. Device resonators may receive energy from a source resonator, convert a portion of that energy to electric power for powering or charging a device, and simultaneously pass a portion of the received energy onto other device or mobile device resonators. Energy may be transferred from a source resonator to multiple device resonators, significantly extending the distance over which energy may be wirelessly transferred. The wireless power transmission systems may be implemented using a variety of system architectures and resonator designs. The systems may include a single source or multiple sources transmitting power to a single device or multiple devices. The resonators may be designed to be source or device resonators, or they may be designed to be repeaters. In some cases, a resonator may be a device and source resonator simultaneously, or it may be switched from operating as a source to operating as a device or a repeater. One skilled in the art will understand that a variety of system architectures may be supported by the wide range of resonator designs and functionalities described in this application.

[0014] In the wireless energy transfer systems we describe, remote devices may be powered directly, using the wirelessly supplied power or energy, or the devices may be coupled to an energy storage unit such as a battery, a super-capacitor, an ultra-capacitor, or the like (or other kind of power drain), where the energy storage unit may be charged or re-charged wirelessly, and/or where the wireless power transfer mechanism is simply supplementary to the main power source of the device. The devices may be powered by hybrid battery/energy storage devices such as batteries with integrated storage capacitors and the like. Furthermore, novel battery and energy storage devices may be designed to take advantage of the operational improvements enabled by wireless power transmission systems.

[0015] Other power management scenarios include using wirelessly supplied power to recharge batteries or charge energy storage units while the devices they power are turned off, in an idle state, in a sleep mode, and the like. Batteries or energy storage units may be charged or recharged at high (fast) or low (slow) rates. Batteries or energy storage units may be trickle charged or float charged. Multiple devices may be charged or powered simultaneously in parallel

InductEV, Inc.
Exhibit 1002
Page 005

or power delivery to multiple devices may be serialized such that one or more devices receive power for a period of time after which other power delivery is switched to other devices. Multiple devices may share power from one or more sources with one or more other devices either simultaneously, or in a time multiplexed manner, or in a frequency multiplexed manner, or in a spatially multiplexed manner, or in an orientation multiplexed manner, or in any combination of time and frequency and spatial and orientation multiplexing. Multiple devices may share power with each other, with at least one device being reconfigured continuously, intermittently, periodically, occasionally, or temporarily, to operate as wireless power sources. It would be understood by one of ordinary skill in the art that there are a variety of ways to power and/or charge devices, and the variety of ways could be applied to the technologies and applications described herein.

[0016] Wireless energy transfer has a variety of possible applications including for example, placing a source (e.g. one connected to the wired electricity grid) on the ceiling, under the floor, or in the walls of a room, while devices such as robots, vehicles, computers, PDAs or similar are placed or move freely within the room. Other applications may include powering or recharging electric-engine vehicles, such as buses and/or hybrid cars and medical devices, such as wearable or implantable devices. Additional example applications include the ability to power or recharge autonomous electronics (e.g. laptops, cell-phones, portable music players, household robots, GPS navigation systems, displays, etc), sensors, industrial and manufacturing equipment, medical devices and monitors, home appliances and tools (e.g. lights, fans, drills, saws, heaters, displays, televisions, counter-top appliances, etc.), military devices, heated or illuminated clothing, communications and navigation equipment, including equipment built into vehicles, clothing and protective-wear such as helmets, body armor and vests, and the like, and the ability to transmit power to physically isolated devices such as to implanted medical devices, to hidden, buried, implanted or embedded sensors or tags, to and/or from roof-top solar panels to indoor distribution panels, and the like.

[0017] In one aspect, disclosed herein is a system including a source resonator having a Q-factor Q_1 and a characteristic size $_{x1}$, coupled to a power generator with direct electrical connections; and a second resonator having a Q-factor Q_2 and a characteristic size x_2, coupled to a load with direct electrical connections, and located a distance D from the source resonator, wherein the source resonator and the second resonator are coupled to exchange energy wirelessly

InductEV, Inc.
Exhibit 1002
Page 006

among the source resonator and the second resonator in order to transmit power from the power generator to the load, and wherein $\sqrt{Q_1 Q_2}$ is greater than 100.

[0018] Q_1 may be greater than 100 and Q_2 may be less than 100. Q_1 may be greater than 100 and Q_2 may be greater than 100. A useful energy exchange may be maintained over an operating distance from 0 to D, where D is larger than the smaller of x_1 and x_2. At least one of the source resonator and the second resonator may be a coil of at least one turn of a conducting material connected to a first network of capacitors. The first network of capacitors may include at least one tunable capacitor. The direct electrical connections of at least one of the source resonator to the ground terminal of the power generator and the second resonator to the ground terminal of the load may be made at a point on an axis of electrical symmetry of the first network of capacitors. The first network of capacitors may include at least one tunable butterfly-type capacitor, wherein the direct electrical connection to the ground terminal is made on a center terminal of the at least one tunable butterfly-type capacitor. The direct electrical connection of at least one of the source resonator to the power generator and the second resonator to the load may be made via a second network of capacitors, wherein the first network of capacitors and the second network of capacitors form an impedance matching network. The impedance matching network may be designed to match the coil to a characteristic impedance of the power generator or the load at a driving frequency of the power generator.

[0019] At least one of the first network of capacitors and the second network of capacitors may include at least one tunable capacitor. The first network of capacitors and the second network of capacitors may be adjustable to change an impedance of the impedance matching network at a driving frequency of the power generator. The first network of capacitors and the second network of capacitors may be adjustable to match the coil to the characteristic impedance of the power generator or the load at a driving frequency of the power generator. At least one of the first network of capacitors and the second network of capacitors may include at least one fixed capacitor that reduces a voltage across the at least one tunable capacitor. The direct electrical connections of at least one of the source resonator to the power generator and the second resonator to the load may be configured to substantially preserve a resonant mode. At least one of the source resonator and the second resonator may be a tunable resonator. The source resonator may be physically separated from the power generator and the second resonator may be physically separated from the load. The second resonator may be coupled to a power

InductEV, Inc.
Exhibit 1002
Page 007

conversion circuit to deliver DC power to the load. The second resonator may be coupled to a power conversion circuit to deliver AC power to the load. The second resonator may be coupled to a power conversion circuit to deliver both AC and DC power to the load. The second resonator may be coupled to a power conversion circuit to deliver power to a plurality of loads.

[0020] In another aspect, a system disclosed herein includes a source resonator having a Q-factor Q_1 and a characteristic size x_1, and a second resonator having a Q-factor Q_2 and a characteristic size x_2, and located a distance D from the source resonator; wherein the source resonator and the second resonator are coupled to exchange energy wirelessly among the source resonator and the second resonator; and wherein $\sqrt{Q_1 Q_2}$ is greater than 100, and wherein at least one of the resonators is enclosed in a low loss tangent material.

[0021] In another aspect, a system disclosed herein includes a source resonator having a Q-factor Q_1 and a characteristic size x_1, and a second resonator having a Q-factor Q_2 and a characteristic size x_2, and located a distance D from the source resonator; wherein the source resonator and the second resonator are coupled to exchange energy wirelessly among the source resonator and the second resonator, and wherein $\sqrt{Q_1 Q_2}$ is greater than 100; and wherein at least one of the resonators includes a coil of a plurality of turns of a conducting material connected to a network of capacitors, wherein the plurality of turns are in a common plane, and wherein a characteristic thickness of the at least one of the resonators is much less than a characteristic size of the at least one of the resonators.

[0022] Throughout this disclosure we may refer to the certain circuit components such as capacitors, inductors, resistors, diodes, switches and the like as circuit components or elements. We may also refer to series and parallel combinations of these components as elements, networks, topologies, circuits, and the like. We may describe combinations of capacitors, diodes, varactors, transistors, and/or switches as adjustable impedance networks, tuning networks, matching networks, adjusting elements, and the like. We may also refer to "self-resonant" objects that have both capacitance, and inductance distributed (or partially distributed, as opposed to solely lumped) throughout the entire object. It would be understood by one of ordinary skill in the art that adjusting and controlling variable components within a circuit or network may adjust the performance of that circuit or network and that those adjustments may be described generally as tuning, adjusting, matching, correcting, and the like. Other methods to

InductEV, Inc.
Exhibit 1002
Page 008

tune or adjust the operating point of the wireless power transfer system may be used alone, or in addition to adjusting tunable components such as inductors and capacitors, or banks of inductors and capacitors.

[0023] Unless otherwise defined, all technical and scientific terms used herein have the same meaning as commonly understood by one of ordinary skill in the art to which this disclosure belongs. In case of conflict with publications, patent applications, patents, and other references mentioned or incorporated herein by reference, the present specification, including definitions, will control.

[0024] Any of the features described above may be used, alone or in combination, without departing from the scope of this disclosure. Other features, objects, and advantages of the systems and methods disclosed herein will be apparent from the following detailed description and figures.

BRIEF DESCRIPTION OF FIGURES

[0025] Fig. 1 (a) and (b) depict exemplary wireless power systems containing a source resonator 1 and device resonator 2 separated by a distance D.

[0026] Fig. 2 shows an exemplary resonator labeled according to the labeling convention described in this disclosure. Note that there are no extraneous objects or additional resonators shown in the vicinity of resonator 1.

[0027] Fig. 3 shows an exemplary resonator in the presence of a "loading" object, labeled according to the labeling convention described in this disclosure.

[0028] Fig. 4 shows an exemplary resonator in the presence of a "perturbing" object, labeled according to the labeling convention described in this disclosure.

[0029] Fig. 5 shows a plot of efficiency, η, vs. strong coupling factor, $U = \kappa \Big/ \sqrt{\Gamma_s \Gamma_d} = k\sqrt{Q_s Q_d}$.

[0030] Fig. 6 (a) shows a circuit diagram of one example of a resonator (b) shows a diagram of one example of a capacitively-loaded inductor loop magnetic resonator, (c) shows a drawing of a self-resonant coil with distributed capacitance and inductance, (d) shows a simplified drawing of the electric and magnetic field lines associated with an exemplary magnetic resonator of the current disclosure, and (e) shows a diagram of one example of an electric resonator.

InductEV, Inc.
Exhibit 1002
Page 009

[0031] Fig. 7 shows a plot of the "quality factor", Q (solid line), as a function of frequency, of an exemplary resonator that may be used for wireless power transmission at MHz frequencies. The absorptive Q (dashed line) increases with frequency, while the radiative Q (dotted line) decreases with frequency, thus leading the overall Q to peak at a particular frequency.

[0032] Fig. 8 shows a drawing of a resonator structure with its characteristic size, thickness and width indicated.

[0033] Fig. 9 (a) and (b) show drawings of exemplary inductive loop elements.

[0034] Fig. 10 (a) and (b) show two examples of trace structures formed on printed circuit boards and used to realize the inductive element in magnetic resonator structures.

[0035] Fig. 11 (a) shows a perspective view diagram of a planar magnetic resonator, (b) shows a perspective view diagram of a two planar magnetic resonator with various geometries, and c) shows is a perspective view diagram of a two planar magnetic resonators separated by a distance D.

[0036] Fig. 12 is a perspective view of an example of a planar magnetic resonator.

[0037] Fig. 13 is a perspective view of a planar magnetic resonator arrangement with a circular resonator coil.

[0038] Fig. 14 is a perspective view of an active area of a planar magnetic resonator.

[0039] Fig. 15 is a perspective view of an application of the wireless power transfer system with a source at the center of a table powering several devices placed around the source.

[0040] Fig. 16(a) shows a 3D finite element model of a copper and magnetic material structure driven by a square loop of current around the choke point at its center. In this example, a structure may be composed of two boxes made of a conducting material such as copper, covered by a layer of magnetic material, and connected by a block of magnetic material. The inside of the two conducting boxes in this example would be shielded from AC electromagnetic fields generated outside the boxes and may house lossy objects that might lower the Q of the resonator or sensitive components that might be adversely affected by the AC electromagnetic fields. Also shown are the calculated magnetic field streamlines generated by this structure, indicating that the magnetic field lines tend to follow the lower reluctance path in the magnetic material. Fig. 16(b) shows interaction, as indicated by the calculated magnetic field streamlines, between two identical structures as shown in (a). Because of symmetry, and to reduce

computational complexity, only one half of the system is modeled (but the computation assumes the symmetrical arrangement of the other half).

[0041] Fig. 17 shows an equivalent circuit representation of a magnetic resonator including a conducting wire wrapped *N* times around a structure, possibly containing magnetically permeable material. The inductance is realized using conducting loops wrapped around a structure comprising a magnetic material and the resistors represent loss mechanisms in the system (R_{wire} for resistive losses in the loop, R_{μ} denoting the equivalent series resistance of the structure surrounded by the loop). Losses may be minimized to realize high-Q resonators.

[0042] Fig. 18 shows a Finite Element Method (FEM) simulation of two high conductivity surfaces above and below a disk composed of lossy dielectric material, in an external magnetic field of frequency 6.78 MHz. Note that the magnetic field was uniform before the disk and conducting materials were introduced to the simulated environment. This simulation is performed in cylindrical coordinates. The image is azimuthally symmetric around the $r = 0$ axis. The lossy dielectric disk has $\epsilon_r = 1$ and $\sigma = 10$ S/m.

[0043] Fig. 19 shows a drawing of a magnetic resonator with a lossy object in its vicinity completely covered by a high-conductivity surface.

[0044] Fig. 20 shows a drawing of a magnetic resonator with a lossy object in its vicinity partially covered by a high-conductivity surface.

[0045] Fig. 21 shows a drawing of a magnetic resonator with a lossy object in its vicinity placed on top of a high-conductivity surface.

[0046] Fig. 22 shows a diagram of a completely wireless projector.

[0047] Fig. 23 shows the magnitude of the electric and magnetic fields along a line that contains the diameter of the circular loop inductor and along the axis of the loop inductor.

[0048] Fig. 24 shows a drawing of a magnetic resonator and its enclosure along with a necessary but lossy object placed either (a) in the corner of the enclosure, as far away from the resonator structure as possible or (b) in the center of the surface enclosed by the inductive element in the magnetic resonator.

[0049] Fig. 25 shows a drawing of a magnetic resonator with a high-conductivity surface above it and a lossy object, which may be brought into the vicinity of the resonator, but above the high-conductivity sheet.

InductEV, Inc.
Exhibit 1002
Page 011

[0050] Fig. 26(a) shows an axially symmetric FEM simulation of a thin conducting (copper) cylinder or disk (20 cm in diameter, 2 cm in height) exposed to an initially uniform, externally applied magnetic field (gray flux lines) along the z-axis. The axis of symmetry is at r=0. The magnetic streamlines shown originate at $z = -\infty$, where they are spaced from r=3 cm to r=10 cm in intervals of 1 cm. The axes scales are in meters. Fig. 26 (b) shows the same structure and externally applied field as in (a), except that the conducting cylinder has been modified to include a 0.25 mm layer of magnetic material (not visible) with $\mu_r^{'}$=40, on its outside surface. Note that the magnetic streamlines are deflected away from the cylinder significantly less than in (a).

[0051] Fig. 27 shows an axi-symmetric view of a variation based on the system shown in Fig. 26. Only one surface of the lossy material is covered by a layered structure of copper and magnetic materials. The inductor loop is placed on the side of the copper and magnetic material structure opposite to the lossy material as shown.

[0052] Fig. 28 (a) depicts a general topology of a matching circuit including an indirect coupling to a high-Q inductive element.

[0053] Fig. 28 (b) shows a block diagram of a magnetic resonator that includes a conductor loop inductor and a tunable impedance network. Physical electrical connections to this resonator may be made to the terminal connections.

[0054] Fig. 28 (c) depicts a general topology of a matching circuit directly coupled to a high-Q inductive element.

[0055] Fig. 28 (d) depicts a general topology of a symmetric matching circuit directly coupled to a high-Q inductive element and driven anti-symmetrically (balanced drive).

[0056] Fig. 28 (e) depicts a general topology of a matching circuit directly coupled to a high-Q inductive element and connected to ground at a point of symmetry of the main resonator (unbalanced drive).

[0057] Figs. 29(a) and 29(b) depict two topologies of matching circuits transformer-coupled (i.e. indirectly or inductively) to a high-Q inductive element. The highlighted portion of the Smith chart in (c) depicts the complex impedances (arising from L and R of the inductive element) that may be matched to an arbitrary real impedance Z_0 by the topology of Fig. 31(b) in the case $\omega L_2 = 1/\omega C_2$.

InductEV, Inc.
Exhibit 1002
Page 012

[0058] Figs. 30(a),(b),(c),(d),(e),(f) depict six topologies of matching circuits directly coupled to a high-Q inductive element and including capacitors in series with Z_0. The topologies shown in Figs. 30(a),(b),(c) are driven with a common-mode signal at the input terminals, while the topologies shown in Figs 30(d),(e),(f) are symmetric and receive a balanced drive. The highlighted portion of the Smith chart in 30(g) depicts the complex impedances that may be matched by these topologies. Figs. 30(h),(i),(j),(k),(l),(m) depict six topologies of matching circuits directly coupled to a high-Q inductive element and including inductors in series with Z_0.

[0059] Figs. 31(a),(b),(c) depict three topologies of matching circuits directly coupled to a high-Q inductive element and including capacitors in series with Z_0. They are connected to ground at the center point of a capacitor and receive an unbalanced drive. The highlighted portion of the Smith chart in Fig. 31(d) depicts the complex impedances that may be matched by these topologies. Figs. 31(e),(f),(g) depict three topologies of matching circuits directly coupled to a high-Q inductive element and including inductors in series with Z_0.

[0060] Figs. 32(a),(b),(c) depict three topologies of matching circuits directly coupled to a high-Q inductive element and including capacitors in series with Z_0. They are connected to ground by tapping at the center point of the inductor loop and receive an unbalanced drive. The highlighted portion of the Smith chart in (d) depicts the complex impedances that may be matched by these topologies, (e),(f),(g) depict three topologies of matching circuits directly coupled to a high-Q inductive element and including inductors in series with Z_0.

[0061] Figs. 33(a),(b),(c),(d),(e),(f) depict six topologies of matching circuits directly coupled to a high-Q inductive element and including capacitors in parallel with Z_o. The topologies shown in Figs. 33(a),(b),(c) are driven with a common-mode signal at the input terminals, while the topologies shown in Figs 33(d),(e),(f) are symmetric and receive a balanced drive. The highlighted portion of the Smith chart in Fig. 33(g) depicts the complex impedances that may be matched by these topologies. Figs. 33(h),(i),(j),(k),(l),(m) depict six topologies of matching circuits directly coupled to a high-Q inductive element and including inductors in parallel with Z_o.

[0062] Figs. 34(a),(b),(c) depict three topologies of matching circuits directly coupled to a high-Q inductive element and including capacitors in parallel with Z_0. They are connected to ground at the center point of a capacitor and receive an unbalanced drive. The highlighted portion of the Smith chart in (d) depicts the complex impedances that may be matched by these

InductEV, Inc.
Exhibit 1002
Page 013

topologies. Figs. 34(e),(f),(g) depict three topologies of matching circuits directly coupled to a high-Q inductive element and including inductors in parallel with Z_0.

[0063] Figs. 35(a),(b),(c) depict three topologies of matching circuits directly coupled to a high-Q inductive element and including capacitors in parallel with Z_0. They are connected to ground by tapping at the center point of the inductor loop and receive an unbalanced drive. The highlighted portion of the Smith chart in Figs. 35(d),(e), and (f) depict the complex impedances that may be matched by these topologies.

[0064] Figs. 36(a),(b),(c),(d) depict four topologies of networks of fixed and variable capacitors designed to produce an overall variable capacitance with finer tuning resolution and some with reduced voltage on the variable capacitor.

[0065] Figs. 37(a) and 37(b) depict two topologies of networks of fixed capacitors and a variable inductor designed to produce an overall variable capacitance.

[0066] Fig. 38 depicts a high level block diagram of a wireless power transmission system.

[0067] Fig. 39 depicts a block diagram of an exemplary wirelessly powered device.

[0068] Fig. 40 depicts a block diagram of the source of an exemplary wireless power transfer system.

[0069] Fig. 41 shows an equivalent circuit diagram of a magnetic resonator. The slash through the capacitor symbol indicates that the represented capacitor may be fixed or variable. The port parameter measurement circuitry may be configured to measure certain electrical signals and may measure the magnitude and phase of signals.

[0070] Fig. 42 shows a circuit diagram of a magnetic resonator where the tunable impedance network is realized with voltage controlled capacitors. Such an implementation may be adjusted, tuned or controlled by electrical circuits including programmable or controllable voltage sources and/or computer processors. The voltage controlled capacitors may be adjusted in response to data measured by the port parameter measurement circuitry and processed by measurement analysis and control algorithms and hardware. The voltage controlled capacitors may be a switched bank of capacitors.

[0071] Fig. 43 shows an end-to-end wireless power transmission system. In this example, both the source and the device contain port measurement circuitry and a processor. The box labeled "coupler/switch" indicates that the port measurement circuitry may be connected to

InductEV, Inc.
Exhibit 1002
Page 014

the resonator by a directional coupler or a switch, enabling the measurement, adjustment and control of the source and device resonators to take place in conjunction with, or separate from, the power transfer functionality.

[0072] Fig. 44 shows an end-to-end wireless power transmission system. In this example, only the source contains port measurement circuitry and a processor. In this case, the device resonator operating characteristics may be fixed or may be adjusted by analog control circuitry and without the need for control signals generated by a processor.

[0073] Fig. 45 shows an end-to-end wireless power transmission system. In this example, both the source and the device contain port measurement circuitry but only the source contains a processor. Data from the device is transmitted through a wireless communication channel, which could be implemented either with a separate antenna, or through some modulation of the source drive signal.

[0074] Fig. 46 shows an end-to-end wireless power transmission system. In this example, only the source contains port measurement circuitry and a processor. Data from the device is transmitted through a wireless communication channel, which could be implemented either with a separate antenna, or through some modulation of the source drive signal.

[0075] Fig. 47 shows coupled magnetic resonators whose frequency and impedance may be automatically adjusted using algorithms implemented using a processor or a computer.

[0076] Fig. 48 shows a varactor array.

[0077] Fig. 49 shows a device (laptop computer) being wirelessly powered or charged by a source, where both the source and device resonator are physically separated from, but electrically connected to, the source and device.

[0078] Fig. 50 (a) is an illustration of a wirelessly powered or charged laptop application where the device resonator is inside the laptop case and is not visible.

[0079] Fig. 50 (b) is an illustration of a wirelessly powered or charged laptop application where the resonator is underneath the laptop base and is electrically connected to the laptop power input by an electrical cable.

[0080] Fig. 50 (c) is an illustration of a wirelessly powered or charged laptop application where the resonator is attached to the laptop base.

[0081] Fig. 50 (d) is an illustration of a wirelessly powered or charged laptop application where the resonator is attached to the laptop display.

InductEV, Inc.
Exhibit 1002
Page 015

[0082] Fig. 51 is a diagram of rooftop PV panels with wireless power transfer.

DETAILED DESCRIPTION

[0083] As described above, this disclosure relates to coupled electromagnetic resonators with long-lived oscillatory resonant modes that may wirelessly transfer power from a power supply to a power drain. However, the technique is not restricted to electromagnetic resonators, but is general and may be applied to a wide variety of resonators and resonant objects. Therefore, we first describe the general technique, and then disclose electromagnetic examples for wireless energy transfer.

[0084] **Resonators**

[0085] A resonator may be defined as a system that can store energy in at least two different forms, and where the stored energy is oscillating between the two forms. The resonance has a specific oscillation mode with a resonant (modal) frequency, f, and a resonant (modal) field. The angular resonant frequency, ω, may be defined as $\omega = 2\pi f$, the resonant wavelength, λ, may be defined as $\lambda = c/f$, where c is the speed of light, and the resonant period, T, may be defined as $T = 1/f = 2\pi/\omega$. In the absence of loss mechanisms, coupling mechanisms or external energy supplying or draining mechanisms, the total resonator stored energy, W, would stay fixed and the two forms of energy would oscillate, wherein one would be maximum when the other is minimum and vice versa.

[0086] In the absence of extraneous materials or objects, the energy in the resonator 102 shown in Fig. 1 may decay or be lost by intrinsic losses. The resonator fields then obey the following linear equation:

$$\frac{da(t)}{dt} = -i(\omega - i\Gamma)a(t),$$

where the variable $a(t)$ is the resonant field amplitude, defined so that the energy contained within the resonator is given by $|a(t)|^2$. Γ is the intrinsic energy decay or loss rate (e.g. due to absorption and radiation losses).

[0087] The Quality Factor, or Q-factor, or Q, of the resonator, which characterizes the energy decay, is inversely proportional to these energy losses. It may be defined as $Q = \omega * W/P$, where P is the time-averaged power lost at steady state. That is, a resonator 102 with

InductEV, Inc.
Exhibit 1002
Page 016

a high-Q has relatively low intrinsic losses and can store energy for a relatively long time. Since the resonator loses energy at its intrinsic decay rate, 2Γ, its Q, also referred to as its intrinsic Q, is given by $Q = \omega/2\Gamma$. The quality factor also represents the number of oscillation periods, T, it takes for the energy in the resonator to decay by a factor of e.

[0088] As described above, we define the quality factor or Q of the resonator as that due only to intrinsic loss mechanisms. A subscript index such as Q_1, indicates the resonator (resonator 1 in this case) to which the Q refers. Fig. 2 shows an electromagnetic resonator 102 labeled according to this convention. Note that in this figure, there are no extraneous objects or additional resonators in the vicinity of resonator 1.

[0089] Extraneous objects and/or additional resonators in the vicinity of a first resonator may perturb or load the first resonator, thereby perturbing or loading the Q of the first resonator, depending on a variety of factors such as the distance between the resonator and object or other resonator, the material composition of the object or other resonator, the structure of the first resonator, the power in the first resonator, and the like. Unintended external energy losses or coupling mechanisms to extraneous materials and objects in the vicinity of the resonators may be referred to as "perturbing" the Q of a resonator, and may be indicated by a subscript within rounded parentheses, (). Intended external energy losses, associated with energy transfer via coupling to other resonators and to generators and loads in the wireless energy transfer system may be referred to as "loading" the Q of the resonator, and may be indicated by a subscript within square brackets, [].

[0090] The Q of a resonator 102 connected or coupled to a power generator, g, or load 302 , l, may be called the "loaded quality factor" or the "loaded Q" and may be denoted by $Q_{[g]}$ or $Q_{[l]}$, as illustrated in Fig. 3. In general, there may be more than one generator or load 302 connected to a resonator 102. However, we do not list those generators or loads separately but rather use "g" and "l" to refer to the equivalent circuit loading imposed by the combinations of generators and loads. In general descriptions, we may use the subscript "l" to refer to either generators or loads connected to the resonators.

[0091] In some of the discussion herein, we define the "loading quality factor" or the "loading Q" due to a power generator or load connected to the resonator, as $\delta Q_{[l]}$, where,

InductEV, Inc.
Exhibit 1002
Page 017

$1/\delta Q_{[l]} \equiv 1/Q_{[l]} - 1/Q$. Note that the larger the loading Q, $\delta Q_{[l]}$, of a generator or load, the less the loaded Q, $Q_{[l]}$, deviates from the unloaded Q of the resonator.

[0092] The Q of a resonator in the presence of an extraneous object 402, *p,* that is not intended to be part of the energy transfer system may be called the "perturbed quality factor" or the "perturbed Q" and may be denoted by $Q_{(p)}$, as illustrated in Fig. 4. In general, there may be many extraneous objects, denoted as *p1*, *p2*, etc., or a set of extraneous objects *{p}*, that perturb the Q of the resonator 102. In this case, the perturbed Q may be denoted $Q_{(p1+p2+...)}$ or $Q_{(\{p\})}$. For example, $Q_{1(brick+wood)}$ may denote the perturbed quality factor of a first resonator in a system for wireless power exchange in the presence of a brick and a piece of wood, and $Q_{2(\{office\})}$ may denote the perturbed quality factor of a second resonator in a system for wireless power exchange in an office environment.

[0093] In some of the discussion herein, we define the "perturbing quality factor" or the "perturbing Q" due to an extraneous object, p, as $\delta Q_{(p)}$, where $1/\delta Q_{(p)} \equiv 1/Q_{(p)} - 1/Q$. As stated before, the perturbing quality factor may be due to multiple extraneous objects, *p1*, *p2*, etc. or a set of extraneous objects, *{p}*. The larger the perturbing Q, $\delta Q_{(p)}$, of an object, the less the perturbed Q, $Q_{(p)}$, deviates from the unperturbed Q of the resonator.

[0094] In some of the discussion herein, we also define $\Theta_{(p)} \equiv Q_{(p)} / Q$ and call it the "quality factor insensitivity" or the "Q-insensitivity" of the resonator in the presence of an extraneous object. A subscript index, such as $\Theta_{1(p)}$, indicates the resonator to which the perturbed and unperturbed quality factors are referring, namely, $\Theta_{1(p)} \equiv Q_{1(p)} / Q_1$.

[0095] Note that the quality factor, Q, may also be characterized as "unperturbed", when necessary to distinguish it from the perturbed quality factor, $Q_{(p)}$, and "unloaded", when necessary to distinguish it from the loaded quality factor, $Q_{[l]}$. Similarly, the perturbed quality factor, $Q_{(p)}$, may also be characterized as "unloaded", when necessary to distinguish them from the loaded perturbed quality factor, $Q_{(p)[l]}$.

[0096] **Coupled Resonators**

[0097] Resonators having substantially the same resonant frequency, coupled through any portion of their near-fields may interact and exchange energy. There are a variety of physical pictures and models that may be employed to understand, design, optimize and characterize this

InductEV, Inc.
Exhibit 1002
Page 018

energy exchange. One way to describe and model the energy exchange between two coupled resonators is using coupled mode theory (CMT).

[0098] In coupled mode theory, the resonator fields obey the following set of linear equations:

$$\frac{da_m(t)}{dt} = -i\left(\omega_m - i\Gamma_m\right)a_m(t) + i\sum_{n\neq m}\kappa_{mn}a_n(t)$$

where the indices denote different resonators and and κ_{mn} are the coupling coefficients between the resonators. For a reciprocal system, the coupling coefficients may obey the relation $\kappa_{mn} = \kappa_{nm}$. Note that, for the purposes of the present specification, far-field radiation interference effects will be ignored and thus the coupling coefficients will be considered real. Furthermore, since in all subsequent calculations of system performance in this specification the coupling coefficients appear only with their square, κ_{mn}^2, we use κ_{mn} to denote the absolute value of the real coupling coefficients.

[0099] Note that the coupling coefficient, κ_{mn}, from the CMT described above is related to the so-called coupling factor, k_{mn}, between resonators *m* and *n* by $k_{mn} = 2\kappa_{mn}/\sqrt{\omega_m\omega_n}$. We define a "strong-coupling factor", U_{mn}, as the ratio of the coupling and loss rates between resonators *m* and *n*, by $U_{mn} = \kappa_{mn}/\sqrt{\Gamma_m\Gamma_n} = k_{mn}\sqrt{Q_mQ_n}$.

[00100] The quality factor of a resonator *m,* in the presence of a similar frequency resonator *n* or additional resonators, may be loaded by that resonator *n* or additional resonators, in a fashion similar to the resonator being loaded by a connected power generating or consuming device. The fact that resonator *m* may be loaded by resonator *n* and vice versa is simply a different way to see that the resonators are coupled.

[00101] The loaded *Q*'s of the resonators in these cases may be denoted as $Q_{m[n]}$ and $Q_{n[m]}$. For multiple resonators or loading supplies or devices, the total loading of a resonator may be determined by modeling each load as a resistive loss, and adding the multiple loads in the appropriate parallel and/or series combination to determine the equivalent load of the ensemble.

[00102] In some of the discussion herein, we define the "loading quality factor" or the "loading Q_m" of resonator *m* due to resonator *n* as $\delta Q_{m[n]}$, where $1/\delta Q_{m[n]} \equiv 1/Q_{m[n]} - 1/Q_m$. Note

InductEV, Inc.
Exhibit 1002
Page 019

that resonator n is also loaded by resonator m and its "loading Q_n" is given by $1/\delta Q_{n[m]} \equiv 1/Q_{n[m]} - 1/Q_n$.

[00103] When one or more of the resonators are connected to power generators or loads, the set of linear equations is modified to:

$$\frac{da_m(t)}{dt} = -i(\omega_m - i\Gamma_m)a_m(t) + i\sum_{n\neq m}\kappa_{mn}a_n(t) - \kappa_m a_m(t) + \sqrt{2\kappa_m}s_{+m}(t)$$
$$s_{-m}(t) = \sqrt{2\kappa_m}a_m(t) - s_{+m}(t)$$
,

where $s_{+m}(t)$ and $s_{-m}(t)$ are respectively the amplitudes of the fields coming from a generator into the resonator m and going out of the resonator m either back towards the generator or into a load, defined so that the power they carry is given by $|s_{+m}(t)|^2$ and $|s_{-m}(t)|^2$. The loading coefficients κ_m relate to the rate at which energy is exchanged between the resonator m and the generator or load connected to it.

[00104] Note that the loading coefficient, κ_m , from the CMT described above is related to the loading quality factor, $\delta Q_{m[l]}$, defined earlier, by $\delta Q_{m[l]} = \omega_m/2\kappa_m$.

[00105] We define a "strong-loading factor", $U_{m[l]}$, as the ratio of the loading and loss rates of resonator m, $U_{m[l]} = \kappa_m/\Gamma_m = Q_m/\delta Q_{m[l]}$.

[00106] Fig. 1(a) shows an example of two coupled resonators 1000, a first resonator 102S, configured as a source resonator and a second resonator 102D, configured as a device resonator. Energy may be transferred over a distance D between the resonators. The source resonator 102S may be driven by a power supply or generator (not shown). Work may be extracted from the device resonator 102D by a power consuming drain or load (e.g. a load resistor, not shown). Let us use the subscripts "s" for the source, "d" for the device, "g" for the generator, and "l" for the load, and, since in this example there are only two resonators and $\kappa_{sd}=\kappa_{ds}$, let us drop the indices on κ_{sd}, k_{sd}, and U_{sd}, and denote them as κ, k, and U, respectively.

[00107] The power generator may be constantly driving the source resonator at a constant driving frequency, f, corresponding to an angular driving frequency, ω, where $\omega=2\pi f$.

[00108] In this case, the efficiency, $\eta = |s_{-d}|^2/|s_{+s}|^2$, of the power transmission from the generator to the load (via the source and device resonators) is maximized under the following

InductEV, Inc.
Exhibit 1002
Page 020

conditions: The source resonant frequency, the device resonant frequency and the generator driving frequency have to be matched, namely

$$\omega_s = \omega_d = \omega .$$

Furthermore, the loading Q of the source resonator due to the generator, $\delta Q_{s[g]}$, has to be matched (equal) to the loaded Q of the source resonator due to the device resonator and the load, $Q_{s[dl]}$, and inversely the loading Q of the device resonator due to the load, $\delta Q_{d[l]}$, has to be matched (equal) to the loaded Q of the device resonator due to the source resonator and the generator, $Q_{d[sg]}$, namely

$$\delta Q_{s[g]} = Q_{s[dl]} \text{ and } \delta Q_{d[l]} = Q_{d[sg]} .$$

These equations determine the optimal loading rates of the source resonator by the generator and of the device resonator by the load as

$$U_{d[l]} = \kappa_d / \Gamma_d = Q_d / \delta Q_{d[l]} = \sqrt{1+U^2} = \sqrt{1+\left(\kappa / \sqrt{\Gamma_s \Gamma_d}\right)^2} = Q_s / \delta Q_{s[g]} = \kappa_s / \Gamma_s = U_{s[g]} .$$

Note that the above frequency matching and Q matching conditions are together known as "impedance matching" in electrical engineering.

[00109] Under the above conditions, the maximized efficiency is a monotonically increasing function of only the strong-coupling factor, $U = \kappa / \sqrt{\Gamma_s \Gamma_d} = k\sqrt{Q_s Q_d}$, between the source and device resonators and is given by, $\eta = U^2 / \left(1+\sqrt{1+U^2}\right)^2$, as shown in Fig. 5. Note that the coupling efficiency, η, is greater than 1% when U is greater than 0.2, is greater than 10% when U is greater than 0.7, is greater than 17% when U is greater than 1, is greater than 52% when U is greater than 3, is greater than 80% when U is greater than 9, is greater than 90% when U is greater than 19, and is greater than 95% when U is greater than 45. In some applications, the regime of operation where $U>1$ may be referred to as the "strong-coupling" regime.

[00110] Since a large $U = \kappa / \sqrt{\Gamma_s \Gamma_d} = \left(2\kappa / \sqrt{\omega_s \omega_d}\right)\sqrt{Q_s Q_d}$ is desired in certain circumstances, resonators may be used that are high-Q. The Q of each resonator may be high. The geometric mean of the resonator Q's, $\sqrt{Q_s Q_d}$ may also or instead be high.

[00111] The coupling factor, k, is a number between $0 \le k \le 1$, and it may be independent (or nearly independent) of the resonant frequencies of the source and device

InductEV, Inc.
Exhibit 1002
Page 021

resonators, rather it may determined mostly by their relative geometry and the physical decay-law of the field mediating their coupling. In contrast, the coupling coefficient, $\kappa = k\sqrt{\omega_s \omega_d}/2$, may be a strong function of the resonant frequencies. The resonant frequencies of the resonators may be chosen preferably to achieve a high Q rather than to achieve a low Γ, as these two goals may be achievable at two separate resonant frequency regimes.

[00112] A high-Q resonator may be defined as one with Q>100. Two coupled resonators may be referred to as a system of high-Q resonators when each resonator has a Q greater than 100, Q_s>100 and Q_d>100. In other implementationss, two coupled resonators may be referred to as a system of high-Q resonators when the geometric mean of the resonator Q's is greater than 100, $\sqrt{Q_s Q_d}$ >100.

[00113] The resonators may be named or numbered. They may be referred to as source resonators, device resonators, first resonators, second resonators, repeater resonators, and the like. It is to be understood that while two resonators are shown in Fig. 1, and in many of the examples below, other implementations may include three (3) or more resonators. For example, a single source resonator 102S may transfer energy to multiple device resonators 102D or multiple devices. Energy may be transferred from a first device to a second, and then from the second device to the third, and so forth. Multiple sources may transfer energy to a single device or to multiple devices connected to a single device resonator or to multiple devices connected to multiple device resonators. Resonators 102 may serve alternately or simultaneously as sources, devices, or they may be used to relay power from a source in one location to a device in another location. Intermediate electromagnetic resonators 102 may be used to extend the distance range of wireless energy transfer systems. Multiple resonators 102 may be daisy chained together, exchanging energy over extended distances and with a wide range of sources and devices. High power levels may be split between multiple sources 102S, transferred to multiple devices and recombined at a distant location.

[00114] The analysis of a single source and a single device resonator may be extended to multiple source resonators and/or multiple device resonators and/or multiple intermediate resonators. In such an analysis, the conclusion may be that large strong-coupling factors, U_{mn}, between at least some or all of the multiple resonators is preferred for a high system efficiency in the wireless energy transfer. Again, implementations may use source, device and intermediate

InductEV, Inc.
Exhibit 1002
Page 022

resonators that have a high Q. The Q of each resonator may be high. The geometric mean $\sqrt{Q_m Q_n}$ of the Q's for pairs of resonators m and n, for which a large U_{mn} is desired, may also or instead be high.

[00115] Note that since the strong-coupling factor of two resonators may be determined by the relative magnitudes of the loss mechanisms of each resonator and the coupling mechanism between the two resonators, the strength of any or all of these mechanisms may be perturbed in the presence of extraneous objects in the vicinity of the resonators as described above.

[00116] Continuing the conventions for labeling from the previous sections, we describe k as the coupling factor in the absence of extraneous objects or materials. We denote the coupling factor in the presence of an extraneous object, p, as $k_{(p)}$, and call it the "perturbed coupling factor" or the "perturbed k". Note that the coupling factor, k, may also be characterized as "unperturbed", when necessary to distinguish from the perturbed coupling factor $k_{(p)}$.

[00117] We define $\delta k_{(p)} \equiv k_{(p)} - k$ and we call it the "perturbation on the coupling factor" or the "perturbation on k" due to an extraneous object, p.

[00118] We also define $\beta_{(p)} \equiv k_{(p)}/k$ and we call it the "coupling factor insensitivity" or the "k-insensitivity". Lower indices, such as $\beta_{12(p)}$, indicate the resonators to which the perturbed and unperturbed coupling factor is referred to, namely $\beta_{12(p)} \equiv k_{12(p)}/k_{12}$.

[00119] Similarly, we describe U as the strong-coupling factor in the absence of extraneous objects. We denote the strong-coupling factor in the presence of an extraneous object, p, as $U_{(p)}$, $U_{(p)} = k_{(p)}\sqrt{Q_{1(p)} Q_{2(p)}}$, and call it the "perturbed strong-coupling factor" or the "perturbed U". Note that the strong-coupling factor U may also be characterized as "unperturbed", when necessary to distinguish from the perturbed strong-coupling factor $U_{(p)}$. Note that the strong-coupling factor U may also be characterized as "unperturbed", when necessary to distinguish from the perturbed strong-coupling factor $U_{(p)}$.

[00120] We define $\delta U_{(p)} \equiv U_{(p)} - U$ and call it the "perturbation on the strong-coupling factor" or the "perturbation on U" due to an extraneous object, p.

[00121] We also define $\Xi_{(p)} \equiv U_{(p)}/U$ and call it the "strong-coupling factor insensitivity" or the "U-insensitivity". Lower indices, such as $\Xi_{12(p)}$, indicate the resonators to which the perturbed and unperturbed coupling factor refers, namely $\Xi_{12(p)} \equiv U_{12(p)}/U_{12}$.

InductEV, Inc.
Exhibit 1002
Page 023

[00122] The efficiency of the energy exchange in a perturbed system may be given by the same formula giving the efficiency of the unperturbed system, where all parameters such as strong-coupling factors, coupling factors, and quality factors are replaced by their perturbed equivalents. For example, in a system of wireless energy transfer including one source and one device resonator, the optimal efficiency may calculated as $\eta_{(p)} = \left[U_{(p)} \Big/ \left(1 + \sqrt{1 + U_{(p)}^{\ 2}} \right) \right]^2$. Therefore, in a system of wireless energy exchange which is perturbed by extraneous objects, large perturbed strong-coupling factors, $U_{mn(p)}$, between at least some or all of the multiple resonators may be desired for a high system efficiency in the wireless energy transfer. Source, device and/or intermediate resonators may have a high $Q_{(p)}$.

[00123] Some extraneous perturbations may sometimes be detrimental for the perturbed strong-coupling factors (via large perturbations on the coupling factors or the quality factors). Therefore, techniques may be used to reduce the effect of extraneous perturbations on the system and preserve large strong-coupling factor insensitivites.

[00124] **Efficiency of Energy Exchange**

[00125] The so-called "useful" energy in a useful energy exchange is the energy or power that must be delivered to a device (or devices) in order to power or charge the device. The transfer efficiency that corresponds to a useful energy exchange may be system or application dependent. For example, high power vehicle charging applications that transfer kilowatts of power may need to be at least 80% efficient in order to supply useful amounts of power resulting in a useful energy exchange sufficient to recharge a vehicle battery, without significantly heating up various components of the transfer system. In some consumer electronics applications, a useful energy exchange may include any energy transfer efficiencies greater than 10%, or any other amount acceptable to keep rechargeable batteries "topped off" and running for long periods of time. For some wireless sensor applications, transfer efficiencies that are much less than 1% may be adequate for powering multiple low power sensors from a single source located a significant distance from the sensors. For still other applications, where wired power transfer is either impossible or impractical, a wide range of transfer efficiencies may be acceptable for a useful energy exchange and may be said to supply useful power to devices in those applications.

InductEV, Inc.
Exhibit 1002
Page 024

In general, an operating distance is any distance over which a useful energy exchange is or can be maintained according to the principles disclosed herein.

[00126] A useful energy exchange for a wireless energy transfer in a powering or recharging application may be efficient, highly efficient, or efficient enough, as long as the wasted energy levels, heat dissipation, and associated field strengths are within tolerable limits. The tolerable limits may depend on the application, the environment and the system location. Wireless energy transfer for powering or recharging applications may be efficient, highly efficient, or efficient enough, as long as the desired system performance may be attained for the reasonable cost restrictions, weight restrictions, size restrictions, and the like. Efficient energy transfer may be determined relative to that which could be achieved using traditional inductive techniques that are not high-Q systems. Then, the energy transfer may be defined as being efficient, highly efficient, or efficient enough, if more energy is delivered than could be delivered by similarly sized coil structures in traditional inductive schemes over similar distances or alignment offsets.

[00127] Note that, even though certain frequency and Q matching conditions may optimize the system efficiency of energy transfer, these conditions may not need to be exactly met in order to have efficient enough energy transfer for a useful energy exchange. Efficient energy exchange may be realized so long as the relative offset of the resonant frequencies ($|\omega_m - \omega_n| / \sqrt{\omega_m \omega_n}$) is less than approximately the maximum among $1/Q_{m(p)}$, $1/Q_{n(p)}$ and $k_{mn(p)}$. The Q matching condition may be less critical than the frequency matching condition for efficient energy exchange. The degree by which the strong-loading factors, $U_{m[i]}$, of the resonators due to generators and/or loads may be away from their optimal values and still have efficient enough energy exchange depends on the particular system, whether all or some of the generators and/or loads are Q-mismatched and so on.

[00128] Therefore, the resonant frequencies of the resonators may not be exactly matched, but may be matched within the above tolerances. The strong-loading factors of at least some of the resonators due to generators and/or loads may not be exactly matched to their optimal value. The voltage levels, current levels, impedance values, material parameters, and the like may not be at the exact values described in the disclosure but will be within some acceptable tolerance of those values. The system optimization may include cost, size, weight, complexity,

InductEV, Inc.
Exhibit 1002
Page 025

and the like, considerations, in addition to efficiency, Q, frequency, strong coupling factor, and the like, considerations. Some system performance parameters, specifications, and designs may be far from optimal in order to optimize other system performance parameters, specifications and designs.

[00129] In some applications, at least some of the system parameters may be varying in time, for example because components, such as sources or devices, may be mobile or aging or because the loads may be variable or because the perturbations or the environmental conditions are changing etc. In these cases, in order to achieve acceptable matching conditions, at least some of the system parameters may need to be dynamically adjustable or tunable. All the system parameters may be dynamically adjustable or tunable to achieve approximately the optimal operating conditions. However, based on the discussion above, efficient enough energy exchange may be realized even if some system parameters are not variable. In some examples, at least some of the devices may not be dynamically adjusted. In some examples, at least some of the sources may not be dynamically adjusted. In some examples, at least some of the intermediate resonators may not be dynamically adjusted. In some examples, none of the system parameters may be dynamically adjusted.

[00130] **Electromagnetic Resonators**

[00131] The resonators used to exchange energy may be electromagnetic resonators. In such resonators, the intrinsic energy decay rates, Γ_m, are given by the absorption (or resistive) losses and the radiation losses of the resonator.

[00132] The resonator may be constructed such that the energy stored by the electric field is primarily confined within the structure and that the energy stored by the magnetic field is primarily in the region surrounding the resonator. Then, the energy exchange is mediated primarily by the resonant magnetic near-field. These types of resonators may be referred to as magnetic resonators.

[00133] The resonator may be constructed such that the energy stored by the magnetic field is primarily confined within the structure and that the energy stored by the electric field is primarily in the region surrounding the resonator. Then, the energy exchange is mediated primarily by the resonant electric near-field. These types of resonators may be referred to as electric resonators.

InductEV, Inc.
Exhibit 1002
Page 026

[00134] Note that the total electric and magnetic energies stored by the resonator have to be equal, but their localizations may be quite different. In some cases, the ratio of the average electric field energy to the average magnetic field energy specified at a distance from a resonator may be used to characterize or describe the resonator.

[00135] Electromagnetic resonators may include an inductive element, a distributed inductance, or a combination of inductances with inductance, *L*, and a capacitive element, a distributed capacitance, or a combination of capacitances, with capacitance, *C*. A minimal circuit model of an electromagnetic resonator 102 is shown in Fig. 6a. The resonator may include an inductive element 108 and a capacitive element 104. Provided with initial energy, such as electric field energy stored in the capacitor 104, the system will oscillate as the capacitor discharges transferring energy into magnetic field energy stored in the inductor 108 which in turn transfers energy back into electric field energy stored in the capacitor 104.

[00136] The resonators 102 shown in Figs. 6(b)(c)(d) may be referred to as magnetic resonators. Magnetic resonators may be preferred for wireless energy transfer applications in populated environments because most everyday materials including animals, plants, and humans are non-magnetic (i.e., $\mu_r \approx 1$), so their interaction with magnetic fields is minimal and due primarily to eddy currents induced by the time-variation of the magnetic fields, which is a second-order effect. This characteristic is important both for safety reasons and because it reduces the potential for interactions with extraneous environmental objects and materials that could alter system performance.

[00137] Fig. 6d shows a simplified drawing of some of the electric and magnetic field lines associated with an exemplary magnetic resonator 102B. The magnetic resonator 102B may include a loop of conductor acting as an inductive element 108 and a capacitive element 104 at the ends of the conductor loop. Note that this drawing depicts most of the energy in the region surrounding the resonator being stored in the magnetic field, and most of the energy in the resonator (between the capacitor plates) stored in the electric field. Some electric field, owing to fringing fields, free charges, and the time varying magnetic field, may be stored in the region around the resonator, but the magnetic resonator may be designed to confine the electric fields to be close to or within the resonator itself, as much as possible.

[00138] The inductor 108 and capacitor 104 of an electromagnetic resonator 102 may be bulk circuit elements, or the inductance and capacitance may be distributed and may result

InductEV, Inc.
Exhibit 1002
Page 027

from the way the conductors are formed, shaped, or positioned, in the structure. For example, the inductor 108 may be realized by shaping a conductor to enclose a surface area, as shown in Figs. 6(b)(c)(d). This type of resonator 102 may be referred to as a capacitively-loaded loop inductor. Note that we may use the terms "loop" or "coil" to indicate generally a conducting structure (wire, tube, strip, etc.), enclosing a surface of any shape and dimension, with any number of turns. In Fig. 6b, the enclosed surface area is circular, but the surface may be any of a wide variety of other shapes and sizes and may be designed to achieve certain system performance specifications. As an example to indicate how inductance scales with physical dimensions, the inductance for a length of circular conductor arranged to form a circular single-turn loop is approximately,

$$L = \mu_0 x(\ln\frac{8x}{a} - 2),$$

where μ_0 is the magnetic permeability of free space, x, is the radius of the enclosed circular surface area and, a, is the radius of the conductor used to form the inductor loop. A more precise value of the inductance of the loop may be calculated analytically or numerically.

[00139] The inductance for other cross-section conductors, arranged to form other enclosed surface shapes, areas, sizes, and the like, and of any number of wire turns, may be calculated analytically, numerically or it may be determined by measurement. The inductance may be realized using inductor elements, distributed inductance, networks, arrays, series and parallel combinations of inductors and inductances, and the like. The inductance may be fixed or variable and may be used to vary impedance matching as well as resonant frequency operating conditions.

[00140] There are a variety of ways to realize the capacitance required to achieve the desired resonant frequency for a resonator structure. Capacitor plates 110 may be formed and utilized as shown in Fig. 6b, or the capacitance may be distributed and be realized between adjacent windings of a multi-loop conductor 114, as shown in Fig. 6c. The capacitance may be realized using capacitor elements, distributed capacitance, networks, arrays, series and parallel combinations of capacitances, and the like. The capacitance may be fixed or variable and may be used to vary impedance matching as well as resonant frequency operating conditions.

[00141] It is to be understood that the inductance and capacitance in an electromagnetic resonator 102 may be lumped, distributed, or a combination of lumped and

InductEV, Inc.
Exhibit 1002
Page 028

distributed inductance and capacitance and that electromagnetic resonators may be realized by combinations of the various elements, techniques and effects described herein.

[00142] Electromagnetic resonators 102 may be include inductors, inductances, capacitors, capacitances, as well as additional circuit elements such as resistors, diodes, switches, amplifiers, diodes, transistors, transformers, conductors, connectors and the like.

[00143] **Resonant Frequency of an Electromagnetic Resonator**

[00144] An electromagnetic resonator 102 may have a characteristic, natural, or resonant frequency determined by its physical properties. This resonant frequency is the frequency at which the energy stored by the resonator oscillates between that stored by the electric field, W_E, ($W_E=q^2/2C$, where q is the charge on the capacitor, C) and that stored by the magnetic field, W_B, ($W_B=Li^2/2$, where i is the current through the inductor, L) of the resonator. In the absence of any losses in the system, energy would continually be exchanged between the electric field in the capacitor 104 and the magnetic field in the inductor 108. The frequency at which this energy is exchanged may be called the characteristic frequency, the natural frequency, or the resonant frequency of the resonator, and is given by ω,

$$\omega = 2\pi f = \sqrt{\frac{1}{LC}}.$$

[00145] The resonant frequency of the resonator may be changed by tuning the inductance, L, and/or the capacitance, C, of the resonator. The resonator frequency may be design to operate at the so-called ISM (Industrial, Scientific and Medical) frequencies as specified by the FCC. The resonator frequency may be chosen to meet certain field limit specifications, specific absorption rate (SAR) limit specifications, electromagnetic compatibility (EMC) specifications, electromagnetic interference (EMI) specifications, component size, cost or performance specifications, and the like.

[00146] **Quality Factor of an Electromagnetic Resonator**

[00147] The energy in the resonators 102 shown in Fig. 6 may decay or be lost by intrinsic losses including absorptive losses (also called ohmic or resistive losses) and/or radiative losses. The Quality Factor, or Q, of the resonator, which characterizes the energy decay, is inversely proportional to these losses. Absorptive losses may be caused by the finite conductivity of the conductor used to form the inductor as well as by losses in other elements, components, connectors, and the like, in the resonator. An inductor formed from low loss materials may be

InductEV, Inc.
Exhibit 1002
Page 029

referred to as a "high-Q inductive element" and elements, components, connectors and the like with low losses may be referred to as having "high resistive Q's". In general, the total absorptive loss for a resonator may be calculated as the appropriate series and/or parallel combination of resistive losses for the various elements and components that make up the resonator. That is, in the absence of any significant radiative or component/connection losses, the Q of the resonator may be given by, Q_{abs},

$$Q_{abs} = \frac{\omega L}{R_{abs}},$$

where ω, is the resonant frequency, L, is the total inductance of the resonator and the resistance for the conductor used to form the inductor, for example, may be given by $R_{abs} = l\rho/A$, (l is the length of the wire, ρ is the resistivity of the conductor material, and A is the cross-sectional area over which current flows in the wire). For alternating currents, the cross-sectional area over which current flows may be less than the physical cross-sectional area of the conductor owing to the skin effect. Therefore, high-Q magnetic resonators may be composed of conductors with high conductivity, relatively large surface areas and/or with specially designed profiles (e.g. Litz wire) to minimize proximity effects and reduce the AC resistance.

[00148] The magnetic resonator structures may include high-Q inductive elements composed of high conductivity wire, coated wire, Litz wire, ribbon, strapping or plates, tubing, paint, gels, traces, and the like. The magnetic resonators may be self-resonant, or they may include external coupled elements such as capacitors, inductors, switches, diodes, transistors, transformers, and the like. The magnetic resonators may include distributed and lumped capacitance and inductance. In general, the Q of the resonators will be determined by the Q's of all the individual components of the resonator.

[00149] Because Q is proportional to inductance, L, resonators may be designed to increase L, within certain other constraints. One way to increase L, for example, is to use more than one turn of the conductor to form the inductor in the resonator. Design techniques and trade-offs may depend on the application, and a wide variety of structures, conductors, components, and resonant frequencies may be chosen in the design of high-Q magnetic resonators.

[00150] In the absence of significant absorption losses, the Q of the resonator may be determined primarily by the radiation losses, and given by, $Q_{rad} = \omega L/R_{rad}$, where R_{rad} is the radiative loss of the resonator and may depend on the size of the resonator relative to the

InductEV, Inc.
Exhibit 1002
Page 030

frequency, ω, or wavelength, λ, of operation. For the magnetic resonators discussed above, radiative losses may scale as $R_{rad} \sim (x/\lambda)^4$ (characteristic of magnetic dipole radiation), where x is a characteristic dimension of the resonator, such as the radius of the inductive element shown in Fig. 6b, and where $\lambda = c/f$, where c is the speed of light and f is as defined above. The size of the magnetic resonator may be much less than the wavelength of operation so radiation losses may be very small. Such structures may be referred to as sub-wavelength resonators. Radiation may be a loss mechanism for non-radiative wireless energy transfer systems and designs may be chosen to reduce or minimize R_{rad}. Note that a high-Q_{rad} may be desirable for non-radiative wireless energy transfer schemes.

[00151] Note too that the design of resonators for non-radiative wireless energy transfer differs from antennas designed for communication or far-field energy transmission purposes. Specifically, capacitively-loaded conductive loops may be used as resonant antennas (for example in cell phones), but those operate in the far-field regime where the radiation Q's are intentionally designed to be small to make the antenna efficient at radiating energy. Such designs are not appropriate for the efficient near-field wireless energy transfer technique disclosed in this application.

[00152] The quality factor of a resonator including both radiative and absorption losses is $Q = \omega L/(R_{abs} + R_{rad})$. Note that there may be a maximum Q value for a particular resonator and that resonators may be designed with special consideration given to the size of the resonator, the materials and elements used to construct the resonator, the operating frequency, the connection mechanisms, and the like, in order to achieve a high-Q resonator. Fig. 7 shows a plot of Q of an exemplary magnetic resonator (in this case a coil with a diameter of 60 cm made of copper pipe with an outside diameter (OD) of 4 cm) that may be used for wireless power transmission at MHz frequencies. The absorptive Q (dashed line) 702 increases with frequency, while the radiative Q (dotted line) 704 decreases with frequency, thus leading the overall Q to peak 708 at a particular frequency. Note that the Q of this exemplary resonator is greater than 100 over a wide frequency range. Magnetic resonators may be designed to have high-Q over a range of frequencies and system operating frequency may set to any frequency in that range.

[00153] When the resonator is being described in terms of loss rates, the Q may be defined using the intrinsic decay rate, 2Γ, as described previously. The intrinsic decay rate is the

InductEV, Inc.
Exhibit 1002
Page 031

rate at which an uncoupled and undriven resonator loses energy. For the magnetic resonators described above, the intrinsic loss rate may be given by $\Gamma = (R_{abs} + R_{rad})/2L$, and the quality factor, Q, of the resonator is given by $Q = \omega/2\Gamma$.

[00154] Note that a quality factor related only to a specific loss mechanism may be denoted as $Q_{mechanism}$, if the resonator is not specified, or as $Q_{1,mechanism}$, if the resonator is specified (e.g. resonator 1). For example, $Q_{1,rad}$ is the quality factor for resonator 1 related to its radiation losses.

[00155] **Electromagnetic Resonator Near-Fields**

[00156] The high-Q electromagnetic resonators used in the near-field wireless energy transfer system disclosed here may be sub-wavelength objects. That is, the physical dimensions of the resonator may be much smaller than the wavelength corresponding to the resonant frequency. Sub-wavelength magnetic resonators may have most of the energy in the region surrounding the resonator stored in their magnetic near-fields, and these fields may also be described as stationary or non-propagating because they do not radiate away from the resonator. The extent of the near-field in the area surrounding the resonator is typically set by the wavelength, so it may extend well beyond the resonator itself for a sub-wavelength resonator. The limiting surface, where the field behavior changes from near-field behavior to far-field behavior may be called the "radiation caustic".

[00157] The strength of the near-field is reduced the farther one gets away from the resonator. While the field strength of the resonator near-fields decays away from the resonator, the fields may still interact with objects brought into the general vicinity of the resonator. The degree to which the fields interact depends on a variety of factors, some of which may be controlled and designed, and some of which may not. The wireless energy transfer schemes described herein may be realized when the distance between coupled resonators is such that one resonator lies within the radiation caustic of the other.

[00158] The near-field profiles of the electromagnetic resonators may be similar to those commonly associated with dipole resonators or oscillators. Such field profiles may be described as omni-directional, meaning the magnitudes of the fields are non-zero in all directions away from the object.

[00159] Characteristic Size of An Electromagnetic Resonator

InductEV, Inc.
Exhibit 1002
Page 032

[00160] Spatially separated and/or offset magnetic resonators of sufficient Q may achieve efficient wireless energy transfer over distances that are much larger than have been seen in the prior art, even if the sizes and shapes of the resonator structures are different. Such resonators may also be operated to achieve more efficient energy transfer than was achievable with previous techniques over shorter range distances. We describe such resonators as being capable of mid-range energy transfer.

[00161] Mid-range distances may be defined as distances that are larger than the characteristic dimension of the smallest of the resonators involved in the transfer, where the distance is measured from the center of one resonator structure to the center of a spatially separated second resonator structure. In this definition, two-dimensional resonators are spatially separated when the areas circumscribed by their inductive elements do not intersect and three-dimensional resonators are spatially separated when their volumes do not intersect. A two-dimensional resonator is spatially separated from a three-dimensional resonator when the area circumscribed by the former is outside the volume of the latter.

[00162] Fig. 8 shows some example resonators with their characteristic dimensions labeled. It is to be understood that the characteristic sizes 802 of resonators 102 may be defined in terms of the size of the conductor and the area circumscribed or enclosed by the inductive element in a magnetic resonator and the length of the conductor forming the capacitive element of an electric resonator. Then, the characteristic size 802 of a resonator 102, x_{char}, may be equal to the radius of the smallest sphere that can fit around the inductive or capacitive element of the magnetic or electric resonator respectively, and the center of the resonator structure is the center of the sphere. The characteristic thickness 804, t_{char}, of a resonator 102 may be the smallest possible height of the highest point of the inductive or capacitive element in the magnetic or capacitive resonator respectively, measured from a flat surface on which it is placed. The characteristic width 808 of a resonator 102, w_{char}, may be the radius of the smallest possible circle through which the inductive or capacitive element of the magnetic or electric resonator respectively, may pass while traveling in a straight line. For example, the characteristic width 808 of a cylindrical resonator may be the radius of the cylinder.

[00163] In this inventive wireless energy transfer technique, energy may be exchanged efficiently over a wide range of distances, but the technique is distinguished by the ability to exchange useful energy for powering or recharging devices over mid-range distances and

InductEV, Inc.
Exhibit 1002
Page 033

between resonators with different physical dimensions, components and orientations. Note that while k may be small in these circumstances, strong coupling and efficient energy transfer may be realized by using high-Q resonators to achieve a high U, $U = k\sqrt{Q_s Q_d}$. That is, increases in Q may be used to at least partially overcome decreases in k, to maintain useful energy transfer efficiencies.

[00164] Note too that while the near-field of a single resonator may be described as omni-directional, the efficiency of the energy exchange between two resonators may depend on the relative position and orientation of the resonators. That is, the efficiency of the energy exchange may be maximized for particular relative orientations of the resonators. The sensitivity of the transfer efficiency to the relative position and orientation of two uncompensated resonators may be captured in the calculation of either k or κ. While coupling may be achieved between resonators that are offset and/or rotated relative to each other, the efficiency of the exchange may depend on the details of the positioning and on any feedback, tuning, and compensation techniques implemented during operation.

[00165] **<u>High-*Q* Magnetic Resonators</u>**

[00166] In the near-field regime of a sub-wavelength capacitively-loaded loop magnetic resonator ($x \ll \lambda$), the resistances associated with a circular conducting loop inductor composed of N turns of wire whose radius is larger than the skin depth, are approximately $R_{abs} = \sqrt{\mu_o \rho \omega / 2} \cdot Nx / a$ and $R_{rad} = \pi / 6 \cdot \eta_o N^2 \left(\omega x / c\right)^4$, where ρ is the resistivity of the conductor material and $\eta_o \approx 120\pi\ \Omega$ is the impedance of free space. . The inductance, L, for such a N-turn loop is approximately N^2 times the inductance of a single-turn loop given previously. The quality factor of such a resonator, $Q = \omega L / \left(R_{abs} + R_{rad}\right)$, is highest for a particular frequency determined by the system parameters (Fig. 4). As described previously, at lower frequencies the Q is determined primarily by absorption losses and at higher frequencies the Q is determined primarily by radiation losses.

[00167] Note that the formulas given above are approximate and intended to illustrate the functional dependence of R_{abs}, R_{rad} and L on the physical parameters of the structure. More accurate numerical calculations of these parameters that take into account deviations from the strict quasi-static limit, for example a non-uniform current/charge distribution along the conductor, may be useful for the precise design of a resonator structure.

InductEV, Inc.
Exhibit 1002
Page 034

[00168] Note that the absorptive losses may be minimized by using low loss conductors to form the inductive elements. The loss of the conductors may be minimized by using large surface area conductors such as conductive tubing, strapping, strips, machined objects, plates, and the like, by using specially designed conductors such as Litz wire, braided wires, wires of any cross-section, and other conductors with low proximity losses, in which case the frequency scaled behavior described above may be different, and by using low resistivity materials such as high-purity copper and silver, for example. One advantage of using conductive tubing as the conductor at higher operating frequencies is that it may be cheaper and lighter than a similar diameter solid conductor, and may have similar resistance because most of the current is traveling along the outer surface of the conductor owing to the skin effect.

[00169] To get a rough estimate of achievable resonator designs made from copper wire or copper tubing and appropriate for operation in the microwave regime, one may calculate the optimum Q and resonant frequency for a resonator composed of one circular inductive element ($N=1$) of copper wire ($\rho=1.69\cdot10^{-8}\ \Omega m$) with various cross sections. Then for an inductive element with characteristic size $x=1\ cm$ and conductor diameter a=1 mm, appropriate for a cell phone for example, the quality factor peaks at Q=1225 when $f=380$ MHz. For $x=30\ cm$ and $a=2\ mm$, an inductive element size that might be appropriate for a laptop or a household robot, $Q=1103$ at $f=17$ MHz. For a larger source inductive element that might be located in the ceiling for example, x=1 m and a=4 mm, Q may be as high as Q=1315 at $f=5$ MHz. Note that a number of practical examples yield expected quality factors of $Q\approx1000\text{-}1500$ at $\lambda/x\approx50\text{-}80$. Measurements of a wider variety of coil shapes, sizes, materials and operating frequencies than described above show that Q's >100 may be realized for a variety of magnetic resonator structures using commonly available materials.

[00170] As described above, the rate for energy transfer between two resonators of characteristic size x_1 and x_2, and separated by a distance D between their centers, may be given by κ. To give an example of how the defined parameters scale, consider the cell phone, laptop, and ceiling resonator examples from above, at three (3) distances; D/x=10, 8, 6. In the examples considered here, the source and device resonators are the same size, $x_1=x_2$, and shape, and are oriented as shown in Fig. 1(b). In the cell phone example, $\omega/2\kappa$ =3033, 1553, 655 respectively. In the laptop example, $\omega/2\kappa$ =7131, 3651, 1540 respectively and for the ceiling resonator example, $\omega/2\kappa$ =6481, 3318, 1400. The corresponding coupling-to-loss ratios peak at the

InductEV, Inc.
Exhibit 1002
Page 035

frequency where the inductive element Q peaks and are κ/Γ =0.4, 0.79, 1.97 and 0.15, 0.3, 0.72 and 0.2, 0.4, 0.94 for the three inductive element sizes and distances described above. An example using different sized inductive elements is that of an x_1=1 m inductor (e.g. source in the ceiling) and an x_2=30 cm inductor (e.g. household robot on the floor) at a distance D=3 m apart (e.g. room height). In this example, the strong-coupling figure of merit, $U=\kappa/\sqrt{\Gamma_1\Gamma_2}$ =0.88, for an efficiency of approximately 14%, at the optimal operating frequency of f=6.4 MHz. Here, the optimal system operating frequency lies between the peaks of the individual resonator Q's.

[00171] Inductive elements may be formed for use in high-Q magnetic resonators. We have demonstrated a variety of high-Q magnetic resonators based on copper conductors that are formed into inductive elements that enclose a surface. Inductive elements may be formed using a variety of conductors arranged in a variety of shapes, enclosing any size or shaped area, and they may be single turn or multiple turn elements. Drawings of exemplary inductive elements 900A-B are shown in Fig. 9. The inductive elements may be formed to enclose a circle, a rectangle, a square, a triangle, a shape with rounded corners, a shape that follows the contour of a particular structure or device, a shape that follows, fills, or utilizes, a dedicated space within a structure or device, and the like. The designs may be optimized for size, cost, weight, appearance, performance, and the like.

[00172] These conductors may be bent or formed into the desired size, shape, and number of turns. However, it may be difficult to accurately reproduce conductor shapes and sizes using manual techniques. In addition, it may be difficult to maintain uniform or desired center-to-center spacings between the conductor segments in adjacent turns of the inductive elements. Accurate or uniform spacing may be important in determining the self capacitance of the structure as well as any proximity effect induced increases in AC resistance, for example.

[00173] Molds may be used to replicate inductor elements for high-Q resonator designs. In addition, molds may be used to accurately shape conductors into any kind of shape without creating kinks, buckles or other potentially deleterious effects in the conductor. Molds may be used to form the inductor elements and then the inductor elements may be removed from the forms. Once removed, these inductive elements may be built into enclosures or devices that may house the high-Q magnetic resonator. The formed elements may also or instead remain in the mold used to form them.

InductEV, Inc.
Exhibit 1002
Page 036

[00174] The molds may be formed using standard CNC (computer numerical control) routing or milling tools or any other known techniques for cutting or forming grooves in blocks. The molds may also or instead be formed using machining techniques, injection molding techniques, casting techniques, pouring techniques, vacuum techniques, thermoforming techniques, cut-in-place techniques, compression forming techniques and the like.

[00175] The formed element may be removed from the mold or it may remain in the mold. The mold may be altered with the inductive element inside. The mold may be covered, machined, attached, painted and the like. The mold and conductor combination may be integrated into another housing, structure or device. The grooves cut into the molds may be any dimension and may be designed to form conducting tubing, wire, strapping, strips, blocks, and the like into the desired inductor shapes and sizes.

[00176] The inductive elements used in magnetic resonators may contain more than one loop and may spiral inward or outward or up or down or in some combination of directions. In general, the magnetic resonators may have a variety of shapes, sizes and number of turns and they may be composed of a variety of conducing materials.

[00177] The magnetic resonators may be free standing or they may be enclosed in an enclosure, container, sleeve or housing. The magnetic resonators may include the form used to make the inductive element. These various forms and enclosures may be composed of almost any kind of material. Low loss materials such as Teflon, REXOLITE, styrene, and the like may be preferable for some applications. These enclosures may contain fixtures that hold the inductive elements.

[00178] Magnetic resonators may be composed of self-resonant coils of copper wire or copper tubing. Magnetic resonators composed of self resonant conductive wire coils may include a wire of length l, and cross section radius a, wound into a helical coil of radius x, height h, and number of turns N, which may for example be characterized as $N = \sqrt{l^2 - h^2} / 2\pi x$.

[00179] A magnetic resonator structure may be configured so that x is about 30 cm, h is about 20 cm, a is about 3 mm and N is about 5.25, and, during operation, a power source coupled to the magnetic resonator may drive the resonator at a resonant frequency, f, where f is about 10.6 MHz. Where x is about 30 cm, h is about 20 cm, a is about 1 cm and N is about 4, the resonator may be driven at a frequency, f, where f is about 13.4 MHz. Where x is about 10 cm, h

InductEV, Inc.
Exhibit 1002
Page 037

is about 3 cm, a is about 2 mm and N is about 6, the resonator may be driven at a frequency, f, where f is about 21.4 MHz.

[00180] High-Q inductive elements may be designed using printed circuit board traces. Printed circuit board traces may have a variety of advantages compared to mechanically formed inductive elements including that they may be accurately reproduced and easily integrated using established printed circuit board fabrication techniques, that their AC resistance may be lowered using custom designed conductor traces, and that the cost of mass-producing them may be significantly reduced.

[00181] High-Q inductive elements may be fabricated using standard PCB techniques on any PCB material such as FR-4 (epoxy E-glass), multi-functional epoxy, high performance epoxy, bismalaimide triazine/epoxy, polyimide, Cyanate Ester, polytetraflouroethylene (Teflon), FR-2, FR-3, CEM-1, CEM-2, Rogers, Resolute, and the like. The conductor traces may be formed on printed circuit board materials with lower loss tangents.

[00182] The conducting traces may be composed of copper, silver, gold, aluminum, nickel and the like, and they may be composed of paints, inks, or other cured materials. The circuit board may be flexible and it may be a flex-circuit. The conducting traces may be formed by chemical deposition, etching, lithography, spray deposition, cutting, and the like. The conducting traces may be applied to form the desired patterns and they may be formed using crystal and structure growth techniques.

[00183] The dimensions of the conducting traces, as well as the number of layers containing conducting traces, the position, size and shape of those traces and the architecture for interconnecting them may be designed to achieve or optimize certain system specifications such as resonator Q, $Q_{(p)}$, resonator size, resonator material and fabrication costs, U, $U_{(p)}$, and the like.

[00184] As an example, a three-turn high-Q inductive element 1001A was fabricated on a four-layer printed circuit board using the rectangular copper trace pattern as shown in Fig. 10(a). The copper trace is shown in black and the PCB in white. The width and thickness of the copper traces in this example was approximately 1 cm (400 mils) and 43 μ m (1.7 mils) respectively. The edge-to-edge spacing between turns of the conducting trace on a single layer was approximately 0.75 cm (300 mils) and each board layer thickness was approximately 100 μ m (4 mils). The pattern shown in Fig. 10(a) was repeated on each layer of the board and the conductors were connected in parallel. The outer dimensions of the 3-loop structure were

approximately 30 cm by 20 cm. The measured inductance of this PCB loop was 5.3 μ H. A magnetic resonator using this inductor element and tunable capacitors had a quality factor, Q, of 550 at its designed resonance frequency of 6.78 MHz. The resonant frequency could be tuned by changing the inductance and capacitance values in the magnetic resonator.

[00185] As another example, a two-turn inductor 1001B was fabricated on a four-layer printed circuit board using the rectangular copper trace pattern shown in Fig. 10(b). The copper trace is shown in black and the PCB in white. The width and height of the copper traces in this example were approximately 0.75 cm (300 mils) and 43 μ m (1.7 mils) respectively. The edge-to-edge spacing between turns of the conducting trace on a single layer was approximately 0.635 cm (250 mils) and each board layer thickness was approximately 100 μ m (4 mils). The pattern shown in Fig. 10(b) was repeated on each layer of the board and the conductors were connected in parallel. The outer dimensions of the two-loop structure were approximately 7.62 cm by 26.7 cm. The measured inductance of this PCB loop was 1.3 μ H. Stacking two boards together with a vertical separation of approximately 0.635 cm (250 mils) and connecting the two boards in series produced a PCB inductor with an inductance of approximately 3.4 μ H. A magnetic resonator using this stacked inductor loop and tunable capacitors had a quality factor, Q, of 390 at its designed resonance frequency of 6.78 MHz. The resonant frequency could be tuned by changing the inductance and capacitance values in the magnetic resonator.

[00186] The inductive elements may be formed using magnetic materials of any size, shape thickness, and the like, and of materials with a wide range of permeability and loss values. These magnetic materials may be solid blocks, they may enclose hollow volumes, they may be formed from many smaller pieces of magnetic material tiled and or stacked together, and they may be integrated with conducting sheets or enclosures made from highly conducting materials. Wires may be wrapped around the magnetic materials to generate the magnetic near-field. These wires may be wrapped around one or more than one axis of the structure. Multiple wires may be wrapped around the magnetic materials and combined in parallel, or in series, or via a switch to form customized near-field patterns.

[00187] The magnetic resonator may include 15 turns of Litz wire wound around a 19.2 cm x 10 cm x 5 mm tiled block of 3F3 ferrite material. The Litz wire may be wound around the ferrite material in any direction or combination of directions to achieve the desire resonator

InductEV, Inc.
Exhibit 1002
Page 039

performance. The number of turns of wire, the spacing between the turns, the type of wire, the size and shape of the magnetic materials and the type of magnetic material are all design parameters that may be varied or optimized for different application scenarios.

[00188] **High-*Q* Magnetic resonators using magnetic material structures**

[00189] It may be possible to use magnetic materials assembled to form an open magnetic circuit, albeit one with an air gap on the order of the size of the whole structure, to realize a magnetic resonator structure. In these structures, high conductivity materials are wound around a structure made from magnetic material to form the inductive element of the magnetic resonator. Capacitive elements may be connected to the high conductivity materials, with the resonant frequency then determined as described above. These magnetic resonators have their dipole moment in the plane of the two dimensional resonator structures, rather than perpendicular to it, as is the case for the capacitively-loaded inductor loop resonators.

[00190] A diagram of a single planar resonator structure is shown in Fig. 11(a). The planar resonator structure is constructed of a core of magnetic material 1121, such as ferrite with a loop or loops of conducting material 1122 wrapped around the core 1121. The structure may be used as the source resonator that transfers power and the device resonator that captures energy. When used as a source, the ends of the conductor may be coupled to a power source. Alternating electrical current flowing through the conductor loops excites alternating magnetic fields. When the structure is being used to receive power, the ends of the conductor may be coupled to a power drain or load. Changing magnetic fields induce an electromotive force in the loop or loops of the conductor wound around the core magnetic material. The dipole moment of these types of structures is in the plane of the structures and is, for example, directed along the Y axis for the structure in Figure 11(a). Two such structures have strong coupling when placed substantially in the same plane (i.e. the X,Y plane of Figure 11). The structures of Figure 11(a) have the most favorable orientation when the resonators are aligned in the same plane along their Y axis.

[00191] The geometry and the coupling orientations of the described planar resonators may be preferable for some applications. The planar or flat resonator shape may be easier to integrate into many electronic devices that are relatively flat and planar. The planar resonators may be integrated into the whole back or side of a device without requiring a change in geometry of the device. Due to the flat shape of many devices, the natural position of the devices when placed on a surface is to lay with their largest dimension being parallel to the surface they are

InductEV, Inc.
Exhibit 1002
Page 040

placed on. A planar resonator integrated into a flat device is naturally parallel to the plane of the surface and is in a favorable coupling orientation relative to the resonators of other devices or planar resonator sources placed on a flat surface.

[00192] As mentioned, the geometry of the planar resonators may allow easier integration into devices. Their low profile may allow a resonator to be integrated into or as part of a complete side of a device. When a whole side of a device is covered by the resonator, magnetic flux can flow through the resonator core without being obstructed by lossy material that may be part of the device or device circuitry.

[00193] The core of the planar resonator structure may be of a variety of shapes and thicknesses and may be flat or planar such that the minimum dimension does not exceed 30% of the largest dimension of the structure. The core may have complex geometries and may have indentations, notches, ridges, and the like. Geometric enhancements may be used to reduce the coupling dependence on orientation and they may be used to facilitate integration into devices, packaging, packages, enclosures, covers, skins, and the like. Two exemplary variations of core geometries are shown in Figure 11(b). For example, the planar core 1131 may be shaped such that the ends are substantially wider than the middle of the structure to create an indentation for the conductor winding. The core material may be of varying thickness with ends that are thicker and wider than the middle. The core material 1132 may have any number of notches or cutouts 1133 of various depths, width, and shapes to accommodate conductor loops, housing, packaging, and the like.

[00194] The shape and dimensions of the core may be further dictated by the dimensions and characteristics of the device that they are integrated into. The core material may curve to follow the contours of the device, or may require non-symmetric notches or cutouts to allow clearance for parts of the device. The core structure may be a single monolithic piece of magnetic material or may be composed of a plurality of tiles, blocks, or pieces that are arranged together to form the larger structure. The different layers, tiles, blocks, or pieces of the structure may be of similar or may be of different materials. It may be desirable to use materials with different magnetic permeability in different locations of the structure. Core structures with different magnetic permeability may be useful for guiding the magnetic flux, improving coupling, and affecting the shape or extent of the active area of a system.

InductEV, Inc.
Exhibit 1002
Page 041

[00195] The conductor of the planar resonator structure may be wound at least once around the core. In certain circumstances, it may be preferred to wind at least three loops. The conductor can be any good conductor including conducting wire, Litz wire, conducting tubing, sheets, strips, gels, inks, traces and the like.

[00196] The size, shape, or dimensions of the active area of source may be further enhanced, altered, or modified with the use of materials that block, shield, or guide magnetic fields. To create non-symmetric active area around a source once side of the source may be covered with a magnetic shield to reduce the strength of the magnetic fields in a specific direction. The shield may be a conductor or a layered combination of conductor and magnetic material which can be used to guide magnetic fields away from a specific direction. Structures composed of layers of conductors and magnetic materials may be used to reduce energy losses that may occur due to shielding of the source.

[00197] The plurality of planar resonators may be integrated or combined into one planar resonator structure. A conductor or conductors may be wound around a core structure such that the loops formed by the two conductors are not coaxial. An example of such a structure is shown in Figure 12 where two conductors 1201,1202 are wrapped around a planar rectangular core 1203 at orthogonal angles. The core may be rectangular or it may have various geometries with several extensions or protrusions. The protrusions may be useful for wrapping of a conductor, reducing the weight, size, or mass of the core, or may be used to enhance the directionality or omni-directionality of the resonator. A multi wrapped planar resonator with four protrusions is shown by the inner structure 1310 in Figure 13, where four conductors 1301, 1302, 1303, 1304 are wrapped around the core. The core may have extensions 1305,1306,1307,1308 with one or more conductor loops. A single conductor may be wrapped around a core to form loops that are not coaxial. The four conductor loops of Figure 13, for example, may be formed with one continuous piece of conductor, or using two conductors where a single conductor is used to make all coaxial loops.

[00198] Non-uniform or asymmetric field profiles around the resonator comprising a plurality of conductor loops may be generated by driving some conductor loops with non-identical parameters. Some conductor loops of a source resonator with a plurality of conductor loops may be driven by a power source with a different frequency, voltage, power level, duty

InductEV, Inc.
Exhibit 1002
Page 042

cycle, and the like all of which may be used to affect the strength of the magnetic field generated by each conductor.

[00199] The planar resonator structures may be combined with a capacitively-loaded inductor resonator coil to provide an omni-directional active area all around, including above and below the source while maintaining a flat resonator structure. As shown in Figure 13, an additional resonator loop coil 1309 comprising of a loop or loops of a conductor, may be placed in a common plane as the planar resonator structure 1310. The outer resonator coil provides an active area that is substantially above and below the source. The resonator coil can be arranged with any number of planar resonator structures and arrangements described herein.

[00200] The planar resonator structures may be enclosed in magnetically permeable packaging or integrated into other devices. The planar profile of the resonators within a single, common plane allows packaging and integration into flat devices. A diagram illustrating the application of the resonators is shown in Figure 14. A flat source 1411 comprising one or more planar resonators 1414 each with one or more conductor loops may transfer power to devices 1412,1413 that are integrated with other planar resonators 1415,1416 and placed within an active area 1417 of the source. The devices may comprise a plurality of planar resonators such that regardless of the orientation of the device with respect to the source the active area of the source does not change. In addition to invariance to rotational misalignment, a flat device comprising of planar resonators may be turned upside down without substantially affecting the active area since the planar resonator is still in the plane of the source.

[00201] Another diagram illustrating a possible use of a power transfer system using the planar resonator structures is shown in Figure 15. A planar source 1521 placed on top of a surface 1525 may create an active area that covers a substantial surface area creating an "energized surface" area. Devices such as computers 1524, mobile handsets 1522, games, and other electronics 1523 that are coupled to their respective planar device resonators may receive energy from the source when placed within the active area of the source, which may be anywhere on top of the surface. Several devices with different dimensions may be placed in the active area and used normally while charging or being powered from the source without having strict placement or alignment constraints. The source may be placed under the surface of a table, countertop, desk, cabinet, and the like, allowing it to be completely hidden while energizing the

InductEV, Inc.
Exhibit 1002
Page 043

top surface of the table, countertop, desk, cabinet and the like, creating an active area on the surface that is much larger than the source.

[00202] The source may include a display or other visual, auditory, or vibration indicators to show the direction of charging devices or what devices are being charged, error or problems with charging, power levels, charging time, and the like.

[00203] The source resonators and circuitry may be integrated into any number of other devices. The source may be integrated into devices such as clocks, keyboards, monitors, picture frames, and the like. For example, a keyboard integrated with the planar resonators and appropriate power and control circuitry may be used as a source for devices placed around the keyboard such as computer mice, webcams, mobile handsets, and the like without occupying any additional desk space.

[00204] While the planar resonator structures have been described in the context of mobile devices it should be clear to those skilled in the art that a flat planar source for wireless power transfer with an active area that extends beyond its physical dimensions has many other consumer and industrial applications. The structures and configuration may be useful for a large number of applications where electronic or electric devices and a power source are typically located, positioned, or manipulated in substantially the same plane and alignment. Some of the possible application scenarios include devices on walls, floor, ceilings or any other substantially planar surfaces.

[00205] Flat source resonators may be integrated into a picture frame or hung on a wall thereby providing an active area within the plane of the wall where other electronic devices such as digital picture frames, televisions, lights, and the like can be mounted and powered without wires. Planar resonators may be integrated into a floor resulting in an energized floor or active area on the floor on which devices can be placed to receive power. Audio speakers, lamps, heaters, and the like can be placed within the active are and receive power wirelessly.

[00206] The planar resonator may have additional components coupled to the conductor. Components such as capacitors, inductors, resistors, diodes, and the like may be coupled to the conductor and may be used to adjust or tune the resonant frequency and the impedance matching for the resonators.

[00207] A planar resonator structure of the type described above and shown in Fig. 11(a), may be created, for example, with a quality factor, Q, of 100 or higher and even Q of

1,000 or higher. Energy may be wirelessly transferred from one planar resonator structure to another over a distance larger than the characteristic size of the resonators, as shown in Fig. 11(c).

[00208] In addition to utilizing magnetic materials to realize a structure with properties similar to the inductive element in the magnetic resonators, it may be possible to use a combination of good conductor materials and magnetic material to realize such inductive structures. Fig. 16(a) shows a magnetic resonator structure 1602 that may include one or more enclosures made of high-conductivity materials (the inside of which would be shielded from AC electromagnetic fields generated outside) surrounded by at least one layer of magnetic material and linked by blocks of magnetic material 1604.

A structure may include a high-conductivity sheet of material covered on one side by a layer of magnetic material. The layered structure may instead be applied conformally to an electronic device, so that parts of the device may be covered by the high-conductivity and magnetic material layers, while other parts that need to be easily accessed (such as buttons or screens) may be left uncovered. The structure may also or instead include only layers or bulk pieces of magnetic material. Thus, a magnetic resonator may be incorporated into an existing device without significantly interfering with its existing functions and with little or no need for extensive redesign. Moreover, the layers of good conductor and/or magnetic material may be made thin enough (of the order of a millimeter or less) that they would add little extra weight and volume to the completed device. An oscillating current applied to a length of conductor wound around the structure, as shown by the square loop in the center of the structure in Figure 16 may be used to excite the electromagnetic fields associated with this structure.

[00209] Quality factor of the structure

[00210] A structure of the type described above may be created with a quality factor, Q, of the order of 1,000 or higher. This high-Q is possible even if the losses in the magnetic material are high, if the fraction of magnetic energy within the magnetic material is small compared to the total magnetic energy associated with the object. For structures composed of layers conducting materials and magnetic materials, the losses in the conducting materials may be reduced by the presence of the magnetic materials as described previously. In structures where the magnetic material layer's thickness is of the order of 1/100 of the largest dimension of the system (e.g., the magnetic material may be of the order of 1 mm thick, while the area of the

InductEV, Inc.
Exhibit 1002
Page 045

structure is of the order of 10 cm x 10 cm), and the relative permeability is of the order of 1,000, it is possible to make the fraction of magnetic energy contained within the magnetic material only a few hundredths of the total magnetic energy associated with the object or resonator. To see how that comes about, note that the expression for the magnetic energy contained in a volume is $U_m = \int_V \mathbf{drB(r)}^2 / (2\mu_r\mu_0)$, so as long as ***B*** (rather than ***H***) is the main field conserved across the magnetic material-air interface (which is typically the case in open magnetic circuits), the fraction of magnetic energy contained in the high-μ_r region may be significantly reduced compared to what it is in air.

[00211] If the fraction of magnetic energy in the magnetic material is denoted by *frac*, and the loss tangent of the material is *tanδ*, then the *Q* of the resonator, assuming the magnetic material is the only source of losses, is *Q=1/(frac x tanδ)*. Thus, even for loss tangents as high as 0.1, it is possible to achieve *Q's* of the order of 1,000 for these types of resonator structures.

[00212] If the structure is driven with *N* turns of wire wound around it, the losses in the excitation inductor loop can be ignored if *N* is sufficiently high. Fig. 17 shows an equivalent circuit 1700 schematic for these structures and the scaling of the loss mechanisms and inductance with the number of turns, *N,* wound around a structure made of conducting and magnetic material. If proximity effects can be neglected (by using an appropriate winding, or a wire designed to minimize proximity effects, such as Litz wire and the like), the resistance 1702 due to the wire in the looped conductor scales linearly with the length of the loop, which is in turn proportional to the number of turns. On the other hand, both the equivalent resistance 1708 and equivalent inductance 1704 of these special structures are proportional to the square of the magnetic field inside the structure. Since this magnetic field is proportional to *N*, the equivalent resistance 1708 and equivalent inductance 1704 are both proportional to N^2. Thus, for large enough N, the resistance 1702 of the wire is much smaller than the equivalent resistance 1708 of the magnetic structure, and the *Q* of the resonator asymptotes to $Q_{max} = \omega L_\mu / R_\mu$.

[00213] Fig. 16 (a) shows a drawing of a copper and magnetic material structure 1602 driven by a square loop of current around the narrowed segment at the center of the structure 1604 and the magnetic field streamlines generated by this structure 1608. This exemplary structure includes two 20 cm x 8 cm x 2 cm hollow regions enclosed with copper and then completely covered with a 2 mm layer of magnetic material having the properties $\mu_r' = 1{,}400$,

InductEV, Inc.
Exhibit 1002
Page 046

$\mu_r'' = 5$, and $\sigma = 0.5$ S/m. These two parallelepipeds are spaced 4 cm apart and are connected by a 2 cm x 4 cm x 2 cm block of the same magnetic material. The excitation loop is wound around the center of this block. At a frequency of 300 kHz, this structure has a calculated Q of 890. The conductor and magnetic material structure may be shaped to optimize certain system parameters. For example, the size of the structure enclosed by the excitation loop may be small to reduce the resistance of the excitation loop, or it may be large to mitigate losses in the magnetic material associated with large magnetic fields. Note that the magnetic streamlines and *Q's* associated with the same structure composed of magnetic material only would be similar to the layer conductor and magnetic material design shown here.

[00214] **Electromagnetic Resonators Interacting with Other Objects**

[00215] For electromagnetic resonators, extrinsic loss mechanisms that perturb the intrinsic Q may include absorption losses inside the materials of nearby extraneous objects and radiation losses related to scattering of the resonant fields from nearby extraneous objects. Absorption losses may be associated with materials that, over the frequency range of interest, have non-zero, but finite, conductivity, σ, (or equivalently a non-zero and finite imaginary part of the dielectric permittivity), such that electromagnetic fields can penetrate it and induce currents in it, which then dissipate energy through resistive losses. An object may be described as lossy if it at least partly includes lossy materials.

[00216] Consider an object including a homogeneous isotropic material of conductivity, σ and magnetic permeability, μ. The penetration depth of electromagnetic fields inside this object is given by the skin depth, $\delta = \sqrt{2/\omega\mu\sigma}$. The power dissipated inside the object, P_d, can be determined from $P_d = \int_V d\mathbf{r}\sigma \,|\, \mathbf{E} \,|^2 = \int_V d\mathbf{r} \,|\, \mathbf{J} \,|^2 / \sigma$ where we made use of Ohm's law, $\mathbf{J} = \sigma\mathbf{E}$, and where $\mathbf{E}$ is the electric field and $\mathbf{J}$ is the current density.

[00217] If over the frequency range of interest, the conductivity, σ, of the material that composes the object is low enough that the material's skin depth, δ, may be considered long, (i.e. δ is longer than the objects' characteristic size, or δ is longer than the characteristic size of the portion of the object that is lossy) then the electromagnetic fields, $\mathbf{E}$ and $\mathbf{H}$, where $\mathbf{H}$ is the magnetic field, may penetrate significantly into the object. Then, these finite-valued fields may give rise to a dissipated power that scales as $P_d \sim \sigma V_{ol} \left\langle |\mathbf{E}|^2 \right\rangle$, where V_{ol} is the volume

InductEV, Inc.
Exhibit 1002
Page 047

of the object that is lossy and $\langle |\mathbf{E}|^2 \rangle$ is the spatial average of the electric-field squared, in the volume under consideration. Therefore, in the low-conductivity limit, the dissipated power scales proportionally to the conductivity and goes to zero in the limit of a non-conducting (purely dielectric) material.

[00218] If over the frequency range of interest, the conductivity, σ, of the material that composes the object is high enough that the material's skin depth may be considered short, then the electromagnetic fields, $\mathbf{E}$ and $\mathbf{H}$, may penetrate only a short distance into the object (namely they stay close to the 'skin' of the material, where δ is smaller than the characteristic thickness of the portion of the object that is lossy). In this case, the currents induced inside the material may be concentrated very close to the material surface, approximately within a skin depth, and their magnitude may be approximated by the product of a surface current density (mostly determined by the shape of the incident electromagnetic fields and, as long as the thickness of the conductor is much larger than the skin-depth, independent of frequency and conductivity to first order) $K(x,y)$ (where x and y are coordinates parameterizing the surface) and a function decaying exponentially into the surface: $\exp(-z/\delta)/\delta$ (where z denotes the coordinate locally normal to the surface): $J(x,y,z) = K(x,y)\exp(-z/\delta)/\delta$. Then, the dissipated power, P_d, may be estimated by,

$$P_d = \int_V d\mathbf{r}\,|\mathbf{J}(\mathbf{r})|^2/\sigma \simeq \left(\int_S \mathbf{dxdy}\,|\mathbf{K}(\mathbf{x},\mathbf{y})|^2\right)\left(\int_0^\infty \mathbf{dz}\exp(2\mathbf{z}/\delta)/(\sigma\delta^2)\right) = \sqrt{\mu\omega/8\sigma}\left(\int_S dxdy\,|K(x,y)|^2\right)$$

[00219] Therefore, in the high-conductivity limit, the dissipated power scales inverse proportionally to the square-root of the conductivity and goes to zero in the limit of a perfectly-conducting material.

[00220] If over the frequency range of interest, the conductivity, σ, of the material that composes the object is finite, then the material's skin depth, δ, may penetrate some distance into the object and some amount of power may be dissipated inside the object, depending also on the size of the object and the strength of the electromagnetic fields. This description can be generalized to also describe the general case of an object including multiple different materials with different properties and conductivities, such as an object with an arbitrary inhomogeneous and anisotropic distribution of the conductivity inside the object.

InductEV, Inc.
Exhibit 1002
Page 048

[00221] Note that the magnitude of the loss mechanisms described above may depend on the location and orientation of the extraneous objects relative to the resonator fields as well as the material composition of the extraneous objects. For example, high-conductivity materials may shift the resonant frequency of a resonator and detune it from other resonant objects. This frequency shift may be fixed by applying a feedback mechanism to a resonator that corrects its frequency, such as through changes in the inductance and/or capacitance of the resonator. These changes may be realized using variable capacitors and inductors, in some cases achieved by changes in the geometry of components in the resonators. Other novel tuning mechanisms, described below, may also be used to change the resonator frequency.

[00222] Where external losses are high, the perturbed Q may be low and steps may be taken to limit the absorption of resonator energy inside such extraneous objects and materials. Because of the functional dependence of the dissipated power on the strength of the electric and magnetic fields, one might optimize system performance by designing a system so that the desired coupling is achieved with shorter evanescent resonant field tails at the source resonator and longer at the device resonator, so that the perturbed Q of the source in the presence of other objects is optimized (or vice versa if the perturbed Q of the device needs to be optimized).

[00223] Note that many common extraneous materials and objects such as people, animals, plants, building materials, and the like, may have low conductivities and therefore may have little impact on the wireless energy transfer scheme disclosed here. An important fact related to the magnetic resonator designs we describe is that their electric fields may be confined primarily within the resonator structure itself, so it should be possible to operate within the commonly accepted guidelines for human safety while providing wireless power exchange over mid range distances.

[00224] **Electromagnetic Resonators with Reduced Interactions**

[00225] One frequency range of interest for near-field wireless power transmission is between 10 kHz and 100 MHz. In this frequency range, a large variety of ordinary non-metallic materials, such as for example several types of wood and plastic may have relatively low conductivity, such that only small amounts of power may be dissipated inside them. In addition, materials with low loss tangents, $\tan\Delta$, where $\tan\Delta = \varepsilon''/\varepsilon'$, and ε'' and ε' are the imaginary and real parts of the permittivity respectively, may also have only small amounts of power dissipated inside them. Metallic materials, such as copper, silver, gold, and the like, with

InductEV, Inc.
Exhibit 1002
Page 049

relatively high conductivity, may also have little power dissipated in them, because electromagnetic fields are not able to significantly penetrate these materials, as discussed earlier. These very high and very low conductivity materials, and low loss tangent materials and objects may have a negligible impact on the losses of a magnetic resonator.

[00226] However, in the frequency range of interest, there are materials and objects such as some electronic circuits and some lower-conductivity metals, which may have moderate (in general inhomogeneous and anisotropic) conductivity, and/or moderate to high loss tangents, and which may have relatively high dissipative losses. Relatively larger amounts of power may be dissipated inside them. These materials and objects may dissipate enough energy to reduce $Q_{(p)}$ by non-trivial amounts, and may be referred to as "lossy objects".

[00227] One way to reduce the impact of lossy materials on the $Q_{(p)}$ of a resonator is to use high-conductivity materials to shape the resonator fields such that they avoid the lossy objects. The process of using high-conductivity materials to tailor electromagnetic fields so that they avoid lossy objects in their vicinity may be understood by visualizing high-conductivity materials as materials that deflect or reshape the fields. This picture is qualitatively correct as long as the thickness of the conductor is larger than the skin-depth because the boundary conditions for electromagnetic fields at the surface of a good conductor force the electric field to be nearly completely perpendicular to, and the magnetic field to be nearly completely tangential to, the conductor surface. Therefore, a perpendicular magnetic field or a tangential electric field will be "deflected away" from the conducting surface. Furthermore, even a tangential magnetic field or a perpendicular electric field may be forced to decrease in magnitude on one side and/or in particular locations of the conducting surface, depending on the relative position of the sources of the fields and the conductive surface.

[00228] As an example, Fig. 18 shows a finite element method (FEM) simulation of two high conductivity surfaces 1802 above and below a lossy dielectric material 1804 in an external, initially uniform, magnetic field of frequency f= 6.78 MHz. The system is azimuthally symmetric around the r=0 axis. In this simulation, the lossy dielectric material 1804 is sandwiched between two conductors 1802, shown as the white lines at approximately z = ±0.01m. In the absence of the conducting surfaces above and below the dielectric disk, the magnetic field (represented by the drawn magnetic field lines) would have remained essentially uniform (field lines straight and parallel with the z-axis), indicating that the magnetic field would

have passed straight through the lossy dielectric material. In this case, power would have been dissipated in the lossy dielectric disk. In the presence of conducting surfaces, however, this simulation shows the magnetic field is reshaped. The magnetic field is forced to be tangential to surface of the conductor and so is deflected around those conducting surfaces 1802, minimizing the amount of power that may be dissipated in the lossy dielectric material 1804 behind or between the conducting surfaces. As used herein, an axis of electrical symmetry refers to any axis about which a fixed or time-varying electrical or magnetic field is substantially symmetric during an exchange of energy as disclosed herein.

[00229] A similar effect is observed even if only one conducting surface, above or below, the dielectric disk, is used. If the dielectric disk is thin, the fact that the electric field is essentially zero at the surface, and continuous and smooth close to it, means that the electric field is very low everywhere close to the surface (i.e. within the dielectric disk). A single surface implementation for deflecting resonator fields away from lossy objects may be preferred for applications where one is not allowed to cover both sides of the lossy material or object (e.g. an LCD screen). Note that even a very thin surface of conducting material, on the order of a few skin-depths, may be sufficient (the skin depth in pure copper at 6.78 MHz is ~20 μ m, and at 250 kHz is ~100 μ m) to significantly improve the $Q_{(p)}$ of a resonator in the presence of lossy materials.

[00230] Lossy extraneous materials and objects may be parts of an apparatus, in which a high-Q resonator is to be integrated. The dissipation of energy in these lossy materials and objects may be reduced by a number of techniques including:

- by positioning the lossy materials and objects away from the resonator, or, in special positions and orientations relative to the resonator.
- by using a high conductivity material or structure to partly or entirely cover lossy materials and objects in the vicinity of a resonator
- by placing a closed surface (such as a sheet or a mesh) of high-conductivity material around a lossy object to completely cover the lossy object and shape the resonator fields such that they avoid the lossy object.

InductEV, Inc.
Exhibit 1002
Page 051

- by placing a surface (such as a sheet or a mesh) of a high-conductivity material around only a portion of a lossy object, such as along the top, the bottom, along the side, and the like, of an object or material.
- by placing even a single surface (such as a sheet or a mesh) of high-conductivity material above or below or on one side of a lossy object to reduce the strength of the fields at the location of the lossy object.

[00231] Fig. 19 shows a capacitively-loaded loop inductor forming a magnetic resonator 102 and a disk-shaped surface of high-conductivity material 1802 that completely surrounds a lossy object 1804 placed inside the loop inductor. Note that some lossy objects may be components, such as electronic circuits, that may need to interact with, communicate with, or be connected to the outside environment and thus cannot be completely electromagnetically isolated. Partially covering a lossy material with high conductivity materials may still reduce extraneous losses while enabling the lossy material or object to function properly.

[00232] Fig. 20 shows a capacitively-loaded loop inductor that is used as the resonator 102 and a surface of high-conductivity material 1802, surrounding only a portion of a lossy object 1804, that is placed inside the inductor loop.

[00233] Extraneous losses may be reduced, but may not be completely eliminated, by placing a single surface of high-conductivity material above, below, on the side, and the like, of a lossy object or material. An example is shown in Fig. 21, where a capacitively-loaded loop inductor is used as the resonator 102 and a surface of high-conductivity material 1802 is placed inside the inductor loop under a lossy object 1804 to reduce the strength of the fields at the location of the lossy object. It may be preferable to cover only one side of a material or object because of considerations of cost, weight, assembly complications, air flow, visual access, physical access, and the like.

[00234] A single surface of high-conductivity material may be used to avoid objects that cannot or should not be covered from both sides (e.g. LCD or plasma screens). Such lossy objects may be avoided using optically transparent conductors. High-conductivity optically opaque materials may instead be placed on only a portion of the lossy object, instead of, or in addition to, optically transparent conductors. The adequacy of single-sided vs. multi-sided covering implementations, and the design trade-offs inherent therein may depend on the details of the wireless energy transfer scenario and the properties of the lossy materials and objects.

InductEV, Inc.
Exhibit 1002
Page 052

[00235] Below we describe an example using high-conductivity surfaces to improve the Q-insensitivity, $\Theta_{(p)}$, of an integrated magnetic resonator used in a wireless energy-transfer system. Fig. 22 shows a wireless projector 2200. The wireless projector may include a device resonator 102C, a projector 2202, a wireless network/video adapter 2204, and power conversion circuits 2208, arranged as shown. The device resonator 102C may include a three-turn conductor loop, arranged to enclose a surface, and a capacitor network 2210. The conductor loop may be designed so that the device resonator 102C has a high Q (e.g., >100) at its operating resonant frequency. Prior to integration in the completely wireless projector 2200, this device resonator 102C has a Q of approximately 477 at the designed operating resonant frequency of 6.78 MHz. Upon integration, and placing the wireless network/video adapter card 2204 in the center of the resonator loop inductor, the resonator $Q_{(integrated)}$ was decreased to approximately 347. At least some of the reduction from Q to $Q_{(integrated)}$ was attributed to losses in the perturbing wireless network/video adapter card. As described above, electromagnetic fields associated with the magnetic resonator 102C may induce currents in and on the wireless network/video adapter card 2204, which may be dissipated in resistive losses in the lossy materials that compose the card. We observed that $Q_{(integrated)}$ of the resonator may be impacted differently depending on the composition, position, and orientation, of objects and materials placed in its vicinity.

[00236] In a completely wireless projector example, covering the network/video adapter card with a thin copper pocket (a folded sheet of copper that covered the top and the bottom of the wireless network/video adapter card, but not the communication antenna) improved the $Q_{(integrated)}$ of the magnetic resonator to a $Q_{(integrated + copper\ pocket)}$ of approximately 444. In other words, most of the reduction in $Q_{(integrated)}$ due to the perturbation caused by the extraneous network/video adapter card could be eliminated using a copper pocket to deflect the resonator fields away from the lossy materials.

[00237] In another completely wireless projector example, covering the network/video adapter card with a single copper sheet placed beneath the card provided a $Q_{(integrated + copper\ sheet)}$ approximately equal to $Q_{(integrated + copper\ pocket)}$. In that example, the high perturbed Q of the system could be maintained with a single high-conductivity sheet used to deflect the resonator fields away from the lossy adapter card.

[00238] It may be advantageous to position or orient lossy materials or objects, which are part of an apparatus including a high-Q electromagnetic resonator, in places where the fields

InductEV, Inc.
Exhibit 1002
Page 053

produced by the resonator are relatively weak, so that little or no power may be dissipated in these objects and so that the Q-insensitivity, $\Theta_{(p)}$, may be large. As was shown earlier, materials of different conductivity may respond differently to electric versus magnetic fields. Therefore, according to the conductivity of the extraneous object, the positioning technique may be specialized to one or the other field.

[00239] Fig. 23 shows the magnitude of the electric 2312 and magnetic fields 2314 along a line that contains the diameter of the circular loop inductor and the electric 2318 and magnetic fields 2320 along the axis of the loop inductor for a capacitively-loaded circular loop inductor of wire of radius 30 cm, resonant at 10 MHz. It can be seen that the amplitude of the resonant near-fields reach their maxima close to the wire and decay away from the loop, 2312 , 2314 . In the plane of the loop inductor 2318, 2320, the fields reach a local minimum at the center of the loop. Therefore, given the finite size of the apparatus, it may be that the fields are weakest at the extrema of the apparatus or it may be that the field magnitudes have local minima somewhere within the apparatus. This argument holds for any other type of electromagnetic resonator 102 and any type of apparatus. Examples are shown in Figs. 24a and 24b, where a capacitively-loaded inductor loop forms a magnetic resonator 102 and an extraneous lossy object 1804 is positioned where the electromagnetic fields have minimum magnitude.

[00240] In a demonstration example, a magnetic resonator was formed using a three-turn conductor loop, arranged to enclose a square surface (with rounded corners), and a capacitor network. The Q of the resonator was approximately 619 at the designed operating resonant frequency of 6.78 MHz. The perturbed Q of this resonator depended on the placement of the perturbing object, in this case a pocket projector, relative to the resonator. When the perturbing projector was located inside the inductor loop and at its center or on top of the inductor wire turns, $Q_{(projector)}$ was approximately 96, lower than when the perturbing projector was placed outside of the resonator, in which case $Q_{(projector)}$ was approximately 513. These measurements support the analysis that shows the fields inside the inductor loop may be larger than those outside it, so lossy objects placed inside such a loop inductor may yield lower perturbed Q's for the system than when the lossy object is placed outside the loop inductor. Depending on the resonator designs and the material composition and orientation of the lossy object, the arrangement shown in Fig. 24b may yield a higher Q-insensitivity, $\Theta_{(projector)}$, than the arrangement shown in Fig. 24a.

InductEV, Inc.
Exhibit 1002
Page 054

[00241] High-Q resonators may be integrated inside an apparatus. Extraneous materials and objects of high dielectric permittivity, magnetic permeability, or electric conductivity may be part of the apparatus into which a high-Q resonator is to be integrated. For these extraneous materials and objects in the vicinity of a high-Q electromagnetic resonator, depending on their size, position and orientation relative to the resonator, the resonator field-profile may be distorted and deviate significantly from the original unperturbed field-profile of the resonator. Such a distortion of the unperturbed fields of the resonator may significantly decrease the Q to a lower $Q_{(p)}$, even if the extraneous objects and materials are lossless.

[00242] It may be advantageous to position high-conductivity objects, which are part of an apparatus including a high-Q electromagnetic resonator, at orientations such that the surfaces of these objects are, as much as possible, perpendicular to the electric field lines produced by the unperturbed resonator and parallel to the magnetic field lines produced by the unperturbed resonator, thus distorting the resonant field profiles by the smallest amount possible. Other common objects that may be positioned perpendicular to the plane of a magnetic resonator loop include screens (LCD, plasma, etc), batteries, cases, connectors, radiative antennas, and the like. The Q-insensitivity, $\Theta_{(p)}$, of the resonator may be much larger than if the objects were positioned at a different orientation with respect to the resonator fields.

[00243] Lossy extraneous materials and objects, which are not part of the integrated apparatus including a high-Q resonator, may be located or brought in the vicinity of the resonator, for example, during the use of the apparatus. It may be advantageous in certain circumstances to use high conductivity materials to tailor the resonator fields so that they avoid the regions where lossy extraneous objects may be located or introduced to reduce power dissipation in these materials and objects and to increase Q-insensitivity, $\Theta_{(p)}$. An example is shown in Fig. 25, where a capacitively-loaded loop inductor and capacitor are used as the resonator 102 and a surface of high-conductivity material 1802 is placed above the inductor loop to reduce the magnitude of the fields in the region above the resonator, where lossy extraneous objects 1804 may be located or introduced.

[00244] Note that a high-conductivity surface brought in the vicinity of a resonator to reshape the fields may also lead to $Q_{(cond.\ surface)}<Q$. The reduction in the perturbed Q may be due to the dissipation of energy inside the lossy conductor or to the distortion of the unperturbed resonator field profiles associated with matching the field boundary conditions at the surface of

InductEV, Inc.
Exhibit 1002
Page 055

the conductor. Therefore, while a high-conductivity surface may be used to reduce the extraneous losses due to dissipation inside an extraneous lossy object, in some cases, especially in some of those where this is achieved by significantly reshaping the electromagnetic fields, using such a high-conductivity surface so that the fields avoid the lossy object may result effectively in $Q_{(p + cond.\ surface)}<Q_{(p)}$ rather than the desired result $Q_{(p + cond.\ surface)}>Q_{(p)}$.

[00245] As described above, in the presence of loss inducing objects, the perturbed quality factor of a magnetic resonator may be improved if the electromagnetic fields associated with the magnetic resonator are reshaped to avoid the loss inducing objects. Another way to reshape the unperturbed resonator fields is to use high permeability materials to completely or partially enclose or cover the loss inducing objects, thereby reducing the interaction of the magnetic field with the loss inducing objects.

[00246] Magnetic field shielding has been described previously, for example in *Electrodynamics 3rd Ed.*, Jackson, pp. 201-203. There, a spherical shell of magnetically permeable material was shown to shield its interior from external magnetic fields. For example, if a shell of inner radius a, outer radius b, and relative permeability μ_r, is placed in an initially uniform magnetic field H_0, then the field inside the shell will have a constant magnitude, $9\mu_r H_0 \Big/ \left[(2\mu_r+1)(\mu_r+2)-2(a/b)^3(\mu_r-1)^2\right]$, which tends to $9H_0 \Big/ 2\mu_r\left(1-(a/b)^3\right)$ if $\mu_r >> 1$. This result shows that an incident magnetic field (but not necessarily an incident electric field) may be greatly attenuated inside the shell, even if the shell is quite thin, provided the magnetic permeability is high enough. It may be advantageous in certain circumstances to use high permeability materials to partly or entirely cover lossy materials and objects so that they are avoided by the resonator magnetic fields and so that little or no power is dissipated in these materials and objects. In such an approach, the Q-insensitivity, $\Theta_{(p)}$, may be larger than if the materials and objects were not covered, possibly larger than 1.

[00247] It may be desirable to keep both the electric and magnetic fields away from loss inducing objects. As described above, one way to shape the fields in such a manner is to use high-conductivity surfaces to either completely or partially enclose or cover the loss inducing objects. A layer of magnetically permeable material, also referred to as magnetic material, (any material or meta-material having a non-trivial magnetic permeability), may be placed on or around the high-conductivity surfaces. The additional layer of magnetic material may present a

InductEV, Inc.
Exhibit 1002
Page 056

lower reluctance path (compared to free space) for the deflected magnetic field to follow and may partially shield the electric conductor underneath it from the incident magnetic flux. This arrangement may reduce the losses due to induced currents in the high-conductivity surface. Under some circumstances the lower reluctance path presented by the magnetic material may improve the perturbed Q of the structure.

[00248] Fig. 26a shows an axially symmetric FEM simulation of a thin conducting 2604 (copper) disk (20 cm in diameter, 2 cm in height) exposed to an initially uniform, externally applied magnetic field (gray flux lines) along the z-axis. The axis of symmetry is at r=0. The magnetic streamlines shown originate at $z = -\infty$, where they are spaced from r=3 cm to r=10 cm in intervals of 1 cm. The axes scales are in meters. Imagine, for example, that this conducing cylinder encloses loss-inducing objects within an area circumscribed by a magnetic resonator in a wireless energy transfer system such as shown in Fig. 19.

[00249] This high-conductivity enclosure may increase the perturbing Q of the lossy objects and therefore the overall perturbed Q of the system, but the perturbed Q may still be less than the unperturbed Q because of induced losses in the conducting surface and changes to the profile of the electromagnetic fields. Decreases in the perturbed Q associated with the high-conductivity enclosure may be at least partially recovered by including a layer of magnetic material along the outer surface or surfaces of the high-conductivity enclosure. Fig. 26b shows an axially symmetric FEM simulation of the thin conducting 2604A (copper) disk (20 cm in diameter, 2 cm in height) from Fig. 26a, but with an additional layer of magnetic material placed directly on the outer surface of the high-conductivity enclosure. Note that the presence of the magnetic material may provide a lower reluctance path for the magnetic field, thereby at least partially shielding the underlying conductor and reducing losses due to induced eddy currents in the conductor.

[00250] Fig. 27 depicts a variation (in axi-symmetric view) to the system shown in Fig. 26 where not all of the lossy material 2708 may be covered by a high-conductivity surface 2706. In certain circumstances it may be useful to cover only one side of a material or object, such as due to considerations of cost, weight, assembly complications, air flow, visual access, physical access, and the like. In the exemplary arrangement shown in Fig. 27, only one surface of the lossy material 2708 is covered and the resonator inductor loop is placed on the opposite side of the high-conductivity surface.

InductEV, Inc.
Exhibit 1002
Page 057

[00251] Mathematical models were used to simulate a high-conductivity enclosure made of copper and shaped like a 20 cm diameter by 2 cm high cylindrical disk placed within an area circumscribed by a magnetic resonator whose inductive element was a single-turn wire loop with loop radius r=11 cm and wire radius a= 1 mm. Simulations for an applied 6.78 MHz electromagnetic field suggest that the perturbing quality factor of this high-conductivity enclosure, $\delta Q_{(enclosure)}$, is 1,870. When the high-conductivity enclosure was modified to include a 0.25 cm-thick layer of magnetic material with real relative permeability, $\mu_r' = 40$, and imaginary relative permeability, $\mu_r'' = 10^{-2}$, simulations suggest the perturbing quality factor is increased to $\delta Q_{(enclosure+magnetic\ material)}$=5,060.

[00252] The improvement in performance due to the addition of thin layers of magnetic material 2702 may be even more dramatic if the high-conductivity enclosure fills a larger portion of the area circumscribed by the resonator's loop inductor 2704. In the example above, if the radius of the inductor loop 2704 is reduced so that it is only 3 mm away from the surface of the high-conductivity enclosure, the perturbing quality factor may be improved from 670 (conducting enclosure only) to 2,730 (conducting enclosure with a thin layer of magnetic material) by the addition of a thin layer of magnetic material 2702around the outside of the enclosure.

[00253] The resonator structure may be designed to have highly confined electric fields, using shielding, or distributed capacitors, for example, which may yield high, even when the resonator is very close to materials that would typically induce loss.

[00254] **Coupled Electromagnetic Resonators**

[00255] The efficiency of energy transfer between two resonators may be determined by the strong-coupling figure-of-merit, $U = \kappa / \sqrt{\Gamma_s \Gamma_d} = \left(2\kappa / \sqrt{\omega_s \omega_d}\right)\sqrt{Q_s Q_d}$. In magnetic resonator implementations the coupling factor between the two resonators may be related to the inductance of the inductive elements in each of the resonators, L_1 and L_2, and the mutual inductance, M, between them by $\kappa_{12} = \omega M / 2\sqrt{L_1 L_2}$. Note that this expression assumes there is negligible coupling through electric-dipole coupling. For capacitively-loaded inductor loop resonators where the inductor loops are formed by circular conducting loops with N turns, separated by a distance D, and oriented as shown in Fig. 1(b), the mutual inductance is

$M = \pi / 4 \cdot \mu_o N_1 N_2 \left(x_1 x_2\right)^2 / D^3$ where x_1 , N_1 and x_2 , N_2 are the characteristic size and number of turns of the conductor loop of the first and second resonators respectively. Note that this is a quasi-static result, and so assumes that the resonator's size is much smaller than the wavelength and the resonators' distance is much smaller than the wavelength, but also that their distance is at least a few times their size. For these circular resonators operated in the quasi-static limit and at mid-range distances, as described above, $k = 2\kappa / \sqrt{\omega_1 \omega_2} \sim \left(\sqrt{x_1 x_2} / D\right)^3$. Strong coupling (a large *U*) between resonators at mid-range distances may be established when the quality factors of the resonators are large enough to compensate for the small *k* at mid-range distances

[00256] For electromagnetic resonators, if the two resonators include conducting parts, the coupling mechanism may be that currents are induced on one resonator due to electric and magnetic fields generated from the other. The coupling factor may be proportional to the flux of the magnetic field produced from the high-Q inductive element in one resonator crossing a closed area of the high-Q inductive element of the second resonator.

[00257] **Coupled Electromagnetic Resonators with Reduced Interactions**

[00258] As described earlier, a high-conductivity material surface may be used to shape resonator fields such that they avoid lossy objects, *p*, in the vicinity of a resonator, thereby reducing the overall extraneous losses and maintaining a high Q-insensitivity $\Theta_{(p + cond.\ surface)}$ of the resonator. However, such a surface may also lead to a perturbed coupling factor, $k_{(p + cond.\ surface)}$, between resonators that is smaller than the perturbed coupling factor, $k_{(p)}$ and depends on the size, position, and orientation of the high-conductivity material relative to the resonators. For example, if high-conductivity materials are placed in the plane and within the area circumscribed by the inductive element of at least one of the magnetic resonators in a wireless energy transfer system, some of the magnetic flux through the area of the resonator, mediating the coupling, may be blocked and *k* may be reduced.

[00259] Consider again the example of Fig. 19. In the absence of the high-conductivity disk enclosure, a certain amount of the external magnetic flux may cross the circumscribed area of the loop. In the presence of the high-conductivity disk enclosure, some of this magnetic flux may be deflected or blocked and may no longer cross the area of the loop, thus leading to a smaller perturbed coupling factor $k_{12(p + cond.\ surfaces)}$. However, because the deflected magnetic-field lines may follow the edges of the high-conductivity surfaces closely, the reduction in the

InductEV, Inc.
Exhibit 1002
Page 059

flux through the loop circumscribing the disk may be less than the ratio of the areas of the face of the disk to the area of the loop.

[00260] One may use high-conductivity material structures, either alone, or combined with magnetic materials to optimize perturbed quality factors, perturbed coupling factors, or perturbed efficiencies.

[00261] Consider the example of Fig. 21. Let the lossy object have a size equal to the size of the capacitively-loaded inductor loop resonator, thus filling its area A 2102. A high-conductivity surface 1802 may be placed under the lossy object 1804. Let this be resonator 1 in a system of two coupled resonators 1 and 2, and let us consider how $U_{12(object + cond.\ surface)}$ scales compared to U_{12} as the area A_s 2104 of the conducting surface increases. Without the conducting surface 1802 below the lossy object 1804, the k-insensitivity, $\beta_{12(object)}$, may be approximately one, but the Q-insensitivity, $\Theta_{1(object)}$, may be small, so the U-insensitivity $\Xi_{12(object)}$ may be small.

[00262] Where the high-conductivity surface below the lossy object covers the entire area of the inductor loop resonator (A_s=A), $k_{12(object + cond.\ surface)}$ may approach zero, because little flux is allowed to cross the inductor loop, so $U_{12(object + cond.\ surface)}$ may approach zero. For intermediate sizes of the high-conductivity surface, the suppression of extrinsic losses and the associated Q-insensitivity, $\Theta_{1(object + cond.\ surface)}$, may be large enough compared to $\Theta_{1(object)}$, while the reduction in coupling may not be significant and the associated k-insensitivity, $\beta_{12(object + cond.\ surface)}$, may be not much smaller than $\beta_{12(object)}$, so that the overall $U_{12(object + cond.\ surface)}$ may be increased compared to $U_{12(object)}$. The optimal degree of avoiding of extraneous lossy objects via high-conductivity surfaces in a system of wireless energy transfer may depend on the details of the system configuration and the application.

[00263] We describe using high-conductivity materials to either completely or partially enclose or cover loss inducing objects in the vicinity of high-Q resonators as one potential method to achieve high perturbed Q's for a system. However, using a good conductor alone to cover the objects may reduce the coupling of the resonators as described above, thereby reducing the efficiency of wireless power transfer. As the area of the conducting surface approaches the area of the magnetic resonator, for example, the perturbed coupling factor, $k_{(p)}$, may approach zero, making the use of the conducting surface incompatible with efficient wireless power transfer.

InductEV, Inc.
Exhibit 1002
Page 060

[00264] One approach to addressing the aforementioned problem is to place a layer of magnetic material around the high-conductivity materials because the additional layer of permeable material may present a lower reluctance path (compared to free space) for the deflected magnetic field to follow and may partially shield the electric conductor underneath it from incident magnetic flux. Under some circumstances the lower reluctance path presented by the magnetic material may improve the electromagnetic coupling of the resonator to other resonators. Decreases in the perturbed coupling factor associated with using conducting materials to tailor resonator fields so that they avoid lossy objects in and around high-Q magnetic resonators may be at least partially recovered by including a layer of magnetic material along the outer surface or surfaces of the conducting materials. The magnetic materials may increase the perturbed coupling factor relative to its initial unperturbed value.

[00265] Note that the simulation results in Fig. 26 show that an incident magnetic field may be deflected less by a layered magnetic material and conducting structure than by a conducting structure alone. If a magnetic resonator loop with a radius only slightly larger than that of the disks shown in Figs. 26(a) and 26(b) circumscribed the disks, it is clear that more flux lines would be captured in the case illustrated in Fig. 26(b) than in Fig. 26(a), and therefore $k_{(disk)}$ would be larger for the case illustrated in Fig. 26(b). Therefore, including a layer of magnetic material on the conducting material may improve the overall system performance. System analyses may be performed to determine whether these materials should be partially, totally, or minimally integrated into the resonator.

[00266] As described above, Fig. 27 depicts a layered conductor 2706 and magnetic material 2702 structure that may be appropriate for use when not all of a lossy material 2708 may be covered by a conductor and/or magnetic material structure. It was shown earlier that for a copper conductor disk with a 20 cm diameter and a 2 cm height, circumscribed by a resonator with an inductor loop radius of 11 cm and a wire radius a=1 mm, the calculated perturbing Q for the copper cylinder was 1,870. If the resonator and the conducting disk shell are placed in a uniform magnetic field (aligned along the axis of symmetry of the inductor loop), we calculate that the copper conductor has an associated coupling factor insensitivity of 0.34. For comparison, we model the same arrangement but include a 0.25 cm-thick layer of magnetic material with a real relative permeability, $\mu_r' = 40$, and an imaginary relative permeability, $\mu_r'' = 10^{-2}$. Using the

InductEV, Inc.
Exhibit 1002
Page 061

same model and parameters described above, we find that the coupling factor insensitivity is improved to 0.64 by the addition of the magnetic material to the surface of the conductor.

[00267] Magnetic materials may be placed within the area circumscribed by the magnetic resonator to increase the coupling in wireless energy transfer systems. Consider a solid sphere of a magnetic material with relative permeability, μ_r, placed in an initially uniform magnetic field. In this example, the lower reluctance path offered by the magnetic material may cause the magnetic field to concentrate in the volume of the sphere. We find that the magnetic flux through the area circumscribed by the equator of the sphere is enhanced by a factor of $3\mu_r/(\mu_r+2)$, by the addition of the magnetic material. If $\mu_r>>1$, this enhancement factor may be close to 3.

[00268] One can also show that the dipole moment of a system comprising the magnetic sphere circumscribed by the inductive element in a magnetic resonator would have its magnetic dipole enhanced by the same factor. Thus, the magnetic sphere with high permeability practically triples the dipole magnetic coupling of the resonator. It is possible to keep most of this increase in coupling if we use a spherical shell of magnetic material with inner radius *a,* and outer radius *b,* even if this shell is on top of block or enclosure made from highly conducting materials. In this case, the enhancement in the flux through the equator is

$$\frac{3\mu_r\left(1-\left(\frac{a}{b}\right)^3\right)}{\mu_r\left(1-\left(\frac{a}{b}\right)^3\right)+2\left(1+\frac{1}{2}\left(\frac{a}{b}\right)^3\right)}.$$

For μ_r=1,000 and (a/b)=0.99, this enhancement factor is still 2.73, so it possible to significantly improve the coupling even with thin layers of magnetic material.

[00269] As described above, structures containing magnetic materials may be used to realize magnetic resonators. Fig. 16(a) shows a 3 dimensional model of a copper and magnetic material structure 1600 driven by a square loop of current around the choke point at its center. Fig. 16(b) shows the interaction, indicated by magnetic field streamlines , between two identical structures 1600A-B with the same properties as the one shown in Fig. 16(a). Because of symmetry, and to reduce computational complexity, only one half of the system is modeled. If

InductEV, Inc.
Exhibit 1002
Page 062

we fix the relative orientation between the two objects and vary their center-to-center distance (the image shown is at a relative separation of 50 cm), we find that, at 300 kHz, the coupling efficiency varies from 87% to 55% as the separation between the structures varies from 30 cm to 60 cm. Each of the example structures shown 1600 A-B includes two 20 cm x 8 cm x 2cm parallelepipeds made of copper joined by a 4 cm x 4 cm x 2 cm block of magnetic material and entirely covered with a 2 mm layer of the same magnetic material (assumed to have μ_r=1,400+j5). Resistive losses in the driving loop are ignored. Each structure has a calculated Q of 815.

[00270] ELECTROMAGNETIC RESONATORS AND IMPEDANCE MATCHING

[00271] Impedance Matching Architectures for Low-Loss Inductive Elements

[00272] For purposes of the present discussion, an inductive element may be any coil or loop structure (the 'loop') of any conducting material, with or without a (gapped or ungapped) core made of magnetic material, which may also be coupled inductively or in any other contactless way to other systems. The element is inductive because its impedance, including both the impedance of the loop and the so-called 'reflected' impedances of any potentially coupled systems, has positive reactance, X, and resistance, R.

[00273] Consider an external circuit, such as a driving circuit or a driven load or a transmission line, to which an inductive element may be connected. The external circuit (e.g. a driving circuit) may be delivering power to the inductive element and the inductive element may be delivering power to the external circuit (e.g. a driven load). The efficiency and amount of power delivered between the inductive element and the external circuit at a desired frequency may depend on the impedance of the inductive element relative to the properties of the external circuit. Impedance-matching networks and external circuit control techniques may be used to regulate the power delivery between the external circuit and the inductive element, at a desired frequency, f.

[00274] The external circuit may be a driving circuit configured to form a amplifier of class A, B, C, D, DE, E, F and the like, and may deliver power at maximum efficiency (namely with minimum losses within the driving circuit) when it is driving a resonant network with specific impedance Z_o^*, where Z_o may be complex and * denotes complex conjugation. The external circuit may be a driven load configured to form a rectifier of class A, B, C, D, DE, E, F and the like, and may receive power at maximum efficiency (namely with minimum losses

InductEV, Inc.
Exhibit 1002
Page 063

within the driven load) when it is driven by a resonant network with specific impedance Z_o^*, where Z_o may be complex. The external circuit may be a transmission line with characteristic impedance, Z_o, and may exchange power at maximum efficiency (namely with zero reflections) when connected to an impedance Z_o^*. We will call the characteristic impedance Z_o of an external circuit the complex conjugate of the impedance that may be connected to it for power exchange at maximum efficiency.

[00275] Typically the impedance of an inductive element, $R+jX$, may be much different from Z_o^*. For example, if the inductive element has low loss (a high X/R), its resistance, R, may be much lower than the real part of the characteristic impedance, Z_0, of the external circuit. Furthermore, an inductive element by itself may not be a resonant network. An impedance-matching network connected to an inductive element may typically create a resonant network, whose impedance may be regulated.

[00276] Therefore, an impedance-matching network may be designed to maximize the efficiency of the power delivered between the external circuit and the inductive element (including the reflected impedances of any coupled systems). The efficiency of delivered power may be maximized by matching the impedance of the combination of an impedance-matching network and an inductive element to the characteristic impedance of an external circuit (or transmission line) at the desired frequency.

[00277] An impedance-matching network may be designed to deliver a specified amount of power between the external circuit and the inductive element (including the reflected impedances of any coupled systems). The delivered power may be determined by adjusting the complex ratio of the impedance of the combination of the impedance-matching network and the inductive element to the impedance of the external circuit (or transmission line) at the desired frequency.

[00278] Impedance-matching networks connected to inductive elements may create magnetic resonators. For some applications, such as wireless power transmission using strongly-coupled magnetic resonators, a high Q may be desired for the resonators. Therefore, the inductive element may be chosen to have low losses (high X/R).

[00279] Since the matching circuit may typically include additional sources of loss inside the resonator, the components of the matching circuit may also be chosen to have low

losses. Furthermore, in high-power applications and/or due to the high resonator Q, large currents may run in parts of the resonator circuit and large voltages may be present across some circuit elements within the resonator. Such currents and voltages may exceed the specified tolerances for particular circuit elements and may be too high for particular components to withstand. In some cases, it may be difficult to find or implement components, such as tunable capacitors for example, with size, cost and performance (loss and current/voltage-rating) specifications sufficient to realize high-Q and high-power resonator designs for certain applications. We disclose matching circuit designs, methods, implementations and techniques that may preserve the high Q for magnetic resonators, while reducing the component requirements for low loss and/or high current/voltage-rating.

[00280] Matching-circuit topologies may be designed that minimize the loss and current-rating requirements on some of the elements of the matching circuit. The topology of a circuit matching a low-loss inductive element to an impedance, Z_0, may be chosen so that some of its components lie outside the associated high-Q resonator by being in series with the external circuit. The requirements for low series loss or high current-ratings for these components may be reduced. Relieving the low series loss and/or high-current-rating requirement on a circuit element may be particularly useful when the element needs to be variable and/or to have a large voltage-rating and/or low parallel loss.

[00281] Matching-circuit topologies may be designed that minimize the voltage rating requirements on some of the elements of the matching circuit. The topology of a circuit matching a low-loss inductive element to an impedance, Z_0, may be chosen so that some of its components lie outside the associated high-Q resonator by being in parallel with Z_0. The requirements for low parallel loss or high voltage-rating for these components may be reduced. Relieving the low parallel loss and/or high-voltage requirement on a circuit element may be particularly useful when the element needs to be variable and/or to have a large current-rating and/or low series loss.

[00282] The topology of the circuit matching a low-loss inductive element to an external characteristic impedance, Z_0, may be chosen so that the field pattern of the associated resonant mode and thus its high Q are preserved upon coupling of the resonator to the external impedance. Otherwise inefficient coupling to the desired resonant mode may occur (potentially

InductEV, Inc.
Exhibit 1002
Page 065

due to coupling to other undesired resonant modes), resulting in an effective lowering of the resonator Q.

[00283] For applications where the low-loss inductive element or the external circuit, may exhibit variations, the matching circuit may need to be adjusted dynamically to match the inductive element to the external circuit impedance, Z_0, at the desired frequency, f. Since there may typically be two tuning objectives, matching or controlling both the real and imaginary part of the impedance level, Z_0, at the desired frequency, f, there may be two variable elements in the matching circuit. For inductive elements, the matching circuit may need to include at least one variable capacitive element.

[00284] A low-loss inductive element may be matched by topologies using two variable capacitors, or two networks of variable capacitors. A variable capacitor may, for example, be a tunable butterfly-type capacitor having, e.g., a center terminal for connection to a ground or other lead of a power source or load, and at least one other terminal across which a capacitance of the tunable butterfly-type capacitor can be varied or tuned, or any other capacitor having a user-configurable, variable capacitance.

[00285] A low-loss inductive element may be matched by topologies using one, or a network of, variable capacitor(s) and one, or a network of, variable inductor(s).

[00286] A low-loss inductive element may be matched by topologies using one, or a network of, variable capacitor(s) and one, or a network of, variable mutual inductance(s), which transformer-couple the inductive element either to an external circuit or to other systems.

[00287] In some cases, it may be difficult to find or implement tunable lumped elements with size, cost and performance specifications sufficient to realize high-Q, high-power, and potentially high-speed, tunable resonator designs. The topology of the circuit matching a variable inductive element to an external circuit may be designed so that some of the variability is assigned to the external circuit by varying the frequency, amplitude, phase, waveform, duty cycle, and the like, of the drive signals applied to transistors, diodes, switches and the like, in the external circuit.

[00288] The variations in resistance, R, and inductance, L, of an inductive element at the resonant frequency may be only partially compensated or not compensated at all. Adequate system performance may thus be preserved by tolerances designed into other system components

InductEV, Inc.
Exhibit 1002
Page 066

or specifications. Partial adjustments, realized using fewer tunable components or less capable tunable components, may be sufficient.

[00289] Matching-circuit architectures may be designed that achieve the desired variability of the impedance matching circuit under high-power conditions, while minimizing the voltage/current rating requirements on its tunable elements and achieving a finer (i.e. more precise, with higher resolution) overall tunability. The topology of the circuit matching a variable inductive element to an impedance, Z_0, may include appropriate combinations and placements of fixed and variable elements, so that the voltage/current requirements for the variable components may be reduced and the desired tuning range may be covered with finer tuning resolution. The voltage/current requirements may be reduced on components that are not variable.

[00290] The disclosed impedance matching architectures and techniques may be used to achieve the following:

- To maximize the power delivered to, or to minimize impedance mismatches between, the source low-loss inductive elements (and any other systems wirelessly coupled to them) from the power driving generators.
- To maximize the power delivered from, or to minimize impedance mismatches between, the device low-loss inductive elements (and any other systems wirelessly coupled to them) to the power driven loads.
- To deliver a controlled amount of power to, or to achieve a certain impedance relationship between, the source low-loss inductive elements (and any other systems wirelessly coupled to them) from the power driving generators.
- To deliver a controlled amount of power from, or to achieve a certain impedance relationship between, the device low-loss inductive elements (and any other systems wirelessly coupled to them) to the power driven loads.

[00291] TOPOLOGIES FOR PRESERVATION OF MODE PROFILE (HIGH-Q)

[00292] The resonator structure may be designed to be connected to the generator or the load wirelessly (indirectly) or with a hard-wired connection (directly).

[00293] Consider a general indirectly coupled matching topology such as that shown by the block diagram in Fig. 28(a). There, an inductive element 2802 , labeled as (R,L) and represented by the circuit symbol for an inductor, may be any of the inductive elements discussed in this disclosure or in the references provided herein, and where an impedance-

InductEV, Inc.
Exhibit 1002
Page 067

matching circuit 2402 includes or consists of parts A and B. B may be the part of the matching circuit that connects the impedance 2804 , Z_0, to the rest of the circuit (the combination of A and the inductive element (A+(*R,L*)) via a wireless connection (an inductive or capacitive coupling mechanism).

[00294] The combination of A and the inductive element 2802 may form a resonator 102, which in isolation may support a high-*Q* resonator electromagnetic mode, with an associated current and charge distribution. The lack of a wired connection between the external circuit, Z_0 and B, and the resonator, A + (*R,L*), may ensure that the high-*Q* resonator electromagnetic mode and its current/charge distributions may take the form of its intrinsic (in-isolation) profile, so long as the degree of wireless coupling is not too large. That is, the electromagnetic mode, current/charge distributions, and thus the high-*Q* of the resonator may be automatically maintained using an indirectly coupled matching topology.

[00295] This matching topology may be referred to as indirectly coupled, or transformer-coupled, or inductively-coupled, in the case where inductive coupling is used between the external circuit and the inductor loop. This type of coupling scenario was used to couple the power supply to the source resonator and the device resonator to the light bulb in the demonstration of wireless energy transfer over mid-range distances described in the referenced *Science* article.

[00296] Next consider examples in which the inductive element may include the inductive element and any indirectly coupled systems. In this case, as disclosed above, and again because of the lack of a wired connection between the external circuit or the coupled systems and the resonator, the coupled systems may not, with good approximation for not-too-large degree of indirect coupling, affect the resonator electromagnetic mode profile and the current/charge distributions of the resonator. Therefore, an indirectly-coupled matching circuit may work equally well for any general inductive element as part of a resonator as well as for inductive elements wirelessly-coupled to other systems, as defined herein. Throughout this disclosure, the matching topologies we disclose refer to matching topologies for a general inductive element of this type, that is, where any additional systems may be indirectly coupled to the low-loss inductive element, and it is to be understood that those additional systems do not greatly affect the resonator electromagnetic mode profile and the current/charge distributions of the resonator.

InductEV, Inc.
Exhibit 1002
Page 068

[00297] Based on the argument above, in a wireless power transmission system of any number of coupled source resonators, device resonators and intermediate resonators the wireless magnetic (inductive) coupling between resonators does not affect the electromagnetic mode profile and the current/charge distributions of each one of the resonators. Therefore, when these resonators have a high (unloaded and unperturbed) Q, their (unloaded and unperturbed) Q may be preserved in the presence of the wireless coupling. (Note that the loaded Q of a resonator may be reduced in the presence of wireless coupling to another resonator, but we may be interested in preserving the unloaded Q, which relates only to loss mechanisms and not to coupling/loading mechanisms.)

[00298] Consider a matching topology such as is shown in Fig. 28(b). The capacitors shown in Fig. 28(b) may represent capacitor circuits or networks. The capacitors shown may be used to form the resonator 102 and to adjust the frequency and/or impedance of the source and device resonators. This resonator 102 may be directly coupled to an impedance, Z_0, using the ports labeled "terminal connections" 2808. Fig. 28(c) shows a generalized directly coupled matching topology, where the impedance-matching circuit 2602 includes or consists of parts A, B and C. Here, circuit elements in A, B and C may be considered part of the resonator 102 as well as part of the impedance matching 2402 (and frequency tuning) topology. B and C may be the parts of the matching circuit 2402 that connect the impedance Z_0 2804 (or the network terminals) to the rest of the circuit (A and the inductive element) via a single wire connection each. Note that B and C could be empty (short-circuits). If we disconnect or open circuit parts B and C (namely those single wire connections), then, the combination of A and the inductive element (R,L) may form the resonator.

[00299] The high-Q resonator electromagnetic mode may be such that the profile of the voltage distribution along the inductive element has nodes, namely positions where the voltage is zero. One node may be approximately at the center of the length of the inductive element, such as the center of the conductor used to form the inductive element, (with or without magnetic materials) and at least one other node may be within A. The voltage distribution may be approximately anti-symmetric along the inductive element with respect to its voltage node. A high Q may be maintained by designing the matching topology (A, B, C) and/or the terminal voltages (V1, V2) so that this high-Q resonator electromagnetic mode distribution may be approximately preserved on the inductive element. This high-Q resonator electromagnetic mode

InductEV, Inc.
Exhibit 1002
Page 069

distribution may be approximately preserved on the inductive element by preserving the voltage node (approximately at the center) of the inductive element. Examples that achieve these design goals are provided herein.

[00300] A, B, and C may be arbitrary (namely not having any special symmetry), and V1 and V2 may be chosen so that the voltage across the inductive element is symmetric (voltage node at the center inductive). These results may be achieved using simple matching circuits but potentially complicated terminal voltages, because a topology-dependent common-mode signal (V1+V2)/2 may be required on both terminals.

[00301] Consider an 'axis' that connects all the voltage nodes of the resonator, where again one node is approximately at the center of the length of the inductive element and the others within A. (Note that the 'axis' is really a set of points (the voltage nodes) within the electric-circuit topology and may not necessarily correspond to a linear axis of the actual physical structure. The 'axis' may align with a physical axis in cases where the physical structure has symmetry.) Two points of the resonator are electrically symmetric with respect to the 'axis', if the impedances seen between each of the two points and a point on the 'axis', namely a voltage-node point of the resonator, are the same.

[00302] B and C may be the same (C=B), and the two terminals may be connected to any two points of the resonator (A + (R,L)) that are electrically symmetric with respect to the 'axis' defined above and driven with opposite voltages (V2=-V1) as shown in Fig. 28(d). The two electrically symmetric points of the resonator 102 may be two electrically symmetric points on the inductor loop. The two electrically symmetric points of the resonator may be two electrically symmetric points inside A. If the two electrically symmetric points, (to which each of the equal parts B and C is connected), are inside A, A may need to be designed so that these electrically-symmetric points are accessible as connection points within the circuit. This topology may be referred to as a 'balanced drive' topology. These balanced-drive examples may have the advantage that any common-mode signal that may be present on the ground line, due to perturbations at the external circuitry or the power network, for example, may be automatically rejected (and may not reach the resonator). In some balanced-drive examples, this topology may require more components than other topologies.

[00303] In other examples, C may be chosen to be a short-circuit and the corresponding terminal to be connected to ground (V=0) and to any point on the electric-

InductEV, Inc.
Exhibit 1002
Page 070

symmetry (zero-voltage) 'axis' of the resonator, and B to be connected to any other point of the resonator not on the electric-symmetry 'axis', as shown in Fig. 28(e). The ground-connected point on the electric-symmetry 'axis' may be the voltage node on the inductive element, approximately at the center of its conductor length. The ground-connected point on the electric-symmetry 'axis' may be inside the circuit A. Where the ground-connected point on the electric-symmetry 'axis' is inside A, A may need to be designed to include one such point on the electrical-symmetric 'axis' that is electrically accessible, namely where connection is possible.

[00304] This topology may be referred to as an 'unbalanced drive' topology. The approximately anti-symmetric voltage distribution of the electromagnetic mode along the inductive element may be approximately preserved, even though the resonator may not be driven exactly symmetrically. The reason is that the high Q and the large associated R-vs.-Z_0 mismatch necessitate that a small current may run through B and ground, compared to the much larger current that may flow inside the resonator, (A+(R,L)). In this scenario, the perturbation on the resonator mode may be weak and the location of the voltage node may stay at approximately the center location of the inductive element. These unbalanced-drive examples may have the advantage that they may be achieved using simple matching circuits and that there is no restriction on the driving voltage at the V1 terminal. In some unbalanced-drive examples, additional designs may be required to reduce common-mode signals that may appear at the ground terminal.

[00305] The directly-coupled impedance-matching circuit, generally including or consisting of parts A, B and C, as shown in Fig. 28(c), may be designed so that the wires and components of the circuit do not perturb the electric and magnetic field profiles of the electromagnetic mode of the inductive element and/or the resonator and thus preserve the high resonator Q. The wires and metallic components of the circuit may be oriented to be perpendicular to the electric field lines of the electromagnetic mode. The wires and components of the circuit may be placed in regions where the electric and magnetic field of the electromagnetic mode are weak.

[00306] TOPOLOGIES FOR ALLEVIATING LOW-SERIES-LOSS AND HIGH-CURRENT-RATING REQUIREMENTS ON ELEMENTS

[00307] If the matching circuit used to match a small resistance, R, of a low-loss inductive element to a larger characteristic impedance, Z_0, of an external circuit may be

InductEV, Inc.
Exhibit 1002
Page 071

considered lossless, then $I_{Z_o}^2 Z_o = I_R^2 R \leftrightarrow I_{Z_o} / I_R = \sqrt{R / Z_o}$ and the current flowing through the terminals is much smaller than the current flowing through the inductive element. Therefore, elements connected immediately in series with the terminals (such as in directly-coupled B, C (Fig. 28(c))) may not carry high currents. Then, even if the matching circuit has lossy elements, the resistive loss present in the elements in series with the terminals may not result in a significant reduction in the high-Q of the resonator. That is, resistive loss in those series elements may not significantly reduce the efficiency of power transmission from Z_0 to the inductive element or vice versa. Therefore, strict requirements for low-series-loss and/or high current-ratings may not be necessary for these components. In general, such reduced requirements may lead to a wider selection of components that may be designed into the high-Q and/or high-power impedance matching and resonator topologies. These reduced requirements may be especially helpful in expanding the variety of variable and/or high voltage and/or low-parallel-loss components that may be used in these high-Q and/or high-power impedance-matching circuits.

[00308] TOPOLOGIES FOR ALLEVIATING LOW-PARALLEL-LOSS AND HIGH-VOLTAGE-RATING REQUIREMENTS ON ELEMENTS

[00309] If, as above, the matching circuit used to match a small resistance, R, of a low-loss inductive element to a larger characteristic impedance, Z_0, of an external circuit is lossless, then using the previous analysis,

$$|V_{Z_o} / V_{load}| = |I_{Z_o} Z_o / I_R (R + jX)| \approx \sqrt{R / Z_o} \cdot Z_o / X = \sqrt{Z_o / R} / (X / R),$$

and, for a low-loss (high-X/R) inductive element, the voltage across the terminals may be typically much smaller than the voltage across the inductive element. Therefore, elements connected immediately in parallel to the terminals may not need to withstand high voltages. Then, even if the matching circuit has lossy elements, the resistive loss present in the elements in parallel with the terminals may not result in a significant reduction in the high-Q of the resonator. That is, resistive loss in those parallel elements may not significantly reduce the efficiency of power transmission from Z_0 to the inductive element or vice versa. Therefore, strict requirements for low-parallel-loss and/or high voltage-ratings may not be necessary for these components. In general, such reduced requirements may lead to a wider selection of components that may be designed into the high-Q and/or high-power impedance matching and resonator topologies. These reduced requirements may be especially helpful in expanding the variety of

InductEV, Inc.
Exhibit 1002
Page 072

variable and/or high current and/or low-series-loss components that may be used in these high-Q and/or high-power impedance-matching and resonator circuits.

[00310] Note that the design principles above may reduce currents and voltages on various elements differently, as they variously suggest the use of networks in series with Z_0 (such as directly-coupled B, C) or the use of networks in parallel with Z_0. The preferred topology for a given application may depend on the availability of low-series-loss/high-current-rating or low-parallel-loss/high-voltage-rating elements.

[00311] COMBINATIONS OF FIXED AND VARIABLE ELEMENTS FOR ACHIEVING FINE TUNABILITY AND ALLEVIATING HIGH-RATING REQUIREMENTS ON VARIABLE ELEMENTS

[00312] **Circuit topologies**

[00313] Variable circuit elements with satisfactory low-loss and high-voltage or current ratings may be difficult or expensive to obtain. In this disclosure, we describe impedance-matching topologies that may incorporate combinations of fixed and variable elements, such that large voltages or currents may be assigned to fixed elements in the circuit, which may be more likely to have adequate voltage and current ratings, and alleviating the voltage and current rating requirements on the variable elements in the circuit.

[00314] Variable circuit elements may have tuning ranges larger than those required by a given impedance-matching application and, in those cases, fine tuning resolution may be difficult to obtain using only such large-range elements. In this disclosure, we describe impedance-matching topologies that incorporate combinations of both fixed and variable elements, such that finer tuning resolution may be accomplished with the same variable elements.

[00315] Therefore, topologies using combinations of both fixed and variable elements may bring two kinds of advantages simultaneously: reduced voltage across, or current through, sensitive tuning components in the circuit and finer tuning resolution. Note that the maximum achievable tuning range may be related to the maximum reduction in voltage across, or current through, the tunable components in the circuit designs.

[00316] **Element topologies**

[00317] A single variable circuit-element (as opposed to the network of elements discussed above) may be implemented by a topology using a combination of fixed and variable components, connected in series or in parallel, to achieve a reduction in the rating requirements

InductEV, Inc.
Exhibit 1002
Page 073

of the variable components and a finer tuning resolution. This can be demonstrated mathematically by the fact that:

$$\text{If } x_{|total|} = x_{|fixed|} + x_{|\text{variable}|},$$
$$\text{then } \Delta x_{|total|} / x_{|total|} = \Delta x_{|\text{variable}|} / (x_{|fixed|} + x_{|\text{variable}|}),$$
$$\text{and } X_{\text{variable}} / X_{total} = X_{\text{variable}} / (X_{fixed} + X_{\text{variable}}),$$

where $x_{|\text{subscript}|}$ is any element value (e.g. capacitance, inductance), X is voltage or current, and the "+ sign" denotes the appropriate (series-addition or parallel-addition) combination of elements. Note that the subscript format for $x_{|\text{subscript}|}$, is chosen to easily distinguish it from the radius of the area enclosed by a circular inductive element (e.g. x, x_1, etc.).

[00318] Furthermore, this principle may be used to implement a variable electric element of a certain type (e.g. a capacitance or inductance) by using a variable element of a different type, if the latter is combined appropriately with other fixed elements.

[00319] In conclusion, one may apply a topology optimization algorithm that decides on the required number, placement, type and values of fixed and variable elements with the required tunable range as an optimization constraint and the minimization of the currents and/or voltages on the variable elements as the optimization objective.

[00320] **EXAMPLES**

[00321] In the following schematics, we show different specific topology implementations for impedance matching to and resonator designs for a low-loss inductive element. In addition, we indicate for each topology: which of the principles described above are used, the equations giving the values of the variable elements that may be used to achieve the matching, and the range of the complex impedances that may be matched (using both inequalities and a Smith-chart description). For these examples, we assume that Z_0 is real, but an extension to a characteristic impedance with a non-zero imaginary part is straightforward, as it implies only a small adjustment in the required values of the components of the matching network. We will use the convention that the subscript, n, on a quantity implies normalization to (division by) Z_0.

[00322] Fig. 29 shows two examples of a transformer-coupled impedance-matching circuit, where the two tunable elements are a capacitor and the mutual inductance between two

InductEV, Inc.
Exhibit 1002
Page 074

inductive elements. If we define respectively $X_2=\omega L_2$ for Fig. 29(a) and $X_2=\omega L_2-1/\omega C_2$ for Fig. 29(b), and $X \equiv \omega L$, then the required values of the tunable elements are:

$$\omega C_1 = \frac{1}{X + RX_{2n}}$$
$$\omega M = \sqrt{Z_o R(1 + X_{2n}^2)}\,.$$

For the topology of Fig. 29(b), an especially straightforward design may be to choose $X_2=0$. In that case, these topologies may match the impedances satisfying the inequalities:

$$R_n > 0\,,\ X_n > 0\,,$$

which are shown by the area enclosed by the bold lines on the Smith chart of Fig. 29(c).

[00323] Given a well pre-chosen fixed M, one can also use the above matching topologies with a tunable C_2 instead.

[00324] Fig. 30 shows six examples (a)-(f) of directly-coupled impedance-matching circuits, where the two tunable elements are capacitors, and six examples (h)-(m) of directly-coupled impedance-matching circuits, where the two tunable elements are one capacitor and one inductor. For the topologies of Figs. 30(a),(b),(c),(h),(i),(j), a common-mode signal may be required at the two terminals to preserve the voltage node of the resonator at the center of the inductive element and thus the high *Q*. Note that these examples may be described as implementations of the general topology shown in Fig. 28(c). For the symmetric topologies of Figs. 30(d),(e),(f),(k),(l),(m), the two terminals may need to be driven anti-symmetrically (balanced drive) to preserve the voltage node of the resonator at the center of the inductive element and thus the high *Q*. Note that these examples may be described as implementations of the general topology shown in Fig. 28(d). It will be appreciated that a network of capacitors, as used herein, may in general refer to any circuit topology including one or more capacitors, including without limitation any of the circuits specifically disclosed herein using capacitors, or any other equivalent or different circuit structure(s), unless another meaning is explicitly provided or otherwise clear from the context.

[00325] Let us define respectively $Z=R+j\omega L$ for Figs. 30(a),(d),(h),(k), $Z=R+j\omega L+1/j\omega C_3$ for Figs. 30(b),(e),(i),(l), and $Z=(R+j\omega L)\|(1/j\omega C_3)$ for Figs. 30(c),(f),(j),(m),

InductEV, Inc.
Exhibit 1002
Page 075

where the symbol "||" means "the parallel combination of", and then $R \equiv \mathrm{Re}\{Z\}$, $X \equiv \mathrm{Im}\{Z\}$. Then, for Figs.30(a)-(f) the required values of the tunable elements may be given by:

$$\omega C_1 = \frac{X - \sqrt{X^2 R_n - R^2(1-R_n)}}{X^2 + R^2},$$
$$\omega C_2 = \frac{R_n \omega C_1}{1 - X\omega C_1 - R_n},$$

and these topologies can match the impedances satisfying the inequalities:

$$R_n \le 1,\ X_n \ge \sqrt{R_n(1-R_n)}$$

which are shown by the area enclosed by the bold lines on the Smith chart of Fig. 30(g).
For Figs.30(h)-(m) the required values of the tunable elements may be given by:

$$\omega C_1 = \frac{X + \sqrt{X^2 R_n - R^2(1-R_n)}}{X^2 + R^2},$$
$$\omega L_2 = -\frac{1 - X\omega C_1 - R_n}{R_n \omega C_1}.$$

[00326] Fig. 31 shows three examples (a)-(c) of directly-coupled impedance-matching circuits, where the two tunable elements are capacitors, and three examples (e)-(g) of directly-coupled impedance-matching circuits, where the two tunable elements are one capacitor and one inductor. For the topologies of Figs. 31(a),(b),(c),(e),(f),(g), the ground terminal is connected between two equal-value capacitors, $2C_1$, (namely on the axis of symmetry of the main resonator) to preserve the voltage node of the resonator at the center of the inductive element and thus the high *Q*. Note that these examples may be described as implementations of the general topology shown in Fig. 28(e).

[00327] Let us define respectively $Z=R+j\omega L$ for Figs. 31(a),(e), $Z=R+j\omega L+1/j\omega C_3$ for Figs. 31(b),(f), and $Z=(R+j\omega L)\|(1/j\omega C_3)$ for Fig. 31(c),(g), and then $R \equiv \mathrm{Re}\{Z\}$, $X \equiv \mathrm{Im}\{Z\}$. Then, for Figs.31(a)-(c) the required values of the tunable elements may be given by:

InductEV, Inc.
Exhibit 1002
Page 076

$$\omega C_1 = \frac{X - \frac{1}{2}\sqrt{X^2 R_n - R^2(4 - R_n)}}{X^2 + R^2},$$

$$\omega C_2 = \frac{R_n \omega C_1}{1 - X\omega C_1 - \frac{R_n}{2}},$$

and these topologies can match the impedances satisfying the inequalities:

$$R_n \le 1, \quad X_n \ge \sqrt{\frac{R_n}{1 - R_n}}(2 - R_n)$$

which are shown by the area enclosed by the bold lines on the Smith chart of Fig. 31(d).
For Figs.31(e)-(g) the required values of the tunable elements may be given by:

$$\omega C_1 = \frac{X + \frac{1}{2}\sqrt{X^2 R_n - R^2(4 - R_n)}}{X^2 + R^2},$$

$$\omega L_2 = -\frac{1 - X\omega C_1 - \frac{R_n}{2}}{R_n \omega C_1}.$$

[00328] Fig. 32 shows three examples (a)-(c) of directly-coupled impedance-matching circuits, where the two tunable elements are capacitors, and three examples (e)-(g) of directly-coupled impedance-matching circuits, where the two tunable elements are one capacitor and one inductor. For the topologies of Figs. 32(a),(b),(c),(e),(f),(g), the ground terminal may be connected at the center of the inductive element to preserve the voltage node of the resonator at that point and thus the high Q. Note that these example may be described as implementations of the general topology shown in Fig. 28(e).

[00329] Let us define respectively Z=R+jωL for Fig. 32(a), Z=R+jωL+1/jωC$_3$ for Fig. 32(b), and Z=(R+jωL)||(1/jωC$_3$) for Fig. 32(c), and then $R \equiv \mathrm{Re}\{Z\}$, $X \equiv \mathrm{Im}\{Z\}$. Then, for Figs.32(a)-(c) the required values of the tunable elements may be given by:

InductEV, Inc.
Exhibit 1002
Page 077

$$\omega C_1 = \frac{X - \sqrt{\frac{X^2 R_n - 2R^2(2-R_n)}{4-R_n}}}{X^2 + R^2},$$
$$\omega C_2 = \frac{R_n \omega C_1}{1 - X\omega C_1 - \frac{R_n}{2} + \frac{R_n X \omega C_1}{2(1+k)}},$$

where k is defined by $M' = -kL'$, where L' is the inductance of each half of the inductor loop and M' is the mutual inductance between the two halves, and these topologies can match the impedances satisfying the inequalities:

$$R_n \le 2, \quad X_n \ge \sqrt{2R_n(2-R_n)}$$

which are shown by the area enclosed by the bold lines on the Smith chart of Fig. 32(d).
For Figs.32(e)-(g) the required values of the tunable elements may be given by:

$$\omega C_1 = \frac{X + \sqrt{\frac{X^2 R_n - 2R^2(2-R_n)}{4-R_n}}}{X^2 + R^2},$$

[00330] In the circuits of Figs. 30, 31, 32, the capacitor, C_2, or the inductor, L_2, is (or the two capacitors, $2C_2$, or the two inductors, $L_2/2$, are) in series with the terminals and may not need to have very low series-loss or withstand a large current.

[00331] Fig. 33 shows six examples (a)-(f) of directly-coupled impedance-matching circuits, where the two tunable elements are capacitors, and six examples (h)-(m) of directly-coupled impedance-matching circuits, where the two tunable elements are one capacitor and one inductor. For the topologies of Figs. 33(a),(b),(c),(h),(i),(j), a common-mode signal may be required at the two terminals to preserve the voltage node of the resonator at the center of the inductive element and thus the high *Q*. Note that these examples may be described as implementations of the general topology shown in Fig. 28(c), where B and C are short-circuits and A is not balanced. For the symmetric topologies of Figs. 33(d),(e),(f),(k),(l),(m), the two terminals may need to be driven anti-symmetrically (balanced drive) to preserve the voltage node

InductEV, Inc.
Exhibit 1002
Page 078

of the resonator at the center of the inductive element and thus the high Q. Note that these examples may be described as implementations of the general topology shown in Fig. 28(d), where B and C are short-circuits and A is balanced.

[00332] Let us define respectively Z=R+jωL for Figs. 33(a),(d),(h),(k), Z=R+jωL+1/jωC$_3$ for Figs. 33(b),(e),(i),(l), and Z=(R+jωL)||(1/jωC$_3$) for Figs. 33(c),(f),(j),(m), and then $R \equiv \mathrm{Re}\{Z\}$, $X \equiv \mathrm{Im}\{Z\}$. Then, for Figs.33(a)-(f) the required values of the tunable elements may be given by:

$$\omega C_1 = \frac{1}{X - Z_o\sqrt{R_n(1-R_n)}},$$
$$\omega C_2 = \frac{1}{Z_o}\sqrt{\frac{1}{R_n}-1},$$

and these topologies can match the impedances satisfying the inequalities:

$$R_n \le 1, \quad X_n \ge \sqrt{R_n(1-R_n)}$$

which are shown by the area enclosed by the bold lines on the Smith chart of Fig. 33(g).
For Figs.35(h)-(m) the required values of the tunable elements may be given by:

$$\omega C_1 = \frac{1}{X + Z_o\sqrt{R_n(1-R_n)}},$$
$$\omega L_2 = \frac{Z_o}{\sqrt{\frac{1}{R_n}-1}}.$$

[00333] Fig. 34 shows three examples (a)-(c) of directly-coupled impedance-matching circuits, where the two tunable elements are capacitors, and three examples (e)-(g) of directly-coupled impedance-matching circuits, where the two tunable elements are one capacitor and one inductor. For the topologies of Figs. 34(a),(b),(c),(e),(f),(g), the ground terminal is connected between two equal-value capacitors, 2C$_2$, (namely on the axis of symmetry of the main resonator) to preserve the voltage node of the resonator at the center of the inductive element and

InductEV, Inc.
Exhibit 1002
Page 079

thus the high *Q*. Note that these examples may be described as implementations of the general topology shown in Fig. 28(e).

[00334] Let us define respectively Z=R+jωL for Fig. 34(a),(e), Z=R+jωL+1/jωC$_3$ for Fig. 34(b),(f), and Z=(R+jωL)||(1/jωC$_3$) for Fig. 34(c),(g), and then $R \equiv \mathrm{Re}\{Z\}$, $X \equiv \mathrm{Im}\{Z\}$. Then, for Figs.34(a)-(c) the required values of the tunable elements may be given by:

$$\omega C_1 = \frac{1}{X - Z_o\sqrt{\frac{1-R_n}{R_n}}(2-R_n)},$$

$$\omega C_2 = \frac{1}{2Z_o}\sqrt{\frac{1}{R_n}-1},$$

and these topologies can match the impedances satisfying the inequalities:

$$R_n \le 1,\ X_n \ge \sqrt{\frac{R_n}{1-R_n}}(2-R_n)$$

which are shown by the area enclosed by the bold lines on the Smith chart of Fig. 34(d).
For Figs.34(e)-(g) the required values of the tunable elements may be given by:

$$\omega C_1 = \frac{1}{X + Z_o\sqrt{\frac{1-R_n}{R_n}}(2-R_n)},$$

$$\omega L_2 = \frac{2Z_o}{\sqrt{\frac{1}{R_n}-1}}.$$

[00335] Fig. 35 shows three examples of directly-coupled impedance-matching circuits, where the two tunable elements are capacitors. For the topologies of Figs. 35, the ground terminal may be connected at the center of the inductive element to preserve the voltage node of the resonator at that point and thus the high *Q*. Note that these examples may be described as implementations of the general topology shown in Fig. 28(e).

InductEV, Inc.
Exhibit 1002
Page 080

[00336] Let us define respectively Z=R+jωL for Fig. 35(a), Z=R+jωL+1/jωC$_3$ for Fig. 35(b), and Z=(R+jωL)||(1/jωC$_3$) for Fig. 35(c), and then $R \equiv \mathrm{Re}\{Z\}$, $X \equiv \mathrm{Im}\{Z\}$. Then, the required values of the tunable elements may be given by:

$$\omega C_1 = \frac{2}{X(1+a) - \sqrt{Z_o R(4-R_n)(1+a^2)}},$$
$$\omega C_2 = \frac{2}{X(1+a) + \sqrt{Z_o R(4-R_n)(1+a^2)}},$$

where $a = \frac{R}{2Z_o - R} \cdot \frac{k}{1+k}$ and k is defined by $M' = -kL'$, where L' is the inductance of each half of the inductive element and M' is the mutual inductance between the two halves. These topologies can match the impedances satisfying the inequalities:

$$R_n \le 2 \,\&\, \frac{2}{\gamma} \le R_n \le 4,$$
$$X_n \ge \sqrt{\frac{R_n(4-R_n)(2-R_n)}{2-\gamma R_n}},$$

where

$$\gamma = \frac{1-6k+k^2}{1+2k+k^2} \le 1$$

which are shown by the area enclosed by the bold lines on the three Smith charts shown in Fig. 35(d) for k=0, Fig. 35(e) for k=0.05, and Fig. 35(f) for k=1. Note that for 0<k<1 there are two disconnected regions of the Smith chart that this topology can match.

[00337] In the circuits of Figs. 33, 34, 35, the capacitor, C$_2$, or the inductor, L$_2$, is (or one of the two capacitors, 2C$_2$, or one of the two inductors, 2L$_2$, are) in parallel with the terminals and thus may not need to have a high voltage-rating. In the case of two capacitors, 2C$_2$, or two inductors, 2L$_2$, both may not need to have a high voltage-rating, since approximately the same current flows through them and thus they experience approximately the same voltage across them.

[00338] For the topologies of Figs. 30-35, where a capacitor, C$_3$, is used, the use of the capacitor, C$_3$, may lead to finer tuning of the frequency and the impedance. For the topologies of

Figs. 30-35, the use of the fixed capacitor, C_3, in series with the inductive element may ensure that a large percentage of the high inductive-element voltage will be across this fixed capacitor, C_3, thus potentially alleviating the voltage rating requirements for the other elements of the impedance matching circuit, some of which may be variable. Whether or not such topologies are preferred depends on the availability, cost and specifications of appropriate fixed and tunable components.

[00339] In all the above examples, a pair of equal-value variable capacitors without a common terminal may be implemented using ganged-type capacitors or groups or arrays of varactors or diodes biased and controlled to tune their values as an ensemble. A pair of equal-value variable capacitors with one common terminal can be implemented using a tunable butterfly-type capacitor or any other tunable or variable capacitor or group or array of varactors or diodes biased and controlled to tune their capacitance values as an ensemble.

[00340] Another criterion which may be considered upon the choice of the impedance matching network is the response of the network to different frequencies than the desired operating frequency. The signals generated in the external circuit, to which the inductive element is coupled, may not be monochromatic at the desired frequency but periodic with the desired frequency, as for example the driving signal of a switching amplifier or the reflected signal of a switching rectifier. In some such cases, it may be desirable to suppress the amount of higher-order harmonics that enter the inductive element (for example, to reduce radiation of these harmonics from this element). Then the choice of impedance matching network may be one that sufficiently suppresses the amount of such harmonics that enters the inductive element.

[00341] The impedance matching network may be such that the impedance seen by the external circuit at frequencies higher than the fundamental harmonic is high, when the external periodic signal is a signal that can be considered to behave as a voltage-source signal (such as the driving signal of a class-D amplifier with a series resonant load), so that little current flows through the inductive element at higher frequencies. Among the topologies of Figs. 30-35, those which use an inductor, L_2, may then be preferable, as this inductor presents a high impedance at high frequencies.

[00342] The impedance matching network may be such that the impedance seen by the external circuit at frequencies higher than the fundamental harmonic is low, when the external periodic signal is a signal that can be considered to behave as a current-source signal, so that

InductEV, Inc.
Exhibit 1002
Page 082

little voltage is induced across the inductive element at higher frequencies. Among the topologies of Figs. 30-35, those which use a capacitor, C_2, are then preferable, as this capacitor presents a low impedance at high frequencies.

[00343] Fig. 36 shows four examples of a variable capacitance, using networks of one variable capacitor and the rest fixed capacitors. Using these network topologies, fine tunability of the total capacitance value may be achieved. Furthermore, the topologies of Figs. 36(a),(c),(d), may be used to reduce the voltage across the variable capacitor, since most of the voltage may be assigned across the fixed capacitors.

[00344] Fig. 37 shows two examples of a variable capacitance, using networks of one variable inductor and fixed capacitors. In particular, these networks may provide implementations for a variable reactance, and, at the frequency of interest, values for the variable inductor may be used such that each network corresponds to a net negative variable reactance, which may be effectively a variable capacitance.

[00345] Tunable elements such as tunable capacitors and tunable inductors may be mechanically-tunable, electrically-tunable, thermally-tunable and the like. The tunable elements may be variable capacitors or inductors, varactors, diodes, Schottky diodes, reverse-biased PN diodes, varactor arrays, diode arrays, Schottky diode arrays and the like. The diodes may be Si diodes, GaN diodes, SiC diodes, and the like. GaN and SiC diodes may be particularly attractive for high power applications. The tunable elements may be electrically switched capacitor banks, electrically-switched mechanically-tunable capacitor banks, electrically-switched varactor-array banks, electrically-switched transformer-coupled inductor banks, and the like. The tunable elements may be combinations of the elements listed above.

[00346] As described above, the efficiency of the power transmission between coupled high-Q magnetic resonators may be impacted by how closely matched the resonators are in resonant frequency and how well their impedances are matched to the power supplies and power consumers in the system. Because a variety of external factors including the relative position of extraneous objects or other resonators in the system, or the changing of those relative positions, may alter the resonant frequency and/or input impedance of a high-Q magnetic resonator, tunable impedance networks may be required to maintain sufficient levels of power transmission in various environments or operating scenarios.

InductEV, Inc.
Exhibit 1002
Page 083

[00347] The capacitance values of the capacitors shown may be adjusted to adjust the resonant frequency and/or the impedance of the magnetic resonator. The capacitors may be adjusted electrically, mechanically, thermally, or by any other known methods. They may be adjusted manually or automatically, such as in response to a feedback signal. They may be adjusted to achieve certain power transmission efficiencies or other operating characteristics between the power supply and the power consumer.

[00348] The inductance values of the inductors and inductive elements in the resonator may be adjusted to adjust the frequency and/or impedance of the magnetic resonator. The inductance may be adjusted using coupled circuits that include adjustable components such as tunable capacitors, inductors and switches. The inductance may be adjusted using transformer coupled tuning circuits. The inductance may be adjusted by switching in and out different sections of conductor in the inductive elements and/or using ferro-magnetic tuning and/or mu-tuning, and the like.

[00349] The resonant frequency of the resonators may be adjusted to or may be allowed to change to lower or higher frequencies. The input impedance of the resonator may be adjusted to or may be allowed to change to lower or higher impedance values. The amount of power delivered by the source and/or received by the devices may be adjusted to or may be allowed to change to lower or higher levels of power. The amount of power delivered to the source and/or received by the devices from the device resonator may be adjusted to or may be allowed to change to lower or higher levels of power. The resonator input impedances, resonant frequencies, and power levels may be adjusted depending on the power consumer or consumers in the system and depending on the objects or materials in the vicinity of the resonators. The resonator input impedances, frequencies, and power levels may be adjusted manually or automatically, and may be adjusted in response to feedback or control signals or algorithms.

[00350] Circuit elements may be connected directly to the resonator, that is, by physical electrical contact, for example to the ends of the conductor that forms the inductive element and/or the terminal connectors. The circuit elements may be soldered to, welded to, crimped to, glued to, pinched to, or closely position to the conductor or attached using a variety of electrical components, connectors or connection techniques. The power supplies and the power consumers may be connected to magnetic resonators directly or indirectly or inductively.

InductEV, Inc.
Exhibit 1002
Page 084

Electrical signals may be supplied to, or taken from, the resonators through the terminal connections.

[00351] It is to be understood by one of ordinary skill in the art that in real implementations of the principles described herein, there may be an associated tolerance, or acceptable variation, to the values of real components (capacitors, inductors, resistors and the like) from the values calculated via the herein stated equations, to the values of real signals (voltages, currents and the like) from the values suggested by symmetry or anti-symmetry or otherwise, and to the values of real geometric locations of points (such as the point of connection of the ground terminal close to the center of the inductive element or the 'axis' points and the like) from the locations suggested by symmetry or otherwise.

[00352] **Examples**

[00353] SYSTEM BLOCK DIAGRAMS

[00354] We disclose examples of high-Q resonators for wireless power transmission systems that may wirelessly power or charge devices at mid-range distances. High-*Q* resonator wireless power transmission systems also may wirelessly power or charge devices with magnetic resonators that are different in size, shape, composition, arrangement, and the like, from any source resonators in the system.

[00355] Fig. 1(a)(b) shows high level diagrams of two exemplary two-resonator systems. These exemplary systems each have a single source resonator 102S or 104S and a single device resonator 102D or 104D. Fig. 38 shows a high level block diagram of a system with a few more features highlighted. The wirelessly powered or charged device 2310 may include or consist of a device resonator 102D, device power and control circuitry 2304, and the like, along with the device 2308 or devices, to which either DC or AC or both AC and DC power is transferred. The energy or power source for a system may include the source power and control circuitry 2302, a source resonator 102S, and the like. The device 2308 or devices that receive power from the device resonator 102D and power and control circuitry 2304 may be any kind of device 2308 or devices as described previously. The device resonator 102D and circuitry 2304 delivers power to the device/devices 2308 that may be used to recharge the battery of the device/devices, power the device/devices directly, or both when in the vicinity of the source resonator 102S.

[00356] The source and device resonators may be separated by many meters or they may be very close to each other or they may be separated by any distance in between. The source and device resonators may be offset from each other laterally or axially. The source and device resonators may be directly aligned (no lateral offset), or they may be offset by meters, or anything in between. The source and device resonators may be oriented so that the surface areas enclosed by their inductive elements are approximately parallel to each other. The source and device resonators may be oriented so that the surface areas enclosed by their inductive elements are approximately perpendicular to each other, or they may be oriented for any relative angle (0 to 360 degrees) between them.

[00357] The source and device resonators may be free standing or they may be enclosed in an enclosure, container, sleeve or housing. These various enclosures may be composed of almost any kind of material. Low loss tangent materials such as Teflon, REXOLITE, styrene, and the like may be preferable for some applications. The source and device resonators may be integrated in the power supplies and power consumers. For example, the source and device resonators may be integrated into keyboards, computer mice, displays, cell phones, etc. so that they are not visible outside these devices. The source and device resonators may be separate from the power supplies and power consumers in the system and may be connected by a standard or custom wires, cables, connectors or plugs.

[00358] The source 102S may be powered from a number of DC or AC voltage, current or power sources including a USB port of a computer. The source 102S may be powered from the electric grid, from a wall plug, from a battery, from a power supply, from an engine, from a solar cell, from a generator, from another source resonator, and the like. The source power and control circuitry 2302 may include circuits and components to isolate the source electronics from the power source, so that any reflected power or signals are not coupled out through the source input terminals. The source power and control circuits 2302 may include power factor correction circuits and may be configured to monitor power usage for monitoring accounting, billing, control, and like functionalities.

[00359] The system may be operated bi-directionally. That is, energy or power that is generated or stored in a device resonator may be fed back to a power source including the electric grid, a battery, any kind of energy storage unit, and the like. The source power and control circuits may include power factor correction circuits and may be configured to monitor

InductEV, Inc.
Exhibit 1002
Page 086

power usage for monitoring accounting, billing, control, and like functionalities for bi-directional energy flow. Wireless energy transfer systems may enable or promote vehicle-to-grid (V2G) applications.

[00360] The source and the device may have tuning capabilities that allow adjustment of operating points to compensate for changing environmental conditions, perturbations, and loading conditions that can affect the operation of the source and device resonators and the efficiency of the energy exchange. The tuning capability may also be used to multiplex power delivery to multiple devices, from multiple sources, to multiple systems, to multiple repeaters or relays, and the like. The tuning capability may be manually controlled, or automatically controlled and may be performed continuously, periodically, intermittently or at scheduled times or intervals.

[00361] The device resonator and the device power and control circuitry may be integrated into any portion of the device, such as a battery compartment, or a device cover or sleeve, or on a mother board, for example, and may be integrated alongside standard rechargeable batteries or other energy storage units. The device resonator may include a device field reshaper which may shield any combination of the device resonator elements and the device power and control electronics from the electromagnetic fields used for the power transfer and which may deflect the resonator fields away from the lossy device resonator elements as well as the device power and control electronics. A magnetic material and/or high-conductivity field reshaper may be used to increase the perturbed quality factor Q of the resonator and increase the perturbed coupling factor of the source and device resonators.

[00362] The source resonator and the source power and control circuitry may be integrated into any type of furniture, structure, mat, rug, picture frame (including digital picture frames, electronic frames), plug-in modules, electronic devices, vehicles, and the like. The source resonator may include a source field reshaper which may shield any combination of the source resonator elements and the source power and control electronics from the electromagnetic fields used for the power transfer and which may deflect the resonator fields away from the lossy source resonator elements as well as the source power and control electronics. A magnetic material and/or high-conductivity field reshaper may be used to increase the perturbed quality factor Q of the resonator and increase the perturbed coupling factor of the source and device resonators.

InductEV, Inc.
Exhibit 1002
Page 087

[00363] A block diagram of the subsystems in an example of a wirelessly powered device is shown in Fig. 39. The power and control circuitry may be designed to transform the alternating current power from the device resonator 102D and convert it to stable direct current power suitable for powering or charging a device. The power and control circuitry may be designed to transform an alternating current power at one frequency from the device resonator to alternating current power at a different frequency suitable for powering or charging a device. The power and control circuitry may include or consist of impedance matching circuitry 2402D, rectification circuitry 2404, voltage limiting circuitry (not shown), current limiting circuitry (not shown), AC-to-DC converter 2408 circuitry, DC-to-DC converter 2408 circuitry, DC-to-AC converter 2408 circuitry, AC-to-AC converter 2408 circuitry, battery charge control circuitry (not shown), and the like.

[00364] The impedance-matching 2402D network may be designed to maximize the power delivered between the device resonator 102D and the device power and control circuitry 2304 at the desired frequency. The impedance matching elements may be chosen and connected such that the high-Q of the resonators is preserved. Depending on the operating conditions, the impedance matching circuitry 2402D may be varied or tuned to control the power delivered from the source to the device, from the source to the device resonator, between the device resonator and the device power and control circuitry, and the like. The power, current and voltage signals may be monitored at any point in the device circuitry and feedback algorithms circuits, and techniques, may be used to control components to achieve desired signal levels and system operation. The feedback algorithms may be implemented using analog or digital circuit techniques and the circuits may include a microprocessor, a digital signal processor, a field programmable gate array processor and the like.

[00365] The third block of Fig. 39 shows a rectifier circuit 2404 that may rectify the AC voltage power from the device resonator into a DC voltage. In this configuration, the output of the rectifier 2404 may be the input to a voltage clamp circuit. The voltage clamp circuit (not shown) may limit the maximum voltage at the input to the DC-to-DC converter 2408D or DC-to-AC converter 2408D. In general, it may be desirable to use a DC-to-DC/AC converter with a large input voltage dynamic range so that large variations in device position and operation may be tolerated while adequate power is delivered to the device. For example, the voltage level at the output of the rectifier may fluctuate and reach high levels as the power input and load

InductEV, Inc.
Exhibit 1002
Page 088

characteristics of the device change. As the device performs different tasks it may have varying power demands. The changing power demands can cause high voltages at the output of the rectifier as the load characteristics change. Likewise as the device and the device resonator are brought closer and further away from the source, the power delivered to the device resonator may vary and cause changes in the voltage levels at the output of the rectifier. A voltage clamp circuit may prevent the voltage output from the rectifier circuit from exceeding a predetermined value which is within the operating range of the DC-to-DC/AC converter. The voltage clamp circuitry may be used to extend the operating modes and ranges of a wireless energy transfer system.

[00366] The next block of the power and control circuitry of the device is the DC-to-DC converter 2408D that may produce a stable DC output voltage. The DC-to-DC converter may be a boost converter, buck converter, boost-buck converter, single ended primary inductance converter (SEPIC), or any other DC-DC topology that fits the requirements of the particular application. If the device requires AC power, a DC-to-AC converter may be substituted for the DC-to-DC converter, or the DC-to-DC converter may be followed by a DC-to-AC converter. If the device contains a rechargeable battery, the final block of the device power and control circuitry may be a battery charge control unit which may manage the charging and maintenance of the battery in battery powered devices.

[00367] The device power and control circuitry 2304 may contain a processor 2410D, such as a microcontroller, a digital signal processor, a field programmable gate array processor, a microprocessor, or any other type of processor. The processor may be used to read or detect the state or the operating point of the power and control circuitry and the device resonator. The processor may implement algorithms to interpret and adjust the operating point of the circuits, elements, components, subsystems and resonator. The processor may be used to adjust the impedance matching, the resonator, the DC to DC converters, the DC to AC converters, the battery charging unit, the rectifier, and the like of the wirelessly powered device.

[00368] The processor may have wireless or wired data communication links to other devices or sources and may transmit or receive data that can be used to adjust the operating point of the system. Any combination of power, voltage, and current signals at a single, or over a range of frequencies, may be monitored at any point in the device circuitry. These signals may be monitored using analog or digital or combined analog and digital techniques. These monitored

InductEV, Inc.
Exhibit 1002
Page 089

signals may be used in feedback loops or may be reported to the user in a variety of known ways or they may be stored and retrieved at later times. These signals may be used to alert a user of system failures, to indicate performance, or to provide audio, visual, vibrational, and the like, feedback to a user of the system.

[00369] Fig. 40 shows components of source power and control circuitry 2302 of an exemplary wireless power transfer system configured to supply power to a single or multiple devices. The source power and control circuitry 2302 of the exemplary system may be powered from an AC voltage source 2502 such as a home electrical outlet, a DC voltage source such as a battery, a USB port of a computer, a solar cell, another wireless power source, and the like. The source power and control circuitry 2302 may drive the source resonator 102S with alternating current, such as with a frequency greater than 10 kHz and less than 100 MHz. The source power and control circuitry 2302 may drive the source resonator 102S with alternating current of frequency less than less than 10 GHz. The source power and control circuitry 2302 may include a DC-to-DC converter 2408S, an AC-to-DC converter 2408S, or both an AC-to-DC converter 2408S and a DC-to-DC 2408S converter, an oscillator 2508, a power amplifier 2504, an impedance matching network 2402S, and the like.

[00370] The source power and control circuitry 2302 may be powered from multiple AC-or-DC voltage sources 2502 and may contain AC-to-DC and DC-to-DC converters 2408S to provide necessary voltage levels for the circuit components as well as DC voltages for the power amplifiers that may be used to drive the source resonator. The DC voltages may be adjustable and may be used to control the output power level of the power amplifier. The source may contain power factor correction circuitry.

[00371] The oscillator 2508 output may be used as the input to a power amplifier 2504 that drives the source resonator 102S. The oscillator frequency may be tunable and the amplitude of the oscillator signal may be varied as one means to control the output power level from the power amplifier. The frequency, amplitude, phase, waveform, and duty cycle of the oscillator signal may be controlled by analog circuitry, by digital circuitry or by a combination of analog and digital circuitry. The control circuitry may include a processor 2410S, such as a microprocessor, a digital signal processor, a field programmable gate array processor, and the like.

InductEV, Inc.
Exhibit 1002
Page 090

[00372] The impedance matching blocks 2402 of the source and device resonators may be used to tune the power and control circuits and the source and device resonators. For example, tuning of these circuits may adjust for perturbation of the quality factor Q of the source or device resonators due to extraneous objects or changes in distance between the source and device in a system. Tuning of these circuits may also be used to sense the operating environment, control power flow to one or more devices, to control power to a wireless power network, to reduce power when unsafe or failure mode conditions are detected, and the like.

[00373] Any combination of power, voltage, and current signals may be monitored at any point in the source circuitry. These signals may be monitored using analog or digital or combined analog and digital techniques. These monitored signals may be used in feedback circuits or may be reported to the user in a variety of known ways or they may be stored and retrieved at later times. These signals may be used to alert a user to system failures, to alert a user to exceeded safety thresholds, to indicate performance, or to provide audio, visual, vibrational, and the like, feedback to a user of the system.

[00374] The source power and control circuitry may contain a processor. The processor may be used to read the state or the operating point of the power and control circuitry and the source resonator. The processor may implement algorithms to interpret and adjust the operating point of the circuits, elements, components, subsystems and resonator. The processor may be used to adjust the impedance matching, the resonator, the DC-to-DC converters, the AC-to-DC converters, the oscillator, the power amplifier of the source, and the like. The processor and adjustable components of the system may be used to implement frequency and/or time power delivery multiplexing schemes. The processor may have wireless or wired data communication links to devices and other sources and may transmit or receive data that can be used to adjust the operating point of the system.

[00375] Although detailed and specific designs are shown in these block diagrams, it should be clear to those skilled in the art that many different modifications and rearrangements of the components and building blocks are possible within the spirit of the exemplary system. The division of the circuitry was outlined for illustrative purposes and it should be clear to those skilled in the art that the components of each block may be further divided into smaller blocks or merged or shared. In equivalent examples the power and control circuitry may be composed of individual discrete components or larger integrated circuits. For example, the rectifier circuitry

InductEV, Inc.
Exhibit 1002
Page 091

may be composed of discrete diodes, or use diodes integrated on a single chip. A multitude of other circuits and integrated devices can be substituted in the design depending on design criteria such as power or size or cost or application. The whole of the power and control circuitry or any portion of the source or device circuitry may be integrated into one chip.

[00376] The impedance matching network of the device and or source may include a capacitor or networks of capacitors, an inductor or networks of inductors, or any combination of capacitors, inductors, diodes, switches, resistors, and the like. The components of the impedance matching network may be adjustable and variable and may be controlled to affect the efficiency and operating point of the system. The impedance matching may be performed by controlling the connection point of the resonator, adjusting the permeability of a magnetic material, controlling a bias field, adjusting the frequency of excitation, and the like. The impedance matching may use or include any number or combination of varactors, varactor arrays, switched elements, capacitor banks, switched and tunable elements, reverse bias diodes, air gap capacitors, compression capacitors, BZT electrically tuned capacitors, MEMS-tunable capacitors, voltage variable dielectrics, transformer coupled tuning circuits, and the like. The variable components may be mechanically tuned, thermally tuned, electrically tuned, piezo-electrically tuned, and the like. Elements of the impedance matching may be silicon devices, gallium nitride devices, silicon carbide devices and the like. The elements may be chosen to withstand high currents, high voltages, high powers, or any combination of current, voltage and power. The elements may be chosen to be high-Q elements.

[00377] The matching and tuning calculations of the source may be performed on an external device through a USB port that powers the device. The device may be a computer a PDA or other computational platform.

[00378] A demonstration system used a source resonator, coupled to a device resonator, to wirelessly power/recharge multiple electronic consumer devices including, but not limited to, a laptop, a DVD player, a projector, a cell-phone, a display, a television, a projector, a digital picture frame, a light, a TV/DVD player, a portable music player, a circuit breaker, a hand-held tool, a personal digital assistant, an external battery charger, a mouse, a keyboard, a camera, an active load, and the like. A variety of devices may be powered simultaneously from a single device resonator. Device resonators may be operated simultaneously as source resonators.

InductEV, Inc.
Exhibit 1002
Page 092

The power supplied to a device resonator may pass through additional resonators before being delivered to its intended device resonator.

[00379] *Monitoring, Feedback and Control*

[00380] So-called port parameter measurement circuitry may measure or monitor certain power, voltage, and current, signals in the system and processors or control circuits may adjust certain settings or operating parameters based on those measurements. In addition to these port parameter measurements, the magnitude and phase of voltage and current signals, and the magnitude of the power signals, throughout the system may be accessed to measure or monitor the system performance. The measured signals referred to throughout this disclosure may be any combination of the port parameter signals, as well as voltage signals, current signals, power signals, and the like. These parameters may be measured using analog or digital signals, they may be sampled and processed, and they may be digitized or converted using a number of known analog and digital processing techniques. Measured or monitored signals may be used in feedback circuits or systems to control the operation of the resonators and/or the system. In general, we refer to these monitored or measured signals as reference signals, or port parameter measurements or signals, although they are sometimes also referred to as error signals, monitor signals, feedback signals, and the like. We will refer to the signals that are used to control circuit elements such as the voltages used to drive voltage controlled capacitors as the control signals.

[00381] In some cases the circuit elements may be adjusted to achieve a specified or predetermined impedance value for the source and device resonators. In other cases the impedance may be adjusted to achieve a desired impedance value for the source and device resonators when the device resonator is connected to a power consumer or consumers. In other cases the impedance may be adjusted to mitigate changes in the resonant frequency, or impedance or power level changes owing to movement of the source and/or device resonators, or changes in the environment (such as the movement of interacting materials or objects) in the vicinity of the resonators. In other cases the impedance of the source and device resonators may be adjusted to different impedance values.

[00382] The coupled resonators may be made of different materials and may include different circuits, components and structural designs or they may be the same. The coupled resonators may include performance monitoring and measurement circuitry, signal processing and control circuitry or a combination of measurement and control circuitry. Some or all of the

InductEV, Inc.
Exhibit 1002
Page 093

high-Q magnetic resonators may include tunable impedance circuits. Some or all of the high-Q magnetic resonators may include automatically controlled tunable impedance circuits.

[00383] Fig. 41 shows a magnetic resonator with port parameter measurement circuitry 3802 configured to measure certain parameters of the resonator. The port parameter measurement circuitry may measure the input impedance of the structure, or the reflected power. Port parameter measurement circuits may be included in the source and/or device resonator designs and may be used to measure two port circuit parameters such as S-parameters (scattering parameters), Z-parameters (impedance parameters), Y-parameters (admittance parameters), T-parameters (transmission parameters), H-parameters (hybrid parameters), ABCD-parameters (chain, cascade or transmission parameters), and the like. These parameters may be used to describe the electrical behavior of linear electrical networks when various types of signals are applied.

[00384] Different parameters may be used to characterize the electrical network under different operating or coupling scenarios. For example, S-parameters may be used to measure matched and unmatched loads. In addition, the magnitude and phase of voltage and current signals within the magnetic resonators and/or within the sources and devices themselves may be monitored at a variety of points to yield system performance information. This information may be presented to users of the system via a user interface such as a light, a read-out, a beep, a noise, a vibration or the like, or it may be presented as a digital signal or it may be provided to a processor in the system and used in the automatic control of the system. This information may be logged, stored, or may be used by higher level monitoring and control systems.

[00385] Fig. 42 shows a circuit diagram of a magnetic resonator where the tunable impedance network may be realized with voltage controlled capacitors 3902 or capacitor networks. Such an implementation may be adjusted, tuned or controlled by electrical circuits and/or computer processors, such as a programmable voltage source 3908, and the like. For example, the voltage controlled capacitors may be adjusted in response to data acquired by the port parameter measurement circuitry 3802 and processed by a measurement analysis and control algorithm subsystem 3904. Reference signals may be derived from the port parameter measurement circuitry or other monitoring circuitry designed to measure the degree of deviation from a desired system operating point. The measured reference signals may include voltage,

InductEV, Inc.
Exhibit 1002
Page 094

current, complex-impedance, reflection coefficient, power levels and the like, at one or several points in the system and at a single frequency or at multiple frequencies.

[00386] The reference signals may be fed to measurement analysis and control algorithm subsystem modules that may generate control signals to change the values of various components in a tunable impedance matching network. The control signals may vary the resonant frequency and/or the input impedance of the magnetic resonator, or the power level supplied by the source, or the power level drawn by the device, to achieve the desired power exchange between power supplies/generators and power drains/loads.

[00387] Adjustment algorithms may be used to adjust the frequency and/or impedance of the magnetic resonators. The algorithms may take in reference signals related to the degree of deviation from a desired operating point for the system and output correction or control signals related to that deviation that control variable or tunable elements of the system to bring the system back towards the desired operating point or points. The reference signals for the magnetic resonators may be acquired while the resonators are exchanging power in a wireless power transmission system, or they may be switched out of the circuit during system operation. Corrections to the system may be applied or performed continuously, periodically, upon a threshold crossing, digitally, using analog methods, and the like.

[00388] Fig. 43 shows an end-to-end wireless power transmission system. Both the source and the device may include port measurement circuitry 3802 and a processor 2410. The box labeled "coupler/switch" 4002 indicates that the port measurement circuitry 3802 may be connected to the resonator 102 by a directional coupler or a switch, enabling the measurement, adjustment and control of the source and device resonators to take place in conjunction with, or separate from, the power transfer functionality.

[00389] The port parameter measurement and/or processing circuitry may reside with some, any, or all resonators in a system. The port parameter measurement circuitry may utilize portions of the power transmission signal or may utilize excitation signals over a range of frequencies to measure the source/device resonator response (i.e. transmission and reflection between any two ports in the system), and may contain amplitude and/or phase information. Such measurements may be achieved with a swept single frequency signal or a multi-frequency signal. The signals used to measure and monitor the resonators and the wireless power transmission system may be generated by a processor or processors and standard input/output

InductEV, Inc.
Exhibit 1002
Page 095

(I/O) circuitry including digital to analog converters (DACs), analog to digital converters (ADCs), amplifiers, signal generation chips, passive components and the like. Measurements may be achieved using test equipment such as a network analyzer or using customized circuitry. The measured reference signals may be digitized by ADCs and processed using customized algorithms running on a computer, a microprocessor, a DSP chip, an ASIC, and the like. The measured reference signals may be processed in an analog control loop.

[00390] The measurement circuitry may measure any set of two port parameters such as S-parameters, Y-parameters, Z-parameters, H-parameters, G-parameters, T-parameters, ABCD-parameters, and the like. Measurement circuitry may be used to characterize current and voltage signals at various points in the drive and resonator circuitry, the impedance and/or admittance of the source and device resonators at opposite ends of the system, i.e. looking into the source resonator matching network ("port 1" in Fig. 43) towards the device and vice versa.

[00391] The device may measure relevant signals and/or port parameters, interpret the measurement data, and adjust its matching network to optimize the impedance looking into the coupled system independently of the actions of the source. The source may measure relevant port parameters, interpret the measurement data, and adjust its matching network to optimize the impedance looking into the coupled system independently of the actions of the device.

[00392] Fig. 43 shows a block diagram of a source and device in a wireless power transmission system. The system may be configured to execute a control algorithm that actively adjusts the tuning/matching networks in either of or both the source and device resonators to optimize performance in the coupled system. Port measurement circuitry 3802S may measure signals in the source and communicate those signals to a processor 2410. A processor 2410 may use the measured signals in a performance optimization or stabilization algorithm and generate control signals based on the outputs of those algorithms. Control signals may be applied to variable circuit elements in the tuning/impedance matching circuits 2402S to adjust the source's operating characteristics, such as power in the resonator and coupling to devices. Control signals may be applied to the power supply or generator to turn the supply on or off, to increase or decrease the power level, to modulate the supply signal and the like.

[00393] The power exchanged between sources and devices may depend on a variety of factors. These factors may include the effective impedance of the sources and devices, the Q's of the sources and devices, the resonant frequencies of the sources and devices, the distances

InductEV, Inc.
Exhibit 1002
Page 096

between sources and devices, the interaction of materials and objects in the vicinity of sources and devices and the like. The port measurement circuitry and processing algorithms may work in concert to adjust the resonator parameters to maximize power transfer, to hold the power transfer constant, to controllably adjust the power transfer, and the like, under both dynamic and steady state operating conditions.

[00394] Some, all or none of the sources and devices in a system implementation may include port measurement circuitry 3802S and processing 2410 capabilities. Fig. 44 shows an end-to-end wireless power transmission system in which only the source 102S contains port measurement circuitry 3802 and a processor 2410S. In this case, the device resonator 102D operating characteristics may be fixed or may be adjusted by analog control circuitry and without the need for control signals generated by a processor.

[00395] Fig. 45 shows an end-to-end wireless power transmission system. Both the source and the device may include port measurement circuitry 3802 but in the system of Fig. 45, only the source contains a processor 2410S. The source and device may be in communication with each other and the adjustment of certain system parameters may be in response to control signals that have been wirelessly communicated, such as though wireless communications circuitry 4202, between the source and the device. The wireless communication channel 4204 may be separate from the wireless power transfer channel 4208, or it may be the same. That is, the resonators 102 used for power exchange may also be used to exchange information. In some cases, information may be exchanged by modulating a component a source or device circuit and sensing that change with port parameter or other monitoring equipment.

[00396] Implementations where only the source contains a processor 2410 may be beneficial for multi-device systems where the source can handle all of the tuning and adjustment "decisions" and simply communicate the control signals back to the device(s). This implementation may make the device smaller and cheaper because it may eliminate the need for, or reduce the required functionality of, a processor in the device. A portion of or an entire data set from each port measurement at each device may be sent back to the source microprocessor for analysis, and the control instructions may be sent back to the devices. These communications may be wireless communications.

[00397] Fig. 46 shows an end-to-end wireless power transmission system. In this example, only the source contains port measurement circuitry 3802 and a processor 2410S. The

InductEV, Inc.
Exhibit 1002
Page 097

source and device may be in communication, such as via wireless communication circuitry 4202, with each other and the adjustment of certain system parameters may be in response to control signals that have been wirelessly communicated between the source and the device.

[00398] Fig. 47 shows coupled electromagnetic resonators 102 whose frequency and impedance may be automatically adjusted using a processor or a computer. Resonant frequency tuning and continuous impedance adjustment of the source and device resonators may be implemented with reverse biased diodes, Schottky diodes and/or varactor elements contained within the capacitor networks shown as C1, C2, and C3 in Fig. 47. The circuit topology that was built and demonstrated and is described here is exemplary and is not meant to limit the discussion of automatic system tuning and control in any way. Other circuit topologies could be utilized with the measurement and control architectures discussed in this disclosure.

[00399] Device and source resonator impedances and resonant frequencies may be measured with a network analyzer 4402A-B, or by other means described above, and implemented with a controller, such as with Lab View 4404. The measurement circuitry or equipment may output data to a computer or a processor that implements feedback algorithms and dynamically adjusts the frequencies and impedances via a programmable DC voltage source.

[00400] In one arrangement, the reverse biased diodes (Schottky, semiconductor junction, and the like) used to realize the tunable capacitance drew very little DC current and could be reverse biased by amplifiers having large series output resistances. This implementation may enable DC control signals to be applied directly to the controllable circuit elements in the resonator circuit while maintaining a very high-Q in the magnetic resonator.

[00401] C2 biasing signals may be isolated from C1 and/or C3 biasing signals with a DC blocking capacitor as shown in Fig. 47, if the required DC biasing voltages are different. The output of the biasing amplifiers may be bypassed to circuit ground to isolate RF voltages from the biasing amplifiers, and to keep non-fundamental RF voltages from being injected into the resonator. The reverse bias voltages for some of the capacitors may instead be applied through the inductive element in the resonator itself, because the inductive element acts as a short circuit at DC.

[00402] The port parameter measurement circuitry may exchange signals with a processor (including any required ADCs and DACs) as part of a feedback or control system that is used to automatically adjust the resonant frequency, input impedance, energy stored or

captured by the resonator or power delivered by a source or to a device load. The processor may also send control signals to tuning or adjustment circuitry in or attached to the magnetic resonator.

[00403] When utilizing varactors or diodes as tunable capacitors, it may be beneficial to place fixed capacitors in parallel and in series with the tunable capacitors operating at high reverse bias voltages in the tuning/matching circuits. This arrangement may yield improvements in circuit and system stability and in power handling capability by optimizing the operating voltages on the tunable capacitors.

[00404] Varactors or other reverse biased diodes may be used as a voltage controlled capacitor. Arrays of varactors may be used when higher voltage compliance or different capacitance is required than that of a single varactor component. Varactors may be arranged in an N by M array connected serially and in parallel and treated as a single two terminal component with different characteristics than the individual varactors in the array. For example, an N by N array of equal varactors where components in each row are connected in parallel and components in each column are connected in series may be used as a two terminal device with the same capacitance as any single varactor in the array but with a voltage compliance that is N times that of a single varactor in the array. Depending on the variability and differences of parameters of the individual varactors in the array additional biasing circuits composed of resistors, inductors, and the like may be needed. A schematic of a four by four array of unbiased varactors 4502 that may be suitable for magnetic resonator applications is shown in Fig. 48.

[00405] Further improvements in system performance may be realized by careful selection of the fixed value capacitor(s) that are placed in parallel and/or in series with the tunable (varactor/diode/capacitor) elements. Multiple fixed capacitors that are switched in or out of the circuit may be able to compensate for changes in resonator Q's, impedances, resonant frequencies, power levels, coupling strengths, and the like, that might be encountered in test, development and operational wireless power transfer systems. Switched capacitor banks and other switched element banks may be used to assure the convergence to the operating frequencies and impedance values required by the system design.

[00406] An exemplary control algorithm for isolated and coupled magnetic resonators may be described for the circuit and system elements shown in Fig. 47. One control algorithm first adjusts each of the source and device resonator loops "in isolation", that is, with the other

InductEV, Inc.
Exhibit 1002
Page 099

resonators in the system "shorted out" or "removed" from the system. For practical purposes, a resonator can be "shorted out" by making it resonant at a much lower frequency such as by maximizing the value of C1 and/or C3. This step effectively reduces the coupling between the resonators, thereby effectively reducing the system to a single resonator at a particular frequency and impedance.

[00407] Tuning a magnetic resonator in isolation includes varying the tunable elements in the tuning and matching circuits until the values measured by the port parameter measurement circuitry are at their predetermined, calculated or measured relative values. The desired values for the quantities measured by the port parameter measurement circuitry may be chosen based on the desired matching impedance, frequency, strong coupling parameter, and the like. For the exemplary algorithms disclosed below, the port parameter measurement circuitry measures S-parameters over a range of frequencies. The range of frequencies used to characterize the resonators may be a compromise between the system performance information obtained and computation/measurement speed. For the algorithms described below the frequency range may be approximately +/- 20% of the operating resonant frequency.

[00408] Each isolated resonator may be tuned as follows. First, short out the resonator not being adjusted. Next minimize C1, C2, and C3, in the resonator that is being characterized and adjusted. In most cases there will be fixed circuit elements in parallel with C1, C2, and C3, so this step does not reduce the capacitance values to zero. Next, start increasing C2 until the resonator impedance is matched to the "target" real impedance at any frequency in the range of measurement frequencies described above. The initial "target" impedance may be less than the expected operating impedance for the coupled system.

[00409] C2 may be adjusted until the initial "target" impedance is realized for a frequency in the measurement range. Then C1 and/or C3 may be adjusted until the loop is resonant at the desired operating frequency.

[00410] Each resonator may be adjusted according to the above algorithm. After tuning each resonator in isolation, a second feedback algorithm may be applied to optimize the resonant frequencies and/or input impedances for wirelessly transferring power in the coupled system.

[00411] The required adjustments to C1 and/or C2 and/or C3 in each resonator in the coupled system may be determined by measuring and processing the values of the real and

imaginary parts of the input impedance from either and/or both "port(s)" shown in Fig. 43. For coupled resonators, changing the input impedance of one resonator may change the input impedance of the other resonator. Control and tracking algorithms may adjust one port to a desired operating point based on measurements at that port, and then adjust the other port based on measurements at that other port. These steps may be repeated until both sides converge to the desired operating point.

[00412] S-parameters may be measured at both the source and device ports and the following series of measurements and adjustments may be made. In the description that follows, Z_0 is an input impedance and may be the target impedance. In some cases Z_0 is 50 ohms or is near 50 ohms. Z_1 and Z_2 are intermediate impedance values that may be the same value as Z_0 or may be different than Z_0. Re{value} means the real part of a value and Im{value} means the imaginary part of a value.

[00413] An algorithm that may be used to adjust the input impedance and resonant frequency of two coupled resonators is set forth below:

1) Adjust each resonator "in isolation" as described above.

2) Adjust source C1/C3 until, at ω_o, Re{S11} = (Z_1 +/- ε_{Re}) as follows:

- If Re{S11 @ ω_o } > (Z_1 + ε_{Re}), decrease C1/C3. If Re{S11 @ ω_o } < (Zo - ε_{Re}), increase C1/C3.

3) Adjust source C2 until, at ω_o, Im{S11} = (+/- ε_{Im}) as follows:

- If Im{S11 @ ω_o } > ε_{Im}, decrease C2. If Im{S11 @ ω_o } < - ε_{Im} , increase C2.

4) Adjust device C1/C3 until, at ω_0, Re{S22} = (Z_2 +/- ε_{Re}) as follows:

- If Re{S22 @ ω_o } > (Z_2 + ε_{Re}), decrease C1/C3. If Re{S22 @ ω_o } < (Zo - ε_{Re}), increase C1/C3.

5) Adjust device C2 until, at ω_o, Im{S22} = 0 as follows:

- If Im{S22 @ ω_o } > ε_{Im}, decrease C2. If Im{S22 @ ω_o } < -ε_{Im} , increase C2.

InductEV, Inc.
Exhibit 1002
Page 101

[00414] We have achieved a working system by repeating steps 1-4 until both (Re{S11}, Im{S11}) and (Re{S22}, Im{S22}) converge to ((Z_0 +/- ε_{Re}), (+/- ε_{Im})) at ω_o, where Z_0 is the desired matching impedance and ω_o is the desired operating frequency. Here, ε_{Im} represents the maximum deviation of the imaginary part, at ω_o, from the desired value of 0, and ε_{Re} represents the maximum deviation of the real part from the desired value of Z_0. It is understood that ε_{Im} and ε_{Re} can be adjusted to increase or decrease the number of steps to convergence at the potential cost of system performance (efficiency). It is also understood that steps 1-4 can be performed in a variety of sequences and a variety of ways other than that outlined above (i.e. first adjust the source imaginary part, then the source real part; or first adjust the device real part, then the device imaginary part, etc.) The intermediate impedances Z_1 and Z_2 may be adjusted during steps 1-4 to reduce the number of steps required for convergence. The desire or target impedance value may be complex, and may vary in time or under different operating scenarios.

[00415] Steps 1-4 may be performed in any order, in any combination and any number of times. Having described the above algorithm, variations to the steps or the described implementation may be apparent to one of ordinary skill in the art. The algorithm outlined above may be implemented with any equivalent linear network port parameter measurements (i.e., Z-parameters, Y-parameters, T-parameters, H-parameters, ABCD-parameters, etc.) or other monitor signals described above, in the same way that impedance or admittance can be alternatively used to analyze a linear circuit to derive the same result.

[00416] The resonators may need to be retuned owing to changes in the "loaded" resistances, Rs and Rd, caused by changes in the mutual inductance M (coupling) between the source and device resonators. Changes in the inductances, Ls and Ld, of the inductive elements themselves may be caused by the influence of external objects, as discussed earlier, and may also require compensation. Such variations may be mitigated by the adjustment algorithm described above.

[00417] A directional coupler or a switch may be used to connect the port parameter measurement circuitry to the source resonator and tuning/adjustment circuitry. The port parameter measurement circuitry may measure properties of the magnetic resonator while it is exchanging power in a wireless power transmission system, or it may be switched out of the

InductEV, Inc.
Exhibit 1002
Page 102

circuit during system operation. The port parameter measurement circuitry may measure the parameters and the processor may control certain tunable elements of the magnetic resonator at start-up, or at certain intervals, or in response to changes in certain system operating parameters.

[00418] A wireless power transmission system may include circuitry to vary or tune the impedance and/or resonant frequency of source and device resonators. Note that while tuning circuitry is shown in both the source and device resonators, the circuitry may instead be included in only the source or the device resonators, or the circuitry may be included in only some of the source and/or device resonators. Note too that while we may refer to the circuitry as "tuning" the impedance and or resonant frequency of the resonators, this tuning operation simply means that various electrical parameters such as the inductance or capacitance of the structure are being varied. In some cases, these parameters may be varied to achieve a specific predetermined value, in other cases they may be varied in response to a control algorithm or to stabilize a target performance value that is changing. In some cases, the parameters are varied as a function of temperature, of other sources or devices in the area, of the environment, at the like.

[00419] **Applications**

[00420] For each listed application, it will be understood by one of ordinary skill-in-the-art that there are a variety of ways that the resonator structures used to enable wireless power transmission may be connected or integrated with the objects that are supplying or being powered. The resonator may be physically separate from the source and device objects. The resonator may supply or remove power from an object using traditional inductive techniques or through direct electrical connection, with a wire or cable for example. The electrical connection may be from the resonator output to the AC or DC power input port on the object. The electrical connection may be from the output power port of an object to the resonator input.

[00421] FIG. 49 shows a source resonator 4904 that is physically separated from a power supply and a device resonator 4902 that is physically separated from the device 4900, in this illustration a laptop computer. Power may be supplied to the source resonator, and power may be taken from the device resonator directly, by an electrical connection. One of ordinary skill in the art will understand from the materials incorporated by reference that the shape, size, material composition, arrangement, position and orientation of the resonators above are provided by way of non-limiting example, and that a wide variation in any and all of these parameters could be supported by the disclosed technology for a variety of applications.

InductEV, Inc.
Exhibit 1002
Page 103

[00422] Continuing with the example of the laptop, and without limitation, the device resonator may be physically connected to the device it is powering or charging. For example, as shown in FIG. 50a and FIG. 50b, the device resonator 5002 may be (a) integrated into the housing of the device 5000 or (b) it may be attached by an adapter. The resonator 5002 may (FIG. 50b-d) or may not (FIG. 50a) be visible on the device. The resonator may be affixed to the device, integrated into the device, plugged into the device, and the like.

[00423] The source resonator may be physically connected to the source supplying the power to the system. As described above for the devices and device resonators, there are a variety of ways the resonators may be attached to, connected to or integrated with the power supply. One of ordinary skill in the art will understand that there are a variety of ways the resonators may be integrated in the wireless power transmission system, and that the sources and devices may utilize similar or different integration techniques.

[00424] Continuing again with the example of the laptop computer, and without limitation, the laptop computer may be powered, charged or recharged by a wireless power transmission system. A source resonator may be used to supply wireless power and a device resonator may be used to capture the wireless power. A device resonator 5002 may be integrated into the edge of the screen (display) as illustrated in FIG. 50d, and/or into the base of the laptop as illustrated in FIG. 50c. The source resonator 5002 may be integrated into the base of the laptop and the device resonator may be integrated into the edge of the screen. The resonators may also or instead be affixed to the power source and/or the laptop. The source and device resonators may also or instead be physically separated from the power supply and the laptop and may be electrically connected by a cable. The source and device resonators may also or instead be physically separated from the power supply and the laptop and may be electrically coupled using a traditional inductive technique. One of ordinary skill in the art will understand that, while the preceding examples relate to wireless power transmission to a laptop, that the methods and systems disclosed for this application may be suitably adapted for use with other electrical or electronic devices. In general, the source resonator may be external to the source and supplying power to a device resonator that in turn supplies power the device, or the source resonator may be connected to the source and supplying power to a device resonator that in turn supplies power to a portion of the device, or the source resonator may internal to the source and supplying power

InductEV, Inc.
Exhibit 1002
Page 104

to a device resonator that in turn supplies power to a portion of the device, as well as any combination of these.

[00425] A system or method disclosed herein may provide power to an electrical or electronics device, such as, and not limited to, phones, cell phones, cordless phones, smart phones, PDAs, audio devices, music players, MP3 players, radios, portable radios and players, wireless headphones, wireless headsets, computers, laptop computers, wireless keyboards, wireless mouse, televisions, displays, flat screen displays, computer displays, displays embedded in furniture, digital picture frames, electronic books, (e.g. the Kindle, e-ink books, magazines, and the like), remote control units (also referred to as controllers, game controllers, commanders, clickers, and the like, and used for the remote control of a plurality of electronics devices, such as televisions, video games, displays, computers, audio visual equipment, lights, and the like), lighting devices, cooling devices, air circulation devices, purification devices, personal hearing aids, power tools, security systems, alarms, bells, flashing lights, sirens, sensors, loudspeakers, electronic locks, electronic keypads, light switches, other electrical switches, and the like. Here the term electronic lock is used to indicate a door lock which operates electronically (e.g. with electronic combo-key, magnetic card, RFID card, and the like) which is placed on a door instead of a mechanical key-lock. Such locks are often battery operated, risking the possibility that the lock might stop working when a battery dies, leaving the user locked-out. This may be avoided where the battery is either charged or completely replaced by a wireless power transmission implementation as described herein.

[00426] Here, the term light switch (or other electrical switch) is meant to indicate any switch (e.g. on a wall of a room) in one part of the room that turns on/off a device (e.g. light fixture at the center of the ceiling) in another part of the room. To install such a switch by direct connection, one would have to run a wire all the way from the device to the switch. Once such a switch is installed at a particular spot, it may be very difficult to move. Alternately, one can envision a 'wireless switch', where "wireless" means the switching (on/off) commands are communicated wirelessly, but such a switch has traditionally required a battery for operation. In general, having too many battery operated switches around a house may be impractical, because those many batteries will need to be replaced periodically. So, a wirelessly communicating switch may be more convenient, provided it is also wirelessly powered. For example, there already exist communications wireless door-bells that are battery powered, but where one still

InductEV, Inc.
Exhibit 1002
Page 105

has to replace the battery in them periodically. The remote doorbell button may be made to be completely wireless, where there may be no need to ever replace the battery again. Note that here, the term 'cordless' or 'wireless' or 'communications wireless' is used to indicate that there is a cordless or wireless communications facility between the device and another electrical component, such as the base station for a cordless phone, the computer for a wireless keyboard, and the like. One skilled in the art will recognize that any electrical or electronics device may include a wireless communications facility, and that the systems and methods described herein may be used to add wireless power transmission to the device. As described herein, power to the electrical or electronics device may be delivered from an external or internal source resonator, and to the device or portion of the device. Wireless power transmission may significantly reduce the need to charge and/or replace batteries for devices that enter the near vicinity of the source resonator and thereby may reduce the downtime, cost and disposal issues often associated with batteries.

[00427] The systems and methods described herein may provide power to lights without the need for either wired power or batteries. That is, the systems and methods described herein may provide power to lights without wired connection to any power source, and provide the energy to the light non-radiatively across mid-range distances, such as across a distance of a quarter of a meter, one meter, three meters, and the like. A 'light' as used herein may refer to the light source itself, such as an incandescent light bulb, florescent light bulb lamps, Halogen lamps, gas discharge lamps, fluorescent lamps, neon lamps, high-intensity discharge lamps, sodium vapor lamps, Mercury-vapor lamps, electroluminescent lamps, light emitting diodes (LED) lamps, and the like; the light as part of a light fixture, such as a table lamp, a floor lamp, a ceiling lamp, track lighting, recessed light fixtures, and the like; light fixtures integrated with other functions, such as a light/ceiling fan fixture, and illuminated picture frame, and the like. As such, the systems and methods described herein may reduce the complexity for installing a light, such as by minimizing the installation of electrical wiring, and allowing the user to place or mount the light with minimal regard to sources of wired power. For instance, a light may be placed anywhere in the vicinity of a source resonator, where the source resonator may be mounted in a plurality of different places with respect to the location of the light, such as on the floor of the room above, (e.g. as in the case of a ceiling light and especially when the room above is the attic); on the wall of the next room, on the ceiling of the room below, (e.g. as in the case of

a floor lamp); in a component within the room or in the infrastructure of the room as described herein; and the like. For example, a light/ceiling fan combination is often installed in a master bedroom, and the master bedroom often has the attic above it. In this instance a user may more easily install the light/ceiling fan combination in the master bedroom, such as by simply mounting the light/ceiling fan combination to the ceiling, and placing a source coil (plugged into the house wired AC power) in the attic above the mounted fixture. In another example, the light may be an external light, such as a flood light or security light, and the source resonator mounted inside the structure. This way of installing lighting may be particularly beneficial to users who rent their homes, because now they may be able to mount lights and such other electrical components without the need to install new electrical wiring. The control for the light may also be communicated by near-field communications as described herein, or by traditional wireless communications methods.

[00428] The systems and methods described herein may provide power from a source resonator to a device resonator that is either embedded into the device component, or outside the device component, such that the device component may be a traditional electrical component or fixture. For instance, a ceiling lamp may be designed or retrofitted with a device resonator integrated into the fixture, or the ceiling lamp may be a traditional wired fixture, and plugged into a separate electrical facility equipped with the device resonator. In an example, the electrical facility may be a wireless junction box designed to have a device resonator for receiving wireless power, say from a source resonator placed on the floor of the room above (e.g. the attic), and which contains a number of traditional outlets that are powered from the device resonator. The wireless junction box, mounted on the ceiling, may now provide power to traditional wired electrical components on the ceiling (e.g. a ceiling light, track lighting, a ceiling fan). Thus, the ceiling lamp may now be mounted to the ceiling without the need to run wires through the infrastructure of the building. This type of device resonator to traditional outlet junction box may be used in a plurality of applications, including being designed for the interior or exterior of a building, to be made portable, made for a vehicle, and the like. Wireless power may be transferred through common building materials, such as wood, wall board, insulation, glass. brick, stone, concrete, and the like. The benefits of reduced installation cost, re-configurability, and increased application flexibility may provide the user significant benefits over traditional wired installations. The device resonator for a traditional outlet junction box may include a

InductEV, Inc.
Exhibit 1002
Page 107

plurality of electrical components for facilitating the transfer of power from the device resonator to the traditional outlets, such as power source electronics which convert the specific frequencies needed to implement efficient power transfer to line voltage, power capture electronics which may convert high frequency AC to usable voltage and frequencies (AC and/or DC), controls which synchronize the capture device and the power output and which ensure consistent, safe, and maximally efficient power transfer, and the like.

[00429] The systems and methods described herein may provide advantages to lights or electrical components that operate in environments that are wet, harsh, controlled, and the like, such has outside and exposed to the rain, in a pool/sauna/shower, in a maritime application, in hermetically sealed components, in an explosive-proof room, on outside signage, a harsh industrial environment in a volatile environment (e.g. from volatile vapors or airborne organics, such as in a grain silo or bakery) , and the like. For example, a light mounted under the water level of a pool is normally difficult to wire up, and is required to be water-sealed despite the need for external wires. But a pool light using the principles disclosed herein may more easily be made water sealed, as there may be no external wires needed. In another example, an explosion proof room, such as containing volatile vapors, may not only need to be hermetically sealed, but may need to have all electrical contacts (that could create a spark) sealed. Again, the principles disclosed herein may provide a convenient way to supply sealed electrical components for such applications.

[00430] The systems and methods disclosed herein may provide power to game controller applications, such as to a remote handheld game controller. These game controllers may have been traditionally powered solely by batteries, where the game controller's use and power profile caused frequent changing of the battery, battery pack, rechargeable batteries, and the like, that may not have been ideal for the consistent use to the game controller, such as during extended game play. A device resonator may be placed into the game controller, and a source resonator, connected to a power source, may be placed in the vicinity. Further, the device resonator in the game controller may provide power directly to the game controller electronics without a battery; provide power to a battery, battery pack, rechargeable battery, and the like, which then provides power to the game controller electronics; and the like. The game controller may utilize multiple battery packs, where each battery pack is equipped with a device resonator, and thus may be constantly recharging while in the vicinity of the source resonator, whether

plugged into the game controller or not. The source resonator may be resident in a main game controller facility for the game, where the main game controller facility and source resonator are supplied power from AC 'house' power; resident in an extension facility form AC power, such as in a source resonator integrated into an 'extension cord'; resident in a game chair, which is at least one of plugged into the wall AC, plugged into the main game controller facility, powered by a battery pack in the game chair; and the like. The source resonator may be placed and implemented in any of the configurations described herein.

[00431] The systems and methods disclosed herein may integrate device resonators into battery packs, such as battery packs that are interchangeable with other battery packs. For instance, some portable devices may use up electrical energy at a high rate such that a user may need to have multiple interchangeable battery packs on hand for use, or the user may operate the device out of range of a source resonator and need additional battery packs to continue operation, such as for power tools, portable lights, remote control vehicles, and the like. The use of the principles disclosed herein may not only provide a way for device resonator enabled battery packs to be recharged while in use and in range, but also for the recharging of battery packs not currently in use and placed in range of a source resonator. In this way, battery packs may always be ready to use when a user runs down the charge of a battery pack being used. For example, a user may be working with a wireless power tool, where the current requirements may be greater than can be realized through direct powering from a source resonator. In this case, despite the fact that the systems and methods described herein may be providing charging power to the in-use battery pack while in range, the battery pack may still run down, as the power usage may have exceeded the recharge rate. Further, the user may simply be moving in and out of range, or be completely out of range while using the device. However, the user may have placed additional battery packs in the vicinity of the source resonator, which have been recharged while not in use, and are now charged sufficiently for use. In another example, the user may be working with the power tool away from the vicinity of the source resonator, but leave the supplemental battery packs to charge in the vicinity of the source resonator, such as in a room with a portable source resonator or extension cord source resonator, in the user's vehicle, in user's tool box, and the like. In this way, the user may not have to worry about taking the time to, and/or remembering to plug in their battery packs for future use. The user may only have to change out the used battery pack for the charged battery pack and place the used one in the vicinity of the source resonator

InductEV, Inc.
Exhibit 1002
Page 109

for recharging. Device resonators may be built into enclosures with known battery form factors and footprints and may replace traditional chemical batteries in known devices and applications. For example, device resonators may be built into enclosures with mechanical dimensions equivalent to AA batteries, AAA batteries, D batteries, 9V batteries, laptop batteries, cell phone batteries, and the like. The enclosures may include a smaller "button battery" in addition to the device resonator to store charge and provide extended operation, either in terms of time or distance. Other energy storage devices in addition to or instead of button batteries may be integrated with the device resonators and any associated power conversion circuitry. These new energy packs may provide similar voltage and current levels as provided by traditional batteries, but may be composed of device resonators, power conversion electronics, a small battery, and the like. These new energy packs may last longer than traditional batteries because they may be more easily recharged and may be recharging constantly when they are located in a wireless power zone. In addition, such energy packs may be lighter than traditional batteries, may be safer to use and store, may operate over wider temperature and humidity ranges, may be less harmful to the environment when thrown away, and the like. As described herein, these energy packs may last beyond the life of the product when used in wireless power zones as described herein.

[00432] The systems and methods described herein may be used to power visual displays, such as in the case of the laptop screen, but more generally to include the great variety and diversity of displays utilized in today's electrical and electronics components, such as in televisions, computer monitors, desktop monitors, laptop displays, digital photo frames, electronic books, mobile device displays (e.g. on phones, PDAs, games, navigation devices, DVD players), and the like. Displays that may be powered through one or more of the wireless power transmission systems described herein may also include embedded displays, such as embedded in electronic components (e.g. audio equipment, home appliances, automotive displays, entertainment devices, cash registers, remote controls), in furniture, in building infrastructure, in a vehicle, on the surface of an object (e.g. on the surface of a vehicle, building, clothing, signs, transportation), and the like. Displays may be very small with tiny resonant devices, such as in a smart card as described herein, or very large, such as in an advertisement sign. Displays powered using the principles disclosed herein may also be any one of a plurality of imaging technologies, such as liquid crystal display (LCD), thin film transistor LCD, passive LCD, cathode ray tube (CRT), plasma display, projector display (e.g. LCD, DLP, LCOS),

InductEV, Inc.
Exhibit 1002
Page 110

surface-conduction electron-emitter display (SED), organic light-emitting diode (OLED), and the like. Source coil configurations may include attaching to a primary power source, such as building power, vehicle power, from a wireless extension cord as described herein, and the like; attached to component power, such as the base of an electrical component (e.g. the base of a computer, a cable box for a TV); an intermediate relay source coil; and the like. For example, hanging a digital display on the wall may be very appealing, such as in the case of a digital photo frame that receives its information signals wirelessly or through a portable memory device, but the need for an unsightly power cord may make it aesthetically unpleasant. However, with a device coil embedded in the digital photo frame, such as wrapped within the frame portion, may allow the digital photo frame to be hung with no wires at all. The source resonator may then be placed in the vicinity of the digital photo frame, such as in the next room on the other side of the wall, plugged directly into a traditional power outlet, from a wireless extension cord as described herein, from a central source resonator for the room, and the like.

[00433] The systems and methods described herein may provide wireless power transmission between different portions of an electronics facility. Continuing with the example of the laptop computer, and without limitation, the screen of the laptop computer may require power from the base of the laptop. In this instance, the electrical power has been traditionally routed via direct electrical connection from the base of the laptop to the screen over a hinged portion of the laptop between the screen and the base. When a wired connection is utilized, the wired connection may tend to wear out and break, the design functionality of the laptop computer may be limited by the required direct electrical connection, the design aesthetics of the laptop computer may be limited by the required direct electrical connection, and the like. However, a wireless connection may be made between the base and the screen. In this instance, the device resonator may be placed in the screen portion to power the display, and the base may be either powered by a second device resonator, by traditional wired connections, by a hybrid of resonator-battery- direct electrical connection, and the like. This may not only improve the reliability of the power connection due to the removal of the physical wired connection, but may also allow designers to improve the functional and/or aesthetic design of the hinge portion of the laptop in light of the absence of physical wires associated with the hinge. Again, the laptop computer has been used here to illustrate how the principles disclosed herein may improve the design of an electric or electronic device, and should not be taken as limiting in any way. For

InductEV, Inc.
Exhibit 1002
Page 111

instance, many other electrical devices with separated physical portions could benefit from the systems and methods described herein, such as a refrigerator with electrical functions on the door, including an ice maker, a sensor system, a light, and the like; a robot with movable portions, separated by joints; a car's power system and a component in the car's door; and the like. The ability to provide power to a device via a device resonator from an external source resonator, or to a portion of the device via a device resonator from either external or internal source resonators, will be recognized by someone skilled in the art to be widely applicable across the range of electric and electronic devices.

[00434] The systems and methods disclosed herein may provide for a sharing of electrical power between devices, such as between charged devices and uncharged devices. For instance a charged up device or appliance may act like a source and send a predetermined amount of energy, dialed in amount of energy, requested and approved amount of energy, and the like, to a nearby device or appliance. For example, a user may have a cell phone and a digital camera that are both capable of transmitting and receiving power through embedded source and device resonators, and one of the devices, say the cell phone, is found to be low on charge. The user may then transfer charge from the digital camera to the cell phone. The source and device resonators in these devices may utilize the same physical resonator for both transmission and reception, utilize separate source and device resonators, one device may be designed to receive and transmit while the other is designed to receive only, one device may be designed to transmit only and the other to receive only, and the like.

[00435] To prevent complete draining the battery of a device it may have a setting allowing a user to specify how much of the power resource the receiving device is entitled to. It may be useful, for example, to put a limit on the amount of power available to external devices and to have the ability to shut down power transmission when battery power falls below a threshold.

[00436] The systems and methods described herein may provide wireless power transfer to a nearby electrical or electronics component in association with an electrical facility, where the source resonator is in the electrical facility and the device resonator is in the electronics component. The source resonator may also be connected to, plugged into, attached to the electrical facility, such as through a universal interface (e.g. a USB interface, PC card interface), supplemental electrical outlet, universal attachment point, and the like, of the

InductEV, Inc.
Exhibit 1002
Page 112

electrical facility. For example, the source resonator may be inside the structure of a computer on a desk, or be integrated into some object, pad, and the like, that is connected to the computer, such as into one of the computer's USB interfaces. In the example of the source resonator embedded in the object, pad, and the like, and powered through a USB interface, the source resonator may then be easily added to a user's desktop without the need for being integrated into any other electronics device, thus conveniently providing a wireless energy zone around which a plurality of electric and/or electronics devices may be powered. The electrical facility may be a computer, a light fixture, a dedicated source resonator electrical facility, and the like, and the nearby components may be computer peripherals, surrounding electronics components, infrastructure devices, and the like, such as computer keyboards, computer mouse, fax machine, printer, speaker system, cell phone, audio device, intercom, music player, PDA, lights, electric pencil sharpener, fan, digital picture frame, calculator, electronic games, and the like. For example, a computer system may be the electrical facility with an integrated source resonator that utilizes a 'wireless keyboard' and 'wireless mouse', where the use of the term wireless here is meant to indicate that there is wireless communication facility between each device and the computer, and where each device must still contain a separate battery power source. As a result, batteries would need to be replaced periodically, and in a large company, may result in a substantial burden for support personnel for replacement of batteries, cost of batteries, and proper disposal of batteries. Alternatively, the systems and methods described herein may provide wireless power transmission from the main body of the computer to each of these peripheral devices, including not only power to the keyboard and mouse, but to other peripheral components such as a fax, printer, speaker system, and the like, as described herein. A source resonator integrated into the electrical facility may provide wireless power transmission to a plurality of peripheral devices, user devices, and the like, such that there is a significant reduction in the need to charge and/or replace batteries for devices in the near vicinity of the source resonator integrated electrical facility. The electrical facility may also provide tuning or auto-tuning software, algorithms, facilities, and the like, for adjusting the power transfer parameters between the electrical facility and the wirelessly powered device. For example, the electrical facility may be a computer on a user's desktop, and the source resonator may be either integrated into the computer or plugged into the computer (e.g. through a USB connection),

where the computer provides a facility for providing the tuning algorithm (e.g. through a software program running on the computer).

[00437] The systems and methods disclosed herein may provide wireless power transfer to a nearby electrical or electronics component in association with a facility infrastructure component, where the source resonator is in, or mounted on, the facility infrastructure component and the device resonator is in the electronics component. For instance, the facility infrastructure component may be a piece of furniture, a fixed wall, a movable wall or partition, the ceiling, the floor, and the source resonator attached or integrated into a table or desk (e.g. just below/above the surface, on the side, integrated into a table top or table leg), a mat placed on the floor (e.g. below a desk, placed on a desk), a mat on the garage floor (e.g. to charge the car and/or devices in the car), in a parking lot/garage (e.g. on a post near where the car is parked), a television (e.g. for charging a remote control), a computer monitor (e.g. to power/charge a wireless keyboard, wireless mouse, cell phone), a chair (e.g. for powering electric blankets, medical devices, personal health monitors), a painting, office furniture, common household appliances, and the like. For example, the facility infrastructure component may be a lighting fixture in an office cubical, where the source resonator and light within the lighting fixture are both directly connected to the facility's wired electrical power. However, with the source resonator now provided in the lighting fixture, there would be no need to have any additional wired connections for those nearby electrical or electronics components that are connected to, or integrated with, a device resonator. In addition, there may be a reduced need for the replacement of batteries for devices with device resonators, as described herein.

[00438] The use of the systems and methods described herein to supply power to electrical and electronic devices from a central location, such as from a source resonator in an electrical facility, from a facility infrastructure component and the like, may minimize the electrical wiring infrastructure of the surrounding work area. For example, in an enterprise office space there are typically a great number of electrical and electronic devices that need to be powered by wired connections. With utilization of the systems and methods described herein, much of this wiring may be eliminated, saving the enterprise the cost of installation, decreasing the physical limitations associated with office walls having electrical wiring, minimizing the need for power outlets and power strips, and the like. The systems and methods described herein may save money for the enterprise through a reduction in electrical infrastructure associated with

InductEV, Inc.
Exhibit 1002
Page 114

installation, re-installation (e.g., reconfiguring office space), maintenance, and the like. In another example, the principles disclosed herein may allow the wireless placement of an electrical outlet in the middle of a room. Here, the source could be placed on the ceiling of a basement below the location on the floor above where one desires to put an outlet. The device resonator could be placed on the floor of the room right above it. Installing a new lighting fixture (or any other electric device for that matter, e.g. camera, sensor, etc., in the center of the ceiling may now be substantially easier for the same reason).

[00439] In another example, the systems and methods described herein may provide power "through" walls. For instance, suppose one has an electric outlet in one room (e.g. on a wall), but one would like to have an outlet in the next room, but without the need to call an electrician, or drill through a wall, or drag a wire around the wall, or the like. Then one might put a source resonator on the wall in one room, and a device resonator outlet/pickup on the other side of the wall. This may power a flat-screen TV or stereo system or the like (e.g. one may not want to have an ugly wire climbing up the wall in the living room, but doesn't mind having a similar wire going up the wall in the next room, e.g. storage room or closet, or a room with furniture that blocks view of wires running along the wall). The systems and methods described herein may be used to transfer power from an indoor source to various electric devices outside of homes or buildings without requiring holes to be drilled through, or conduits installed in, these outside walls. In this case, devices could be wirelessly powered outside the building without the aesthetic or structural damage or risks associated with drilling holes through walls and siding. In addition, the systems and methods described herein may provide for a placement sensor to assist in placing an interior source resonator for an exterior device resonator equipped electrical component. For example, a home owner may place a security light on the outside of their home which includes a wireless device resonator, and now needs to adequately or optimally position the source resonator inside the home. A placement sensor acting between the source and device resonators may better enable that placement by indicating when placement is good, or to a degree of good, such as in a visual indication, an audio indication, a display indication, and the like. In another example, and in a similar way, the systems and methods described herein may provide for the installation of equipment on the roof of a home or building, such as radio transmitters and receivers, solar panels and the like. In the case of the solar panel, the source resonator may be associated with the panel, and power may be wirelessly transferred to a distribution panel inside

the building without the need for drilling through the roof. The systems and methods described herein may allow for the mounting of electric or electrical components across the walls of vehicles (such as through the roof) without the need to drill holes, such as for automobiles, water craft, planes, trains, and the like. In this way, the vehicle's walls may be left intact without holes being drilled, thus maintaining the value of the vehicle, maintaining watertightness, eliminating the need to route wires, and the like. For example, mounting a siren or light to the roof of a police car decreases the future resale of the car, but with the systems and methods described herein, any light, horn, siren, and the like, may be attached to the roof without the need to drill a hole.

[00440] The systems and methods described herein may be used for wireless transfer of power from solar photovoltaic (PV) panels. PV panels with wireless power transfer capability may have several benefits including simpler installation, more flexible, reliable, and weatherproof design. Wireless power transfer may be used to transfer power from the PV panels to a device, house, vehicle, and the like. Solar PV panels may have a wireless source resonator allowing the PV panel to directly power a device that is enabled to receive the wireless power. For example, a solar PV panel may be mounted directly onto the roof of a vehicle, building, and the like. The energy captured by the PV panel may be wirelessly transferred directly to devices inside the vehicle or under the roof of a building. Devices that have resonators can wirelessly receive power from the PV panel. Wireless power transfer from PV panels may be used to transfer energy to a resonator that is coupled to the wired electrical system of a house, vehicle, and the like allowing traditional power distribution and powering of conventional devices without requiring any direct contact between the exterior PV panels and the internal electrical system.

[00441] With wireless power transfer significantly simpler installation of rooftop PV panels is possible because power may be transmitted wirelessly from the panel to a capture resonator in the house, eliminating all outside wiring, connectors, and conduits, and any holes through the roof or walls of the structure. Wireless power transfer used with solar cells may have a benefit in that it can reduced roof danger since it eliminates the need for electricians to work on the roof to interconnect panels, strings, and junction boxes. Installation of solar panels integrated with wireless power transfer may require less skilled labor since fewer electrical contacts need to be made. Less site specific design may be required with wireless power transfer since the

InductEV, Inc.
Exhibit 1002
Page 116

technology gives the installer the ability to individually optimize and position each solar PV panel, significantly reducing the need for expensive engineering and panel layout services. There may not be need to carefully balance the solar load on every panel and no need for specialized DC wiring layout and interconnections.

[00442] For rooftop or on-wall installations of PV panels, the capture resonator may be mounted on the underside of the roof, inside the wall, or in any other easily accessible inside space within a foot or two of the solar PV panel. A diagram showing a possible general rooftop PV panel installation is shown in Figure 51. Various PV solar collectors may be mounted in top of a roof with wireless power capture coils mounted inside the building under the roof. The resonator coils in the PV panels can transfer their energy wirelessly through the roof to the wireless capture coils. The captured energy from the PV cells may be collected and coupled to the electrical system of the house to power electric and electronic devices or coupled to the power grid when more power than needed is generated. Energy is captured from the PV cells without requiring holes or wires that penetrate the roof or the walls of the building. Each PV panel may have a resonator that is coupled to a corresponding resonator on the interior of the vehicle or building. Multiple panels may utilize wireless power transfer between each other to transfer or collect power to one or a couple of designated panels that are coupled to resonators on the interior of the vehicle of house. Panels may have wireless power resonators on their sides or in their perimeter that can couple to resonators located in other like panels allowing transfer of power from panel to panel. An additional bus or connection structure may be provided that wirelessly couples the power from multiple panels on the exterior of a building or vehicle and transfers power to one or a more resonators on the interior of building or vehicle.

[00443] For example, as shown in Fig. 51, a source resonator 5102 may be coupled to a PV cell 5100 mounted on top of roof 5104 of a building. A corresponding capture resonator 5106 is placed inside the building. The solar energy captured by the PV cells can then be transferred between the source resonators 5102 outside to the device resonators 5106 inside the building without having direct holes and connections through the building.

[00444] Each solar PV panel with wireless power transfer may have its own inverter, significantly improving the economics of these solar systems by individually optimizing the power production efficiency of each panel, supporting a mix of panel sizes and types in a single installation, including single panel "pay-as-you-grow" system expansions. Reduction of

InductEV, Inc.
Exhibit 1002
Page 117

installation costs may make a single panel economical for installation. Eliminating the need for panel string designs and careful positioning and orienting of multiple panels, and eliminating a single point of failure for the system.

[00445] Wireless power transfer in PV solar panels may enable more solar deployment scenarios because the weather-sealed solar PV panels eliminate the need to drill holes for wiring through sealed surfaces such as car roofs and ship decks, and eliminate the requirement that the panels be installed in fixed locations. With wireless power transfer, PV panels may be deployed temporarily, and then moved or removed, without leaving behind permanent alterations to the surrounding structures. They may be placed out in a yard on sunny days, and moved around to follow the sun, or brought inside for cleaning or storage, for example. For backyard or mobile solar PV applications, an extension cord with a wireless energy capture device may be thrown on the ground or placed near the solar unit. The capture extension cord can be completely sealed from the elements and electrically isolated, so that it may be used in any indoor or outdoor environment.

[00446] With wireless power transfer no wires or external connections may be necessary and the PV solar panels can be completely weather sealed. Significantly improved reliability and lifetime of electrical components in the solar PV power generation and transmission circuitry can be expected since the weather-sealed enclosures can protect components from UV radiation, humidity, weather, and the like. With wireless power transfer and weather-sealed enclosures it may be possible to use less expensive components since they will no longer be directly exposed to external factors and weather elements and it may reduce the cost of PV panels.

[00447] Power transfer between the PV panels and the capture resonators inside a building or a vehicle may be bidirectional. Energy may be transmitted from the house grid to the PV panels to provide power when the panels do not have enough energy to perform certain tasks such. Reverse power flow can be used to melt snow from the panels, or power motors that will position the panels in a more favorable positions with respect to the sun energy. Once the snow is melted or the panels are repositioned and the PV panels can generate their own energy the direction of power transfer can be returned to normal delivering power from the PV panels to buildings, vehicles, or devices.

[00448] PV panels with wireless power transfer may include auto-tuning on installation to ensure maximum and efficient power transfer to the wireless collector. Variations in roofing materials or variations in distances between the PV panels and the wireless power collector in different installations may affect the performance or perturb the properties of the resonators of the wireless power transfer. To reduce the installation complexity the wireless power transfer components may include a tuning capability to automatically adjust their operating point to compensate for any effects due to materials or distance. Frequency, impedance, capacitance, inductance, duty cycle, voltage levels and the like may be adjusted to ensure efficient and safe power transfer

[00449] The systems and methods described herein may be used to provide a wireless power zone on a temporary basis or in extension of traditional electrical outlets to wireless power zones, such as through the use of a wireless power extension cord. For example, a wireless power extension cord may be configured as a plug for connecting into a traditional power outlet, a long wire such as in a traditional power extension cord, and a resonant source coil on the other end (e.g. in place of, or in addition to, the traditional socket end of the extension The wireless extension cord may also be configured where there are source resonators at a plurality of locations along the wireless extension cord. This configuration may then replace any traditional extension cord where there are wireless power configured devices, such as providing wireless power to a location where there is no convenient power outlet (e.g. a location in the living room where there's no outlet), for temporary wireless power where there is no wired power infrastructure (e.g. a construction site), out into the yard where there are no outlets (e.g. for parties or for yard grooming equipment that is wirelessly powered to decrease the chances of cutting the traditional electrical cord), and the like. The wireless extension cord may also be used as a drop within a wall or structure to provide wireless power zones within the vicinity of the drop. For example, a wireless extension cord could be run within a wall of a new or renovated room to provide wireless power zones without the need for the installation of traditional electrical wiring and outlets.

[00450] The systems and methods described herein may be utilized to provide power between moving parts or rotating assemblies of a vehicle, a robot, a mechanical device, a wind turbine, or any other type of rotating device or structure with moving parts such as robot arms, construction vehicles, movable platforms and the like. Traditionally, power in such systems may

InductEV, Inc.
Exhibit 1002
Page 119

have been provided by slip rings or by rotary joints for example. Using wireless power transfer as described herein, the design simplicity, reliability and longevity of these devices may be significantly improved because power can be transferred over a range of distances without any physical connections or contact points that may wear down or out with time. In particular, the preferred coaxial and parallel alignment of the source and device coils may provide wireless power transmission that is not severely modulated by the relative rotational motion of the two coils.

[00451] The systems and methods described herein may be utilized to extend power needs beyond the reach of a single source resonator by providing a series of source-device-source-device resonators. For instance, suppose an existing detached garage has no electrical power and the owner now wants to install a new power service. However, the owner may not want to run wires all over the garage, or have to break into the walls to wire electrical outlets throughout the structure. In this instance, the owner may elect to connect a source resonator to the new power service, enabling wireless power to be supplied to device resonator outlets throughout the back of the garage. The owner may then install a device-source 'relay' to supply wireless power to device resonator outlets in the front of the garage. That is, the power relay may now receive wireless power from the primary source resonator, and then supply available power to a second source resonator to supply power to a second set of device resonators in the front of the garage. This configuration may be repeated again and again to extend the effective range of the supplied wireless power.

[00452] Multiple resonators may be used to extend power needs around an energy blocking material. For instance, it may be desirable to integrate a source resonator into a computer or computer monitor such that the resonator may power devices placed around and especially in front of the monitor or computer such as keyboards, computer mice, telephones , and the like. Due to aesthetics, space constraints, and the like an energy source that may be used for the source resonator may only be located or connected to in the back of the monitor or computer. In many designs of computer or monitors metal components and metal containing circuits are used in the design and packaging which may limit and prevent power transfer from source resonator in the back of the monitor or computer to the front of the monitor or computer. An additional repeater resonator may be integrated into the base or pedestal of the monitor or computer that couples to the source resonator in the back of the monitor or computer and allows

InductEV, Inc.
Exhibit 1002
Page 120

power transfer to the space in front of the monitor or computer. The intermediate resonator integrated into the base or pedestal of the monitor or computer does not require an additional power source, it captures power from the source resonator and transfers power to the front around the blocking or power shielding metal components of the monitor or computer.

[00453] The systems and methods described herein may be built-into, placed on, hung from, embedded into, integrated into, and the like, the structural portions of a space, such as a vehicle, office, home, room, building, outdoor structure, road infrastructure, and the like. For instance, one or more sources may be built into, placed on, hung from, embedded or integrated into a wall, a ceiling or ceiling panel, a floor, a divider, a doorway, a stairwell, a compartment, a road surface, a sidewalk, a ramp, a fence, an exterior structure, and the like. One or more sources may be built into an entity within or around a structure, for instance a bed, a desk, a chair, a rug, a mirror, a clock, a display, a television, an electronic device, a counter, a table, a piece of furniture, a piece of artwork, an enclosure, a compartment, a ceiling panel, a floor or door panel, a dashboard, a trunk, a wheel well, a post, a beam, a support or any like entity. For example, a source resonator may be integrated into the dashboard of a user's car so that any device that is equipped with or connected to a device resonator may be supplied with power from the dashboard source resonator. In this way, devices brought into or integrated into the car may be constantly charged or powered while in the car.

[00454] The systems and methods described herein may provide power through the walls of vehicles, such as boats, cars, trucks, busses, trains, planes, satellites and the like. For instance, a user may not want to drill through the wall of the vehicle in order to provide power to an electric device on the outside of the vehicle. A source resonator may be placed inside the vehicle and a device resonator may be placed outside the vehicle (e.g. on the opposite side of a window, wall or structure). In this way the user may achieve greater flexibility in optimizing the placement, positioning and attachment of the external device to the vehicle, (such as without regard to supplying or routing electrical connections to the device). In addition, with the electrical power supplied wirelessly, the external device may be sealed such that it is water tight, making it safe if the electric device is exposed to weather (e.g. rain), or even submerged under water. Similar techniques may be employed in a variety of applications, such as in charging or powering hybrid vehicles, navigation and communications equipment, construction equipment, remote controlled or robotic equipment and the like, where electrical risks exist because of

exposed conductors. The systems and methods described herein may provide power through the walls of vacuum chambers or other enclosed spaces such as those used in semiconductor growth and processing, material coating systems, aquariums, hazardous materials handling systems and the like. Power may be provided to translation stages, robotic arms, rotating stages, manipulation and collection devices, cleaning devices and the like.

[00455] The systems and methods described herein may provide wireless power to a kitchen environment, such as to counter-top appliances, including mixers, coffee makers, toasters, toaster ovens, grills, griddles, electric skillets, electric pots, electric woks, waffle makers, blenders, food processors, crock pots, warming trays, induction cooktops, lights, computers, displays, and the like. This technology may improve the mobility and/or positioning flexibility of devices, reduce the number of power cords stored on and strewn across the counter-top, improve the washability of the devices, and the like. For example, an electric skillet may traditionally have separate portions, such as one that is submersible for washing and one that is not submersible because it includes an external electrical connection (e.g. a cord or a socket for a removable cord). However, with a device resonator integrated into the unit, all electrical connections may be sealed, and so the entire device may now be submersed for cleaning. In addition, the absence of an external cord may eliminate the need for an available electrical wall outlet, and there is no longer a need for a power cord to be placed across the counter or for the location of the electric griddle to be limited to the location of an available electrical wall outlet.

[00456] The systems and methods described herein may provide continuous power/charging to devices equipped with a device resonator because the device doesn't leave the proximity of a source resonator, such as fixed electrical devices, personal computers, intercom systems, security systems, household robots, lighting, remote control units, televisions, cordless phones, and the like. For example, a household robot (e.g. ROOMBA) could be powered/charged via wireless power, and thus work arbitrarily long without recharging. In this way, the power supply design for the household robot may be changed to take advantage of this continuous source of wireless power, such as to design the robot to only use power from the source resonator without the need for batteries, use power from the source resonator to recharge the robot's batteries, use the power from the source resonator to trickle charge the robot's batteries, use the power from the source resonator to charge a capacitive energy storage unit, and the like. Similar

InductEV, Inc.
Exhibit 1002
Page 122

optimizations of the power supplies and power circuits may be enabled, designed, and realized, for any and all of the devices disclosed herein.

[00457] The systems and methods described herein may be able to provide wireless power to electrically heated blankets, heating pads/patches, and the like. These electrically heated devices may find a variety of indoor and outdoor uses. For example, hand and foot warmers supplied to outdoor workers such as guards, policemen, construction workers and the like might be remotely powered from a source resonator associated with or built into a nearby vehicle, building, utility pole, traffic light, portable power unit, and the like.

[00458] The systems and methods described herein may be used to power a portable information device that contains a device resonator and that may be powered up when the information device is near an information source containing a source resonator. For instance, the information device may be a card (e.g. credit card, smart card, electronic card, and the like) carried in a user's pocket, wallet, purse, vehicle, bike, and the like. The portable information device may be powered up when it is in the vicinity of an information source that then transmits information to the portable information device that may contain electronic logic, electronic processors, memory, a display, an LCD display, LEDs, RFID tags, and the like. For example, the portable information device may be a credit card with a display that "turns on" when it is near an information source, and provide the user with some information such as, "You just received a coupon for 50% off your next Coca Cola purchase". The information device may store information such as coupon or discount information that could be used on subsequent purchases. The portable information device may be programmed by the user to contain tasks, calendar appointments, to-do lists, alarms and reminders, and the like. The information device may receive up-to-date price information and inform the user of the location and price of previously selected or identified items.

[00459] The systems and methods described herein may provide wireless power transmission to directly power or recharge the batteries in sensors, such as environmental sensors, security sensors, agriculture sensors, appliance sensors, food spoilage sensors, power sensors, and the like, which may be mounted internal to a structure, external to a structure, buried underground, installed in walls, and the like. For example, this capability may replace the need to dig out old sensors to physically replace the battery, or to bury a new sensor because the old sensor is out of power and no longer operational. These sensors may be charged up periodically

InductEV, Inc.
Exhibit 1002
Page 123

through the use of a portable sensor source resonator charging unit. For instance, a truck carrying a source resonator equipped power source, say providing ~kW of power, may provide enough power to a ~mW sensor in a few minutes to extend the duration of operation of the sensor for more than a year. Sensors may also be directly powered, such as powering sensors that are in places where it is difficult to connect to them with a wire but they are still within the vicinity of a source resonator, such as devices outside of a house (security camera), on the other side of a wall, on an electric lock on a door, and the like. In another example, sensors that may need to be otherwise supplied with a wired power connection may be powered through the systems and methods described herein. For example, a ground fault interrupter breaker combines residual current and over-current protection in one device for installation into a service panel. However, the sensor traditionally has to be independently wired for power, and this may complicate the installation. However, with the systems and methods described herein the sensor may be powered with a device resonator, where a single source resonator is provided within the service panel, thus simplifying the installation and wiring configuration within the service panel. In addition, the single source resonator may power device resonators mounted on either side of the source resonator mounted within the service panel, throughout the service panel, to additional nearby service panels, and the like. The systems and methods described herein may be employed to provide wireless power to any electrical component associated with electrical panels, electrical rooms, power distribution and the like, such as in electric switchboards, distribution boards, circuit breakers, transformers, backup batteries, fire alarm control panels, and the like. Through the use of the systems and methods described herein, it may be easier to install, maintain, and modify electrical distribution and protection components and system installations.

[00460] In another example, sensors that are powered by batteries may run continuously, without the need to change the batteries, because wireless power may be supplied to periodically or continuously recharge or trickle charge the battery. In such applications, even low levels of power may adequately recharge or maintain the charge in batteries, significantly extending their lifetime and usefulness. In some cases, the battery life may be extended to be longer than the lifetime of the device it is powering, making it essentially a battery that "lasts forever".

[00461] The systems and methods described herein may be used for charging implanted medical device batteries, such as in an artificial heart, pacemaker, heart pump, insulin

InductEV, Inc.
Exhibit 1002
Page 124

pump, implanted coils for nerve or acupressure/acupuncture point stimulation, and the like. For instance, it may not be convenient or safe to have wires sticking out of a patient because the wires may be a constant source of possible infection and may generally be very unpleasant for the patient. The systems and methods described herein may also be used to charge or power medical devices in or on a patient from an external source, such as from a bed or a hospital wall or ceiling with a source resonator. Such medical devices may be easier to attach, read, use and monitor the patient. The systems and methods described herein may ease the need for attaching wires to the patient and the patient's bed or bedside, making it more convenient for the patient to move around and get up out of bed without the risk of inadvertently disconnecting a medical device. This may, for example, be usefully employed with patients that have multiple sensors monitoring them, such as for measuring pulse, blood pressure, glucose, and the like. For medical and monitoring devices that utilize batteries, the batteries may need to be replaced quite often, perhaps multiple times a week. This may present risks associated with people forgetting to replace batteries, not noticing that the devices or monitors are not working because the batteries have died, infection associated with improper cleaning of the battery covers and compartments, and the like.

[00462] The systems and methods described herein may reduce the risk and complexity of medical device implantation procedures. Today many implantable medical devices such as ventricular assist devices, pacemakers, defibrillators and the like, require surgical implantation due to their device form factor, which is heavily influenced by the volume and shape of the long-life battery that is integrated in the device. In one aspect, there is described herein a non-invasive method of recharging the batteries so that the battery size may be dramatically reduced, and the entire device may be implanted, such as via a catheter. A catheter implantable device may include an integrated capture or device coil. A catheter implantable capture or device coil may be designed so that it may be wired internally, such as after implantation. The capture or device coil may be deployed via a catheter as a rolled up flexible coil (e.g. rolled up like two scrolls, easily unrolled internally with a simple spreader mechanism). The power source coil may be worn in a vest or article of clothing that is tailored to fit in such a way that places the source in proper position, may be placed in a chair cushion or bed cushion, may be integrated into a bed or piece of furniture, and the like.

InductEV, Inc.
Exhibit 1002
Page 125

[00463] The systems and methods described herein may enable patients to have a 'sensor vest', sensor patch, and the like, that may include at least one of a plurality of medical sensors and a device resonator that may be powered or charged when it is in the vicinity of a source resonator. Traditionally, this type of medical monitoring facility may have required batteries, thus making the vest, patch, and the like, heavy, and potentially impractical. But using the principles disclosed herein, no batteries (or a lighter rechargeable battery) may be required, thus making such a device more convenient and practical, especially in the case where such a medical device could be held in place without straps, such as by adhesive, in the absence of batteries or with substantially lighter batteries. A medical facility may be able to read the sensor data remotely with the aim of anticipating (e.g. a few minutes ahead of) a stroke, a heart-attack, or the like. When the vest is used by a person in a location remote from the medical facility, such as in their home, the vest may then be integrated with a cell-phone or communications device to call an ambulance in case of an accident or a medical event. The systems and methods described herein may be of particular value in the instance when the vest is to be used by an elderly person, where traditional non-wireless recharging practices (e.g. replacing batteries, plugging in at night, and the like) may not be followed as required. The systems and methods described herein may also be used for charging devices that are used by or that aid handicapped or disabled people who may have difficulty replacing or recharging batteries, or reliably supplying power to devices they enjoy or rely on.

[00464] The systems and methods described herein may be used for the charging and powering of artificial limbs. Artificial limbs have become very capable in terms of replacing the functionality of original limbs, such as arms, legs, hands and feet. However, an electrically powered artificial limb may require substantial power, (such as 10-20W) which may translate into a substantial battery. In that case, the amputee may be left with a choice between a light battery that doesn't last very long, and a heavy battery that lasts much longer, but is more difficult to 'carry' around. The systems and methods described herein may enable the artificial limb to be powered with a device resonator, where the source resonator is either carried by the user and attached to a part of the body that may more easily support the weight (such as on a belt around the waist, for example) or located in an external location where the user will spend an adequate amount of time to keep the device charged or powered, such as at their desk, in their car, in their bed, and the like.

InductEV, Inc.
Exhibit 1002
Page 126

[00465] The systems and methods described herein may be used for charging and powering of electrically powered exo-skeletons, such as those used in industrial and military applications, and for elderly/weak/sick people. An electrically powered exo-skeleton may provide up to a 10-to-20 times increase in "strength" to a person, enabling the person to perform physically strenuous tasks repeatedly without much fatigue. However, exo-skeletons may require more than 100W of power under certain use scenarios, so battery powered operation may be limited to 30 minutes or less. The delivery of wireless power as described herein may provide a user of an exo-skeleton with a continuous supply of power both for powering the structural movements of the exo-skeleton and for powering various monitors and sensors distributed throughout the structure. For instance, an exo-skeleton with an embedded device resonator(s) may be supplied with power from a local source resonator. For an industrial exo-skeleton, the source resonator may be placed in the walls of the facility. For a military exo-skeleton, the source resonator may be carried by an armored vehicle. For an exo-skeleton employed to assist a caretaker of the elderly, the source resonator(s) may be installed or placed in or the room(s) of a person's home.

[00466] The systems and methods described herein may be used for the powering/charging of portable medical equipment, such as oxygen systems, ventilators, defibrillators, medication pumps, monitors, and equipment in ambulances or mobile medical units, and the like. Being able to transport a patient from an accident scene to the hospital, or to move patients in their beds to other rooms or areas, and bring all the equipment that is attached with them and have it powered the whole time offers great benefits to the patients' health and eventual well-being. Certainly one can understand the risks and problems caused by medical devices that stop working because their battery dies or because they must be unplugged while a patient is transported or moved in any way. For example, an emergency medical team on the scene of an automotive accident might need to utilize portable medical equipment in the emergency care of patients in the field. Such portable medical equipment must be properly maintained so that there is sufficient battery life to power the equipment for the duration of the emergency. However, it is too often the case that the equipment is not properly maintained so that batteries are not fully charged and in some cases, necessary equipment is not available to the first responders. The systems and methods described herein may provide for wireless power to portable medical equipment (and associated sensor inputs on the patient) in such a way that the

InductEV, Inc.
Exhibit 1002
Page 127

charging and maintaining of batteries and power packs is provided automatically and without human intervention. Such a system also benefits from the improved mobility of a patient unencumbered by a variety of power cords attached to the many medical monitors and devices used in their treatment.

[00467] The systems and methods described herein may be used to for the powering/charging of personal hearing aids. Personal hearing aids need to be small and light to fit into or around the ear of a person. The size and weight restrictions limit the size of batteries that can be used. Likewise, the size and weight restrictions of the device make battery replacement difficult due to the delicacy of the components. The dimensions of the devices and hygiene concerns make it difficult to integrate additional charging ports to allow recharging of the batteries. The systems and methods described herein may be integrated into the hearing aid and may reduce the size of the necessary batteries which may allow even smaller hearing aids. Using the principles disclosed herein, the batteries of the hearing aid may be recharged without requiring external connections or charging ports. Charging and device circuitry and a small rechargeable battery may be integrated into a form factor of a conventional hearing aid battery allowing retrofit into existing hearing aids. The hearing aid may be recharged while it is used and worn by a person. The energy source may be integrated into a pad or a cup allowing recharging when the hearing is placed on such a structure. The charging source may be integrated into a hearing aid dryer box allowing wireless recharging while the hearing aid is drying or being sterilized. The source and device resonator may be used to also heat the device reducing or eliminating the need for an additional heating element. Portable charging cases powered by batteries or AC adaptors may be used as storage and charging stations.

[00468] The source resonator for the medical systems described above may be in the main body of some or all of the medical equipment, with device resonators on the patient's sensors and devices; the source resonator may be in the ambulance with device resonators on the patient's sensors and the main body of some or all of the equipment; a primary source resonator may be in the ambulance for transferring wireless power to a device resonator on the medical equipment while the medical equipment is in the ambulance and a second source resonator is in the main body of the medical equipment and a second device resonator on the patient sensors when the equipment is away from the ambulance; and the like. The systems and methods described herein may significantly improve the ease with which medical personnel are able to

InductEV, Inc.
Exhibit 1002
Page 128

transport patients from one location to another, where power wires and the need to replace or manually charge associated batteries may now be reduced.

[00469] The systems and methods described herein may be used for the charging of devices inside a military vehicle or facility, such as a tank, armored carrier, mobile shelter, and the like. For instance, when soldiers come back into a vehicle after "action" or a mission, they may typically start charging their electronic devices. If their electronic devices were equipped with device resonators, and there was a source resonator inside the vehicle, (e.g. integrated in the seats or on the ceiling of the vehicle), their devices would start charging immediately. In fact, the same vehicle could provide power to soldiers/robots (e.g. packbot from iRobot) standing outside or walking beside the vehicle. This capability may be useful in minimizing accidental battery-swapping with someone else (this may be a significant issue, as soldiers tend to trust only their own batteries); in enabling quicker exits from a vehicle under attack; in powering or charging laptops or other electronic devices inside a tank, as too many wires inside the tank may present a hazard in terms of reduced ability to move around fast in case of "trouble" and/or decreased visibility; and the like. The systems and methods described herein may provide a significant improvement in association with powering portable power equipment in a military environment.

[00470] The systems and methods described herein may provide wireless powering or charging capabilities to mobile vehicles such as golf carts or other types of carts, all-terrain vehicles, electric bikes, scooters, cars, mowers, bobcats and other vehicles typically used for construction and landscaping and the like. The systems and methods described herein may provide wireless powering or charging capabilities to miniature mobile vehicles, such as mini-helicopters, airborne drones, remote control planes, remote control boats, remote controlled or robotic rovers, remote controlled or robotic lawn mowers or equipment, bomb detection robots, and the like. For instance, mini-helicopter flying above a military vehicle to increase its field of view can fly for a few minutes on standard batteries. If these mini-helicopters were fitted with a device resonator, and the control vehicle had a source resonator, the mini-helicopter might be able to fly indefinitely. The systems and methods described herein may provide an effective alternative to recharging or replacing the batteries for use in miniature mobile vehicles. In addition, the systems and methods described herein may provide power/charging to even smaller devices, such as microelectromechanical systems (MEMS), nano-robots, nano devices, and the like. In addition, the systems and methods described herein may be implemented by installing a

InductEV, Inc.
Exhibit 1002
Page 129

source device in a mobile vehicle or flying device to enable it to serve as an in-field or in-flight re-charger, that may position itself autonomously in proximity to a mobile vehicle that is equipped with a device resonator.

[00471] The systems and methods described herein may be used to provide power networks for temporary facilities, such as military camps, oil drilling setups, remote filming locations, and the like, where electrical power is required, such as for power generators, and where power cables are typically run around the temporary facility. There are many instances when it is necessary to set up temporary facilities that require power. The systems and methods described herein may enable a more efficient way to rapidly set up and tear down these facilities, and may reduce the number of wires that must be run throughout the faculties to supply power. For instance, when Special Forces move into an area, they may erect tents and drag many wires around the camp to provide the required electricity. Instead, the systems and methods described herein may enable an army vehicle, outfitted with a power supply and a source resonator, to park in the center of the camp, and provide all the power to nearby tents where the device resonator may be integrated into the tents, or some other piece of equipment associated with each tent or area. A series of source-device-source-device resonators may be used to extend the power to tents that are farther away. That is, the tents closest to the vehicle could then provide power to tents behind them. The systems and methods described herein may provide a significant improvement to the efficiency with which temporary installations may be set up and torn down, thus improving the mobility of the associated facility.

[00472] The systems and methods described herein may be used in vehicles, such as for replacing wires, installing new equipment, powering devices brought into the vehicle, charging the battery of a vehicle (e.g. for a traditional gas powered engine, for a hybrid car, for an electric car, and the like), powering devices mounted to the interior or exterior of the vehicle, powering devices in the vicinity of the vehicle, and the like. For example, the systems and methods described herein may be used to replace wires such as those are used to power lights, fans and sensors distributed throughout a vehicle. As an example, a typical car may have 50kg of wires associated with it, and the use of the systems and methods described herein may enable the elimination of a substantial amount of this wiring. The performance of larger and more weight sensitive vehicles such as airplanes or satellites could benefit greatly from having the number of cables that must be run throughout the vehicle reduced. The systems and methods described

herein may allow the accommodation of removable or supplemental portions of a vehicle with electric and electrical devices without the need for electrical harnessing. For example, a motorcycle may have removable side boxes that act as a temporary trunk space for when the cyclist is going on a long trip. These side boxes may have exterior lights, interior lights, sensors, auto equipment, and the like, and if not for being equipped with the systems and methods described herein might require electrical connections and harnessing.

[00473] An in-vehicle wireless power transmission system may charge or power one or more mobile devices used in a car: mobile phone handset, Bluetooth headset, blue tooth hands free speaker phone, GPS, MP3 player, wireless audio transceiver for streaming MP3 audio through car stereo via FM, Bluetooth, and the like. The in vehicle wireless power source may utilize source resonators that are arranged in any of several possible configurations including charging pad on dash, charging pad otherwise mounted on floor, or between seat and center console, charging "cup" or receptacle that fits in cup holder or on dash, and the like.

[00474] The wireless power transmission source may utilize a rechargeable battery system such that said supply battery gets charged whenever the vehicle power is on such that when the vehicle is turned off the wireless supply can draw power from the supply battery and can continue to wirelessly charge or power mobile devices that are still in the car.

[00475] The plug-in electric cars, hybrid cars, and the like, of the future need to be charged, and the user may need to plug in to an electrical supply when they get home or to a charging station. Based on a single over-night recharging, the user may be able to drive up to 50 miles the next day. Therefore, in the instance of a hybrid car, if a person drives less than 50 miles on most days, they will be driving mostly on electricity. However, it would be beneficial if they didn't have to remember to plug in the car at night. That is, it would be nice to simply drive into a garage, and have the car take care of its own charging. To this end, a source resonator may be built into the garage floor and/or garage side-wall, and the device resonator may be built into the bottom (or side) of the car. Even a few kW transfer may be sufficient to recharge the car over-night. The in-vehicle device resonator may measure magnetic field properties to provide feedback to assist in vehicle (or any similar device) alignment to a stationary resonating source. The vehicle may use this positional feedback to automatically position itself to achieve optimum alignment, thus optimum power transmission efficiency. Another method may be to use the positional feedback to help the human operator to properly position the vehicle or device, such as

by making LED's light up, providing noises, and the like when it is well positioned. In such cases where the amount of power being transmitted could present a safety hazard to a person or animal that intrudes into the active field volume, the source or receiver device may be equipped with an active light curtain or some other external device capable of sensing intrusion into the active field volume, and capable of shutting off the source device and alert a human operator. In addition, the source device may be equipped with self-sensing capability such that it may detect that its expected power transmission rate has been interrupted by an intruding element, and in such case shut off the source device and alert a human operator. Physical or mechanical structures such as hinged doors or inflatable bladder shields may be incorporated as a physical barrier to prevent unwanted intrusions. Sensors such as optical, magnetic, capacitive, inductive, and the like may also be used to detect foreign structures or interference between the source and device resonators. The shape of the source resonator may be shaped such to prevent water or debris accumulation. The source resonator may be placed in a cone shaped enclosure or may have an enclosure with an angled top to allow water and debris to roll off. The source of the system may use battery power of the vehicle or its own battery power to transmit its presence to the source to initiate power transmission.

[00476] The source resonator may be mounted on an embedded or hanging post, on a wall, on a stand, and the like for coupling to a device resonator mounted on the bumper, hood, body panel, and the like, of an electric vehicle. The source resonator may be enclosed or embedded into a flexible enclosure such as a pillow, a pad, a bellows, a spring loaded enclosure and the like so that the electric vehicle may make contact with the structure containing the source coil without damaging the car in any way. The structure containing the source may prevent objects from getting between the source and device resonators. Because the wireless power transfer may be relatively insensitive to misalignments between the source and device coils, a variety of flexible source structures and parking procedures may be appropriate for this application.

[00477] The systems and methods described herein may be used to trickle charge batteries of electric, hybrid or combustion engine vehicles. Vehicles may require small amounts of power to maintain or replenish battery power. The power may be transferred wirelessly from a source to a device resonator that may be incorporated into the front grill, roof, bottom, or other parts of the vehicle. The device resonator may be designed to fit into a shape of a logo on the

InductEV, Inc.
Exhibit 1002
Page 132

front of a vehicle or around the grill as not to obstruct air flow through the radiator. The device or source resonator may have additional modes of operation that allow the resonator to be used as a heating element which can be used to melt of snow or ice from the vehicle.

[00478] An electric vehicle or hybrid vehicle may require multiple device resonators, such as to increase the ease with which the vehicle may come in proximity with a source resonator for charging (i.e. the greater the number and varied position of device resonators are, the greater the chances that the vehicle can pull in and interface with a diversity of charging stations), to increase the amount of power that can be delivered in a period of time (e.g. additional device resonators may be required to keep the local heating due to charging currents to acceptable levels), to aid in automatic parking/docking the vehicle with the charging station, and the like. For example, the vehicle may have multiple resonators (or a single resonator) with a feedback system that provides guidance to either the driver or an automated parking/docking facility in the parking of the vehicle for optimized charging conditions (i.e., the optimum positioning of the vehicle's device resonator to the charging station's source resonator may provide greater power transfer efficiency). An automated parking/docking facility may allow for the automatic parking of the vehicle based on how well the vehicle is coupled.

[00479] The power transmission system may be used to power devices and peripherals of a vehicle. Power to peripherals may be provided while a vehicle is charging, or while not charging, or power may be delivered to conventional vehicles that do not need charging. For example, power may be transferred wirelessly to conventional non-electric cars to power air conditioning, refrigeration units, heaters, lights, and the like while parked to avoid running the engine which may be important to avoid exhaust build up in garage parking lots or loading docks. Power may for example be wirelessly transferred to a bus while it is parked to allow powering of lights, peripherals, passenger devices, and the like avoiding the use of onboard engines or power sources. Power may be wirelessly transferred to an airplane while parked on the tarmac or in a hanger to power instrumentation, climate control, de-icing equipment, and the like without having to use onboard engines or power sources.

[00480] Wireless power transmission on vehicles may be used to enable the concept of Vehicle to Grid (V2G). Vehicle to grid is based on utilizing electric vehicles and plug-in hybrid electric vehicles (PHEV) as distributed energy storage devices, charged at night when the electric grid is underutilized, and available to discharge back into the grid during episodes of peak

InductEV, Inc.
Exhibit 1002
Page 133

demand that occur during the day. The wireless power transmission system on a vehicle and the respective infrastructure may be implemented in such a way as to enable bidirectional energy flow—so that energy can flow back into the grid from the vehicle—without requiring a plug in connection. Vast fleets of vehicles, parked at factories, offices, parking lots, can be viewed as "peaking power capacity" by the smart grid. Wireless power transmission on vehicles can make such a V2G vision a reality. By simplifying the process of connecting a vehicle to the grid, (i.e. by simply parking it in a wireless charging enabled parking spot), it becomes much more likely that a certain number of vehicles will be "dispatchable" when the grid needs to tap their power. Without wireless charging, electric and PHEV owners will likely charge their vehicles at home, and park them at work in conventional parking spots. Who will want to plug their vehicle in at work, if they do not need charging? With wireless charging systems capable of handling 3 kW, 100,000 vehicles can provide 300 Megawatts back to the grid—using energy generated the night before by cost effective base load generating capacity. It is the streamlined ergonomics of the cordless self charging PHEV and electric vehicles that make it a viable V2G energy source.

[00481] The systems and methods described herein may be used to power sensors on the vehicle, such as sensors in tires to measure air-pressure, or to run peripheral devices in the vehicle, such as cell phones, GPS devices, navigation devices, game players, audio or video players, DVD players, wireless routers, communications equipment, anti-theft devices, radar devices, and the like. For example, source resonators described herein may be built into the main compartment of the car in order to supply power to a variety of devices located both inside and outside of the main compartment of the car. Where the vehicle is a motorcycle or the like, devices described herein may be integrated into the body of the motorcycle, such as under the seat, and device resonators may be provided in a user's helmet, such as for communications, entertainment, signaling, and the like, or device resonators may be provided in the user's jacket, such as for displaying signals to other drivers for safety, and the like.

[00482] The systems and methods described herein may be used in conjunction with transportation infrastructure, such as roads, trains, planes, shipping, and the like. For example, source resonators may be built into roads, parking lots, rail-lines, and the like. Source resonators may be built into traffic lights, signs, and the like. For example, with source resonators embedded into a road, and device resonators built into vehicles, the vehicles may be provided power as they drive along the road or as they are parked in lots or on the side of the road. The

InductEV, Inc.
Exhibit 1002
Page 134

systems and methods described herein may provide an effective way for electrical systems in vehicles to be powered and/or charged while the vehicle traverses a road network, or a portion of a road network. In this way, the systems and methods described herein may contribute to the powering/charging of autonomous vehicles, automatic guided vehicles, and the like. The systems and methods described herein may provide power to vehicles in places where they typically idle or stop, such as in the vicinity of traffic lights or signs, on highway ramps, or in parking lots.

[00483] The systems and methods described herein may be used in an industrial environment, such as inside a factory for powering machinery, powering/charging robots, powering and/or charging wireless sensors on robot arms, powering/charging tools and the like. For example, using the systems and methods described herein to supply power to devices on the arms of robots may help eliminate direct wire connections across the joints of the robot arm. In this way, the wearing out of such direct wire connections may be reduced, and the reliability of the robot increased. In this case, the device resonator may be out on the arm of the robot, and the source resonator may be at the base of the robot, in a central location near the robot, integrated into the industrial facility in which the robot is providing service, and the like. The use of the systems and methods described herein may help eliminate wiring otherwise associated with power distribution within the industrial facility, and thus benefit the overall reliability of the facility.

[00484] The systems and methods described herein may be used for underground applications, such as drilling, mining, digging, and the like. For example, electrical components and sensors associated with drilling or excavation may utilize the systems and methods described herein to eliminate cabling associated with a digging mechanism, a drilling bit, and the like, thus eliminating or minimizing cabling near the excavation point. In another example, the systems and methods described herein may be used to provide power to excavation equipment in a mining application where the power requirements for the equipment may be high and the distances large, but where there are no people to be subjected to the associated required fields. For instance, the excavation area may have device resonator powered digging equipment that has high power requirements and may be digging relatively far from the source resonator. As a result the source resonator may need to provide high field intensities to satisfy these requirements, but personnel are far enough away to be outside these high intensity fields. This high power, no personnel, scenario may be applicable to a plurality of industrial applications.

InductEV, Inc.
Exhibit 1002
Page 135

[00485] The systems and methods described herein may also use the near-field non-radiative resonant scheme for information transfer rather than, or in addition to, power transfer. For instance, information being transferred by near-field non-radiative resonance techniques may not be susceptible to eavesdropping and so may provide an increased level of security compared to traditional wireless communication schemes. In addition, information being transferred by near-field non-radiative resonance techniques may not interfere with the EM radiative spectrum and so may not be a source of EM interference, thereby allowing communications in an extended frequency range and well within the limits set by any regulatory bodies. Communication services may be provided between remote, inaccessible or hard-to-reach places such as between remote sensors, between sections of a device or vehicle, in tunnels, caves and wells (e.g. oil wells, other drill sites) and between underwater or underground devices, and the like. Communications services may be provided in places where magnetic fields experience less loss than electric fields.

[00486] The systems and methods described herein may enable the simultaneous transmission of power and communication signals between sources and devices in wireless power transmission systems, or it may enable the transmission of power and communication signals during different time periods or at different frequencies. The performance characteristics of the resonator may be controllably varied to preferentially support or limit the efficiency or range of either energy or information transfer. The performance characteristics of the resonators may be controlled to improve the security by reducing the range of information transfer, for example. The performance characteristics of the resonators may be varied continuously, periodically, or according to a predetermined, computed or automatically adjusted algorithm. For example, the power and information transfer enabled by the systems and methods described herein may be provided in a time multiplexed or frequency multiplexed manner. A source and device may signal each other by tuning, changing, varying, dithering, and the like, the resonator impedance which may affect the reflected impedance of other resonators that can be detected. The information transferred as described herein may include information regarding device identification, device power requirements, handshaking protocols, and the like.

[00487] The source and device may sense, transmit, process and utilize position and location information on any other sources and/or devices in a power network. The source and device may capture or use information such as elevation, tilt, latitude and longitude, and the like

InductEV, Inc.
Exhibit 1002
Page 136

from a variety of sensors and sources that may be built into the source and device or may be part of a component the source or device connect. The positioning and orientation information may include sources such as global positioning sensors (GPS), compasses, accelerometers, pressure sensors, atmospheric barometric sensors, positioning systems which use Wi-Fi or cellular network signals, and the like. The source and device may use the position and location information to find nearby wireless power transmission sources. A source may broadcast or communicate with a central station or database identifying its location. A device may obtain the source location information from the central station or database or from the local broadcast and guide a user or an operator to the source with the aid of visual, vibrational, or auditory signals. Sources and devices may be nodes in a power network, in a communications network, in a sensor network, in a navigational network, and the like or in kind of combined functionality network.

[00488] The position and location information may also be used to optimize or coordinate power delivery. Additional information about the relative position of a source and a device may be used to optimize magnetic field direction and resonator alignment. The orientation of a device and a source which may be obtained from accelerometers and magnetic sensors, and the like, for example, may be used to identify the orientation of resonators and the most favorable direction of a magnetic field such that the magnetic flux is not blocked by the device circuitry. With such information a source with the most favorable orientation, or a combination of sources, may be used. Likewise, position and orientation information may be used to move or provide feedback to a user or operator of a device to place a device in a favorable orientation or location to maximize power transmission efficiency, minimize losses, and the like.

[00489] The source and device may include power metering and measuring circuitry and capability. The power metering may be used to track how much power was delivered to a device or how much power was transferred by a source. The power metering and power usage information may be used in fee based power delivery arrangements for billing purposes. Power metering may be also be used to enable power delivery policies to ensure power is distributed to multiple devices according to specific criteria. For example, the power metering may be used to categorize devices based on the amount of power they received and priority in power delivery may be given to those having received the least power. Power metering may be used to provide tiered delivery services such as “guaranteed power” and “best effort power” which may be billed at separate rates. Power metering may be used to institute and enforce hierarchical power

InductEV, Inc.
Exhibit 1002
Page 137

delivery structures and may enable priority devices to demand and receive- more power under certain circumstances or use scenarios.

[00490] Power metering may be used to optimize power delivery efficiency and minimize absorption and radiation losses. Information related to the power received by devices may be used by a source in conjunction with information about the power output of the source to identify unfavorable operating environments or frequencies. For example, a source may compare the amount of power which was received by the devices and the amount of power which it transmitted to determine if the transmission losses may be unusually or unacceptably large. Large transmission losses may be due to an unauthorized device receiving power from the source and the source and other devices may initiate frequency hopping of the resonance frequency or other defensive measures to prevent or deter unauthorized use. Large transmission losses may be due to absorption losses for example, and the device and source may tune to alternate resonance frequencies to minimize such losses. Large transmission losses may also indicate the presence of unwanted or unknown objects or materials and the source may turn down or off its power level until the unwanted or unknown object is removed or identified, at which point the source may resume powering remote devices.

[00491] The source and device may include authentication capability. Authentication may be used to ensure that only compatible sources and devices are able to transmit and receive power. Authentication may be used to ensure that only authentic devices that are of a specific manufacturer and not clones or devices and sources from other manufacturers, or only devices that are part of a specific subscription or plan, are able to receive power from a source. Authentication may be based on cryptographic request and respond protocols or it may be based on the unique signatures of perturbations of specific devices allowing them to be used and authenticated based on properties similar to physically unclonable functions. Authentication may be performed locally between each source and device with local communication or it may be used with third person authentication methods where the source and device authenticate with communications to a central authority. Authentication protocols may use position information to alert a local source or sources of a genuine device.

[00492] The source and device may use frequency hopping techniques to prevent unauthorized use of a wireless power source. The source may continuously adjust or change the resonant frequency of power delivery. The changes in frequency may be performed in a

InductEV, Inc.
Exhibit 1002
Page 138

pseudorandom or predetermined manner that is known, reproducible, or communicated to authorized device but difficult to predict. The rate of frequency hopping and the number of various frequencies used may be large and frequent enough to ensure that unauthorized use is difficult or impractical. Frequency hopping may be implemented by tuning the impedance network, tuning any of the driving circuits, using a plurality of resonators tuned or tunable to multiple resonant frequencies, and the like.

[00493] The source may have a user notification capability to show the status of the source as to whether it is coupled to a device resonator and transmitting power, if it is in standby mode, or if the source resonator is detuned or perturbed by an external object. The notification capability may include visual, auditory, and vibrational methods. The notification may be as simple as three color lights, one for each state, and optionally a speaker to provide notification in case of an error in operation. Alternatively, the notification capability may involve an interactive display that shows the status of the source and optionally provides instructions on how to fix or solve any errors or problems identified.

[00494] As another example, wireless power transfer may be used to improve the safety of electronic explosive detonators. Explosive devices are detonated with an electronic detonator, electric detonator, or shock tube detonator. The electronic detonator utilizes stored electrical energy (usually in a capacitor) to activate the igniter charge, with a low energy trigger signal transmitted conductively or by radio. The electric detonator utilizes a high energy conductive trigger signal to provide both the signal and the energy required to activate the igniter charge. A shock tube sends a controlled explosion through a hollow tube coated with explosive from the generator to the igniter charge. There are safety issues associated with the electric and electronic detonators, as there are cases of stray electromagnetic energy causing unintended activation. Wireless power transfer via sharply resonant magnetic coupling can improve the safety of such systems.

[00495] Using the wireless power transfer methods disclosed herein, one can build an electronic detonation system that has no locally stored energy, thus reducing the risk of unintended activation. A wireless power source can be placed in proximity (within a few meters) of the detonator. The detonator can be equipped with a resonant capture coil. The activation energy can be transferred when the wireless power source has been triggered. The triggering of the wireless power source can be initiated by any number of mechanisms: radio, magnetic near

field radio, conductive signaling, ultrasonics, laser light. Wireless power transfer based on resonant magnetic coupling also has the benefit of being able to transfer power through materials such as rock, soil, concrete, water, and other dense materials. The use of very high Q coils as receivers and sources, having very narrow band response and sharply tuned to proprietary frequencies, further ensure that the detonator circuits cannot capture stray EMI and activate unintentionally.

[00496] The resonator of a wirelessly powered device may be external, or outside of the device, and wired to the battery of the device. The battery of the device may be modified to include appropriate rectification and control circuitry to receive the alternating currents of the device resonator. This can enable configurations with larger external coils, such as might be built into a battery door of a keyboard or mouse, or digital still camera, or even larger coils that are attached to the device but wired back to the battery/converter with ribbon cable. The battery door can be modified to provide interconnection from the external coil to the battery/converter (which will need an exposed contact that can touch the battery door contacts.

[00497] While the invention has been described in connection with certain preferred embodiments, other embodiments will be understood by one of ordinary skill in the art and are intended to fall within the scope of this disclosure, which is to be interpreted in the broadest sense allowable by law.

[00498] All documents referenced herein are hereby incorporated by reference.

InductEV, Inc.
Exhibit 1002
Page 140

PTO/SB/14 (07-07)
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Application Data Sheet 37 CFR 1.76	Attorney Docket Number	WTCY-0026-P01
	Application Number	
Title of Invention	WIRELESS ENERGY TRANSFER SYSTEMS	

The application data sheet is part of the provisional or nonprovisional application for which it is being submitted. The following form contains the bibliographic data arranged in a format specified by the United States Patent and Trademark Office as outlined in 37 CFR 1.76.
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Secrecy Order 37 CFR 5.2

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Applicant Information:

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Applicant Authority ◉ Inventor ○ Legal Representative under 35 U.S.C. 117 ○ Party of Interest under 35 U.S.C. 118

Prefix	Given Name	Middle Name	Family Name	Suffix
	Morris	P.	Kessler	

Residence Information (Select One) ◉ US Residency ○ Non US Residency ○ Active US Military Service

City	Bedford	State/Province	MA	Country of Residence[i]	US

Citizenship under 37 CFR 1.41(b)[i] US

Mailing Address of Applicant:

Address 1	95 Hancock Street		
Address 2			
City	Bedford	State/Province	MA
Postal Code	01730	Country[i]	US

Applicant 2 Remove

Applicant Authority ◉ Inventor ○ Legal Representative under 35 U.S.C. 117 ○ Party of Interest under 35 U.S.C. 118

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	Aristeidis		Karalis	

Residence Information (Select One) ◉ US Residency ○ Non US Residency ○ Active US Military Service

City	Boston	State/Province	MA	Country of Residence[i]	US

Citizenship under 37 CFR 1.41(b)[i] GR

Mailing Address of Applicant:

Address 1	151 Tremont Street		
Address 2	Apartment 21F		
City	Boston	State/Province	MA
Postal Code	02111	Country[i]	US

Applicant 3 Remove

Applicant Authority ◉ Inventor ○ Legal Representative under 35 U.S.C. 117 ○ Party of Interest under 35 U.S.C. 118

Prefix	Given Name	Middle Name	Family Name	Suffix
	Andre	B.	Kurs	

Residence Information (Select One) ◉ US Residency ○ Non US Residency ○ Active US Military Service

City	Chestnut Hill	State/Province	MA	Country of Residence[i]	US

Application Data Sheet 37 CFR 1.76	Attorney Docket Number	WTCY-0026-P01
	Application Number	
Title of Invention	WIRELESS ENERGY TRANSFER SYSTEMS	

Citizenship under 37 CFR 1.41(b) i	BR				
Mailing Address of Applicant:					
Address 1	250 Hammond Pond Parkway				
Address 2	Apartment 1203S				
City	Chestnut Hill	**State/Province**	MA		
Postal Code	02467	**Country**i	US		

Applicant 4 Remove

Applicant Authority (•) Inventor ( ) Legal Representative under 35 U.S.C. 117 ( ) Party of Interest under 35 U.S.C. 118

Prefix	Given Name	Middle Name	Family Name	Suffix
	Andrew	J.	Campanella	

Residence Information (Select One) (•) US Residency ( ) Non US Residency ( ) Active US Military Service

City	Waltham	**State/Province**	MA	**Country of Residence** i	US
Citizenship under 37 CFR 1.41(b) i	US				
Mailing Address of Applicant:					
Address 1	30 Orange Street				
Address 2					
City	Waltham	**State/Province**	MA		
Postal Code	02453	**Country**i	US		

Applicant 5 Remove

Applicant Authority (•) Inventor ( ) Legal Representative under 35 U.S.C. 117 ( ) Party of Interest under 35 U.S.C. 118

Prefix	Given Name	Middle Name	Family Name	Suffix
	Ron		Fiorello	

Residence Information (Select One) (•) US Residency ( ) Non US Residency ( ) Active US Military Service

City	Tewksbury	**State/Province**	MA	**Country of Residence** i	US
Citizenship under 37 CFR 1.41(b) i	US				
Mailing Address of Applicant:					
Address 1	20 Scotland Drive				
Address 2					
City	Tewksbury	**State/Province**	MA		
Postal Code	01876	**Country**i	US		

Applicant 6 Remove

Applicant Authority (•) Inventor ( ) Legal Representative under 35 U.S.C. 117 ( ) Party of Interest under 35 U.S.C. 118

Prefix	Given Name	Middle Name	Family Name	Suffix
	Qiang		Li	

Residence Information (Select One) (•) US Residency ( ) Non US Residency ( ) Active US Military Service

City	Malden	**State/Province**	MA	**Country of Residence** i	US
Citizenship under 37 CFR 1.41(b) i	CN				

Application Data Sheet 37 CFR 1.76	Attorney Docket Number	WTCY-0026-P01
	Application Number	
Title of Invention	WIRELESS ENERGY TRANSFER SYSTEMS	

Mailing Address of Applicant:					
Address 1	654 Main Street				
Address 2					
City	Malden	**State/Province**	MA		
Postal Code	02148	**Country**[i]	US		
Applicant 7				Remove	
Applicant Authority (•) Inventor	( ) Legal Representative under 35 U.S.C. 117	( ) Party of Interest under 35 U.S.C. 118			
Prefix	**Given Name**	**Middle Name**	**Family Name**	**Suffix**	
	Konrad		Kulikowski		
Residence Information (Select One) (•) US Residency	( ) Non US Residency	( ) Active US Military Service			
City	Somerville	**State/Province**	MA	**Country of Residence**[i]	US
Citizenship under 37 CFR 1.41(b)[i]	US				

Mailing Address of Applicant:					
Address 1	91 Pearson Avenue				
Address 2	Apartment 1				
City	Somerville	**State/Province**	MA		
Postal Code	02144	**Country**[i]	US		
Applicant 8				Remove	
Applicant Authority (•) Inventor	( ) Legal Representative under 35 U.S.C. 117	( ) Party of Interest under 35 U.S.C. 118			
Prefix	**Given Name**	**Middle Name**	**Family Name**	**Suffix**	
	Eric	G.	Giler		
Residence Information (Select One) (•) US Residency	( ) Non US Residency	( ) Active US Military Service			
City	Wellesley	**State/Province**	MA	**Country of Residence**[i]	US
Citizenship under 37 CFR 1.41(b)[i]	US				

Mailing Address of Applicant:					
Address 1	105 Benvenue Street				
Address 2					
City	Wellesley	**State/Province**	MA		
Postal Code	02482	**Country**[i]	US		
Applicant 9				Remove	
Applicant Authority (•) Inventor	( ) Legal Representative under 35 U.S.C. 117	( ) Party of Interest under 35 U.S.C. 118			
Prefix	**Given Name**	**Middle Name**	**Family Name**	**Suffix**	
	Frank	J.	Pergal		
Residence Information (Select One) (•) US Residency	( ) Non US Residency	( ) Active US Military Service			
City	Gloucester	**State/Province**	MA	**Country of Residence**[i]	US
Citizenship under 37 CFR 1.41(b)[i]	US				

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Application Data Sheet 37 CFR 1.76	Attorney Docket Number	WTCY-0026-P01
	Application Number	
Title of Invention	WIRELESS ENERGY TRANSFER SYSTEMS	

Mailing Address of Applicant:					
Address 1	14 Norrock Road				
Address 2					
City	Gloucester	**State/Province**	MA		
Postal Code	01930	**Country**[i]	US		
Applicant 10				Remove	
Applicant Authority	◉ Inventor	○ Legal Representative under 35 U.S.C. 117		○ Party of Interest under 35 U.S.C. 118	
Prefix	**Given Name**	**Middle Name**	**Family Name**		**Suffix**
	David	A.	Schatz		
Residence Information (Select One)	◉ US Residency	○ Non US Residency	○ Active US Military Service		
City	Needham	**State/Province**	MA	**Country of Residence** [i]	US
Citizenship under 37 CFR 1.41(b) [i]	US				

Mailing Address of Applicant:					
Address 1	37 White Pine Road				
Address 2					
City	Needham	**State/Province**	MA		
Postal Code	02492	**Country**[i]	US		
Applicant 11				Remove	
Applicant Authority	◉ Inventor	○ Legal Representative under 35 U.S.C. 117		○ Party of Interest under 35 U.S.C. 118	
Prefix	**Given Name**	**Middle Name**	**Family Name**		**Suffix**
	Katherine	L.	Hall		
Residence Information (Select One)	◉ US Residency	○ Non US Residency	○ Active US Military Service		
City	Westford	**State/Province**	MA	**Country of Residence** [i]	US
Citizenship under 37 CFR 1.41(b) [i]	US				

Mailing Address of Applicant:					
Address 1	21 Griffin Road				
Address 2					
City	Westford	**State/Province**	MA		
Postal Code	01886	**Country**[i]	US		
Applicant 12				Remove	
Applicant Authority	◉ Inventor	○ Legal Representative under 35 U.S.C. 117		○ Party of Interest under 35 U.S.C. 118	
Prefix	**Given Name**	**Middle Name**	**Family Name**		**Suffix**
	Marin		Soljacic		
Residence Information (Select One)	◉ US Residency	○ Non US Residency	○ Active US Military Service		
City	Belmont	**State/Province**	MA	**Country of Residence** [i]	US
Citizenship under 37 CFR 1.41(b) [i]	HR				

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Application Data Sheet 37 CFR 1.76	Attorney Docket Number	WTCY-0026-P01
	Application Number	
Title of Invention	WIRELESS ENERGY TRANSFER SYSTEMS	

Mailing Address of Applicant:			
Address 1	44 Westlund Road		
Address 2			
City	Belmont	State/Province	MA
Postal Code	02478	Country[i]	US

All Inventors Must Be Listed - Additional Inventor Information blocks may be generated within this form by selecting the **Add** button. Add

Correspondence Information:

Enter either Customer Number or complete the Correspondence Information section below. For further information see 37 CFR 1.33(a).

☐ **An Address is being provided for the correspondence Information of this application.**

Customer Number	43520		
Email Address	patents@strategic-patents.com	Add Email	Remove Email

Application Information:

Title of the Invention	WIRELESS ENERGY TRANSFER SYSTEMS		
Attorney Docket Number	WTCY-0026-P01	**Small Entity Status Claimed**	☐
Application Type	Nonprovisional		
Subject Matter	Utility		
Suggested Class (if any)		**Sub Class (if any)**	
Suggested Technology Center (if any)			
Total Number of Drawing Sheets (if any)	51	**Suggested Figure for Publication (if any)**	

Publication Information:

☐ Request Early Publication (Fee required at time of Request 37 CFR 1.219)

☐ **Request Not to Publish.** I hereby request that the attached application not be published under 35 U.S.C. 122(b) and certify that the invention disclosed in the attached application **has not and will not** be the subject of an application filed in another country, or under a multilateral international agreement, that requires publication at eighteen months after filing.

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Representative information should be provided for all practitioners having a power of attorney in the application. Providing this information in the Application Data Sheet does not constitute a power of attorney in the application (see 37 CFR 1.32). Enter either Customer Number or complete the Representative Name section below. If both sections are completed the Customer Number will be used for the Representative Information during processing.

Please Select One:	◉ Customer Number	○ US Patent Practitioner	○ Limited Recognition (37 CFR 11.9)
Customer Number	43520		

Application Data Sheet 37 CFR 1.76	Attorney Docket Number	WTCY-0026-P01
	Application Number	
Title of Invention	WIRELESS ENERGY TRANSFER SYSTEMS	

Domestic Benefit/National Stage Information:

This section allows for the applicant to either claim benefit under 35 U.S.C. 119(e), 120, 121, or 365(c) or indicate National Stage entry from a PCT application. Providing this information in the application data sheet constitutes the specific reference required by 35 U.S.C. 119(e) or 120, and 37 CFR 1.78(a)(2) or CFR 1.78(a)(4), and need not otherwise be made part of the specification.

Prior Application Status	Pending		Remove
Application Number	Continuity Type	Prior Application Number	Filing Date (YYYY-MM-DD)
	non provisional of	61/100721	2008-09-27
Prior Application Status	Pending		Remove
Application Number	Continuity Type	Prior Application Number	Filing Date (YYYY-MM-DD)
	non provisional of	61/108743	2008-10-27
Prior Application Status	Pending		Remove
Application Number	Continuity Type	Prior Application Number	Filing Date (YYYY-MM-DD)
	non provisional of	61/147386	2009-01-26
Prior Application Status	Pending		Remove
Application Number	Continuity Type	Prior Application Number	Filing Date (YYYY-MM-DD)
	non provisional of	61/152086	2009-02-12
Prior Application Status	Pending		Remove
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	non provisional of	61/178508	2009-05-15
Prior Application Status	Pending		Remove
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	non provisional of	61/182768	2009-06-01
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	non provisional of	61/121159	2008-12-09
Prior Application Status	Pending		Remove
Application Number	Continuity Type	Prior Application Number	Filing Date (YYYY-MM-DD)
	non provisional of	61/142977	2009-01-07
Prior Application Status	Pending		Remove
Application Number	Continuity Type	Prior Application Number	Filing Date (YYYY-MM-DD)
	non provisional of	61/142885	2009-01-06
Prior Application Status	Pending		Remove
Application Number	Continuity Type	Prior Application Number	Filing Date (YYYY-MM-DD)
	non provisional of	61/142796	2009-01-06
Prior Application Status	Pending		Remove

Application Data Sheet 37 CFR 1.76	Attorney Docket Number	WTCY-0026-P01
	Application Number	
Title of Invention	WIRELESS ENERGY TRANSFER SYSTEMS	

Application Number	Continuity Type	Prior Application Number	Filing Date (YYYY-MM-DD)
	non provisional of	61/142889	2009-01-06
Prior Application Status	Pending		Remove
Application Number	Continuity Type	Prior Application Number	Filing Date (YYYY-MM-DD)
	non provisional of	61/142880	2009-01-06
Prior Application Status	Pending		Remove
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	non provisional of	61/142818	2009-01-06
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Application Number	Continuity Type	Prior Application Number	Filing Date (YYYY-MM-DD)
	non provisional of	61/142887	2009-01-06
Prior Application Status	Pending		Remove
Application Number	Continuity Type	Prior Application Number	Filing Date (YYYY-MM-DD)
	non provisional of	61/156764	2009-03-02
Prior Application Status	Pending		Remove
Application Number	Continuity Type	Prior Application Number	Filing Date (YYYY-MM-DD)
	non provisional of	61/143058	2009-01-07
Prior Application Status	Pending		Remove
Application Number	Continuity Type	Prior Application Number	Filing Date (YYYY-MM-DD)
	non provisional of	61/152390	2009-02-13
Prior Application Status	Pending		Remove
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	non provisional of	61/163695	2009-03-26
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	non provisional of	61/172633	2009-04-24
Prior Application Status	Pending		Remove
Application Number	Continuity Type	Prior Application Number	Filing Date (YYYY-MM-DD)
	non provisional of	61/169240	2009-04-14
Prior Application Status	Pending		Remove
Application Number	Continuity Type	Prior Application Number	Filing Date (YYYY-MM-DD)
	non provisional of	61/173747	2009-04-29
Additional Domestic Benefit/National Stage Data may be generated within this form by selecting the **Add** button.			Add

Foreign Priority Information:

PTO/SB/14 (07-07)
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U.S. Patent and Trademark Office; U.S. DEPARTMENT OF COMMERCE
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Application Data Sheet 37 CFR 1.76	Attorney Docket Number	WTCY-0026-P01
	Application Number	
Title of Invention	WIRELESS ENERGY TRANSFER SYSTEMS	

This section allows for the applicant to claim benefit of foreign priority and to identify any prior foreign application for which priority is not claimed. Providing this information in the application data sheet constitutes the claim for priority as required by 35 U.S.C. 119(b) and 37 CFR 1.55(a).

Remove

Application Number	Country [i]	Parent Filing Date (YYYY-MM-DD)	Priority Claimed
			(•) Yes ( ) No

Additional Foreign Priority Data may be generated within this form by selecting the **Add** button. Add

Assignee Information:

Providing this information in the application data sheet does not substitute for compliance with any requirement of part 3 of Title 37 of the CFR to have an assignment recorded in the Office.

Assignee 1 Remove

If the Assignee is an Organization check here. ☐

Prefix	**Given Name**	Middle Name	**Family Name**	Suffix

Mailing Address Information:

Address 1			
Address 2			
City		**State/Province**	
Country [i]		Postal Code	
Phone Number		Fax Number	
Email Address			

Additional Assignee Data may be generated within this form by selecting the **Add** button. Add

Signature:

A signature of the applicant or representative is required in accordance with 37 CFR 1.33 and 10.18. Please see 37 CFR 1.4(d) for the form of the signature.

Signature	/Robert A. Mazzarese/			Date (YYYY-MM-DD)	2009-09-25
First Name	Robert	Last Name	Mazzarese	Registration Number	42852

This collection of information is required by 37 CFR 1.76. The information is required to obtain or retain a benefit by the public which is to file (and by the USPTO to process) an application. Confidentiality is governed by 35 U.S.C. 122 and 37 CFR 1.14. This collection is estimated to take 23 minutes to complete, including gathering, preparing, and submitting the completed application data sheet form to the USPTO. Time will vary depending upon the individual case. Any comments on the amount of time you require to complete this form and/or suggestions for reducing this burden, should be sent to the Chief Information Officer, U.S. Patent and Trademark Office, U.S. Department of Commerce, P.O. Box 1450, Alexandria, VA 22313-1450. DO NOT SEND FEES OR COMPLETED FORMS TO THIS ADDRESS. **SEND TO: Commissioner for Patents, P.O. Box 1450, Alexandria, VA 22313-1450.**

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The information provided by you in this form will be subject to the following routine uses:

1. The information on this form will be treated confidentially to the extent allowed under the Freedom of Information Act (5 U.S.C. 552) and the Privacy Act (5 U.S.C. 552a). Records from this system of records may be disclosed to the Department of Justice to determine whether the Freedom of Information Act requires disclosure of these records.

2. A record from this system of records may be disclosed, as a routine use, in the course of presenting evidence to a court, magistrate, or administrative tribunal, including disclosures to opposing counsel in the course of settlement negotiations.

3. A record in this system of records may be disclosed, as a routine use, to a Member of Congress submitting a request involving an individual, to whom the record pertains, when the individual has requested assistance from the Member with respect to the subject matter of the record.

4. A record in this system of records may be disclosed, as a routine use, to a contractor of the Agency having need for the information in order to perform a contract. Recipients of information shall be required to comply with the requirements of the Privacy Act of 1974, as amended, pursuant to 5 U.S.C. 552a(m).

5. A record related to an International Application filed under the Patent Cooperation Treaty in this system of records may be disclosed, as a routine use, to the International Bureau of the World Intellectual Property Organization, pursuant to the Patent Cooperation Treaty.

6. A record in this system of records may be disclosed, as a routine use, to another federal agency for purposes of National Security review (35 U.S.C. 181) and for review pursuant to the Atomic Energy Act (42 U.S.C. 218(c)).

7. A record from this system of records may be disclosed, as a routine use, to the Administrator, General Services, or his/her designee, during an inspection of records conducted by GSA as part of that agency's responsibility to recommend improvements in records management practices and programs, under authority of 44 U.S.C. 2904 and 2906. Such disclosure shall be made in accordance with the GSA regulations governing inspection of records for this purpose, and any other relevant (i.e., GSA or Commerce) directive. Such disclosure shall not be used to make determinations about individuals.

8. A record from this system of records may be disclosed, as a routine use, to the public after either publication of the application pursuant to 35 U.S.C. 122(b) or issuance of a patent pursuant to 35 U.S.C. 151. Further, a record may be disclosed, subject to the limitations of 37 CFR 1.14, as a routine use, to the public if the record was filed in an application which became abandoned or in which the proceedings were terminated and which application is referenced by either a published application, an application open to public inspections or an issued patent.

9. A record from this system of records may be disclosed, as a routine use, to a Federal, State, or local law enforcement agency, if the USPTO becomes aware of a violation or potential violation of law or regulation.

ABSTRACT

[00499] Described herein are improved capabilities for a source resonator having a Q-factor $Q_1>100$ and a characteristic size x_1 coupled to an energy source, and a second resonator having a Q-factor $Q_2>100$ and a characteristic size x_2 coupled to an energy drain located a distance D from the source resonator, where the source resonator and the second resonator are coupled to exchange energy wirelessly among the source resonator and the second resonator.

InductEV, Inc.
Exhibit 1002
Page 150

CLAIMS

What is claimed is:

1. A system, comprising:

a source resonator having a Q-factor Q_1 and a characteristic size x_1, coupled to a power generator with direct electrical connections; and

a second resonator having a Q-factor Q_2 and a characteristic size x_2, coupled to a load with direct electrical connections, and located a distance D from the source resonator, wherein the source resonator and the second resonator are coupled to exchange energy wirelessly among the source resonator and the second resonator in order to transmit power from the power generator to the load, and wherein $\sqrt{Q_1 Q_2}$ is greater than 100.

2. The system of claim 1, wherein Q_1 is greater than 100 and Q_2 is less than 100.

3. The system of claim 1, wherein Q_1 is greater than 100 and Q_2 is greater than 100.

4. The system of claim 1, wherein a useful energy exchange is maintained over an operating distance from 0 to D, where D is larger than the smaller of x_1 and x_2.

5. The system of claim 1, wherein at least one of the source resonator and the second resonator is a coil of at least one turn of a conducting material connected to a first network of capacitors.

6. The system of claim 5, wherein the first network of capacitors includes at least one tunable capacitor.

7. The system of claim 5, wherein the direct electrical connections of at least one of the source resonator to the ground terminal of the power generator and the second resonator to the

InductEV, Inc.
Exhibit 1002
Page 151

ground terminal of the load is made at a point on an axis of electrical symmetry of the first network of capacitors.

8. The system of claim 7, wherein the first network of capacitors includes at least one tunable butterfly-type capacitor, wherein the direct electrical connection to the ground terminal is made on a center terminal of the at least one tunable butterfly-type capacitor.

9. The system of claim 5, wherein the direct electrical connection of at least one of the source resonator to the power generator and the second resonator to the load is made via a second network of capacitors, wherein the first network of capacitors and the second network of capacitors form an impedance matching network.

10. The system of claim 9, wherein the impedance matching network is designed to match the coil to a characteristic impedance of the power generator or the load at a driving frequency of the power generator.

11. The system of claim 9, wherein at least one of the first network of capacitors and the second network of capacitors includes at least one tunable capacitor.

12. The system of claim 11, wherein the first network of capacitors and the second network of capacitors are adjustable to change an impedance of the impedance matching network at a driving frequency of the power generator.

13. The system of claim 11, wherein the first network of capacitors and the second network of capacitors are adjustable to match the coil to the characteristic impedance of the power generator or the load at a driving frequency of the power generator.

14. The system of claim 11, wherein at least one of the first network of capacitors and the second network of capacitors includes at least one fixed capacitor that reduces a voltage across the at least one tunable capacitor.

InductEV, Inc.
Exhibit 1002
Page 152

15. The system of claim 1, wherein the direct electrical connections of at least one of the source resonator to the power generator and the second resonator to the load are configured to substantially preserve a resonant mode.

16. The system of claim 1, wherein at least one of the source resonator and the second resonator is a tunable resonator.

17. The system of claim 1, wherein the source resonator is physically separated from the power generator and the second resonator is physically separated from the load.

18. The system of claim 1, wherein the second resonator is coupled to a power conversion circuit to deliver DC power to the load.

19. The system of claim 1, wherein the second resonator is coupled to a power conversion circuit to deliver AC power to the load.

20. The system of claim 1, wherein the second resonator is coupled to a power conversion circuit to deliver both AC and DC power to the load.

21. The system of claim 1, wherein the second resonator is coupled to a power conversion circuit to deliver power to a plurality of loads.

22. A system, comprising:

a source resonator having a Q-factor Q_1 and a characteristic size x_1, and a second resonator having a Q-factor Q_2 and a characteristic size x_2, and located a distance D from the source resonator;

wherein the source resonator and the second resonator are coupled to exchange energy wirelessly among the source resonator and the second resonator; and

wherein $\sqrt{Q_1 Q_2}$ is greater than 100, and wherein at least one of the resonators is enclosed in a low loss tangent material.

23. A system, comprising:

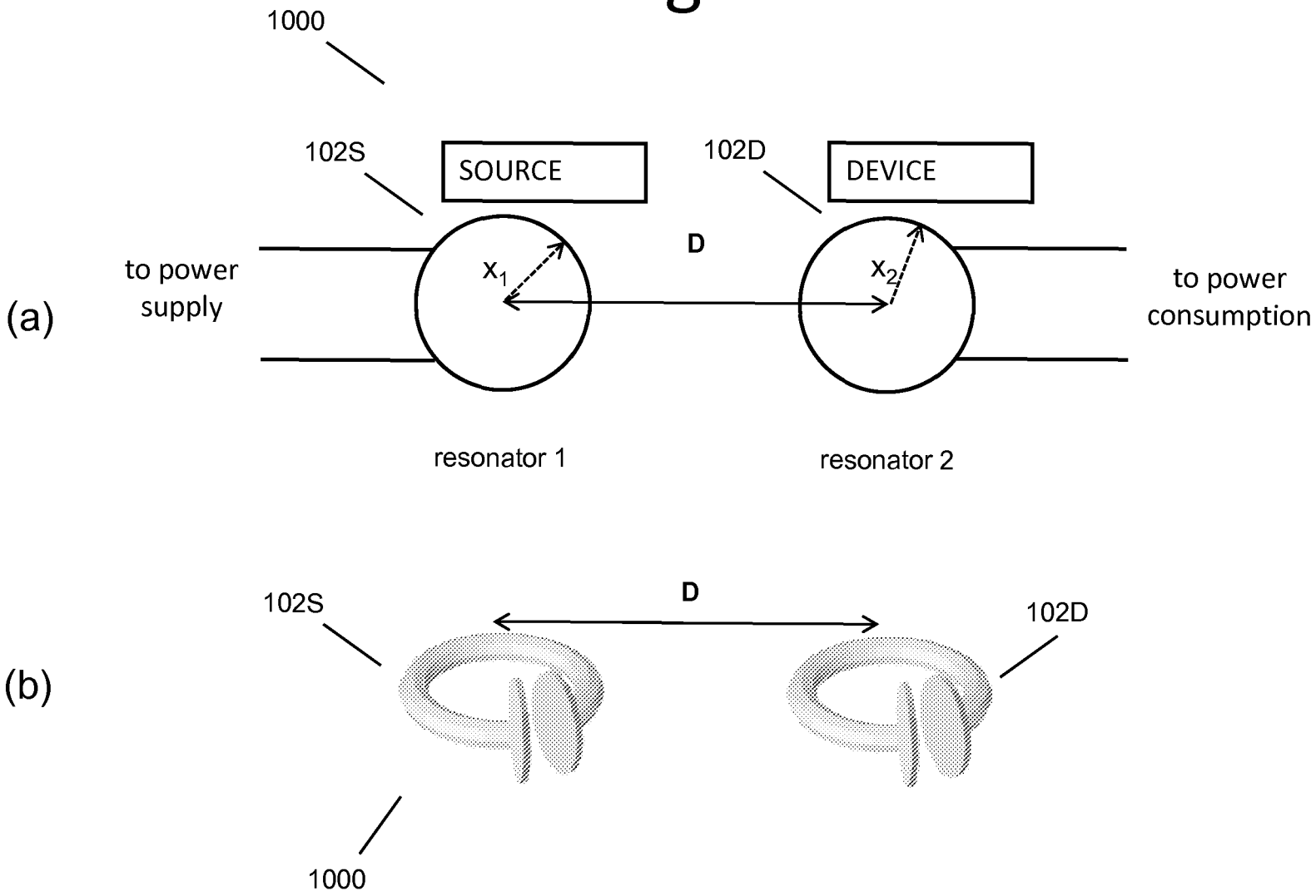
a source resonator having a Q-factor Q_1 and a characteristic size x_1, and a second resonator having a Q-factor Q_2 and a characteristic size x_2, and located a distance D from the source resonator;

wherein the source resonator and the second resonator are coupled to exchange energy wirelessly among the source resonator and the second resonator, and wherein $\sqrt{Q_1 Q_2}$ is greater than 100; and

wherein at least one of the resonators includes a coil of a plurality of turns of a conducting material connected to a network of capacitors, wherein the plurality of turns are in a common plane, and wherein a characteristic thickness of the at least one of the resonators is much less than a characteristic size of the at least one of the resonators.

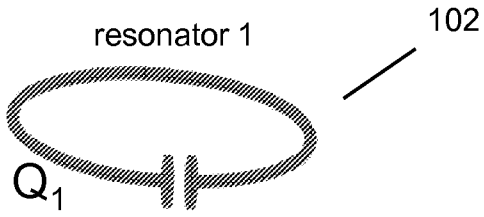
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Page 154

Fig. 1



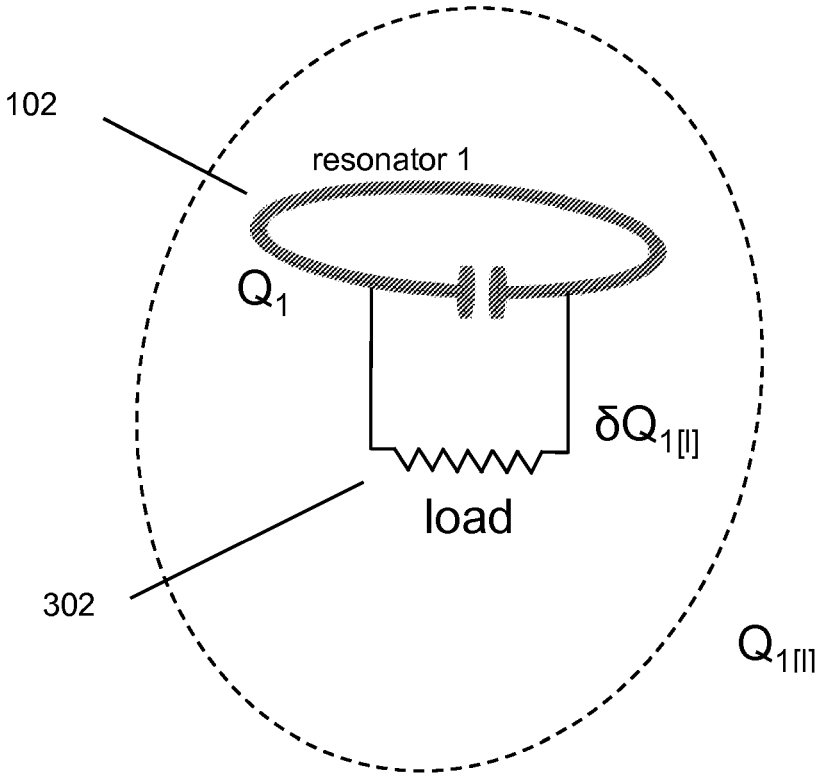
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Exhibit 1002
Page 155

Fig. 2



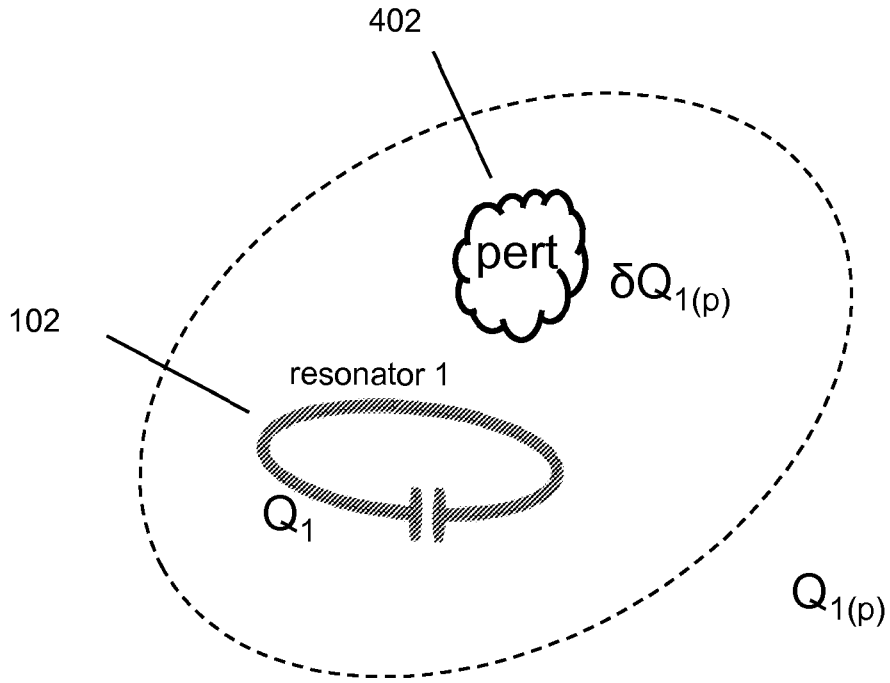
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Page 156

Fig. 3



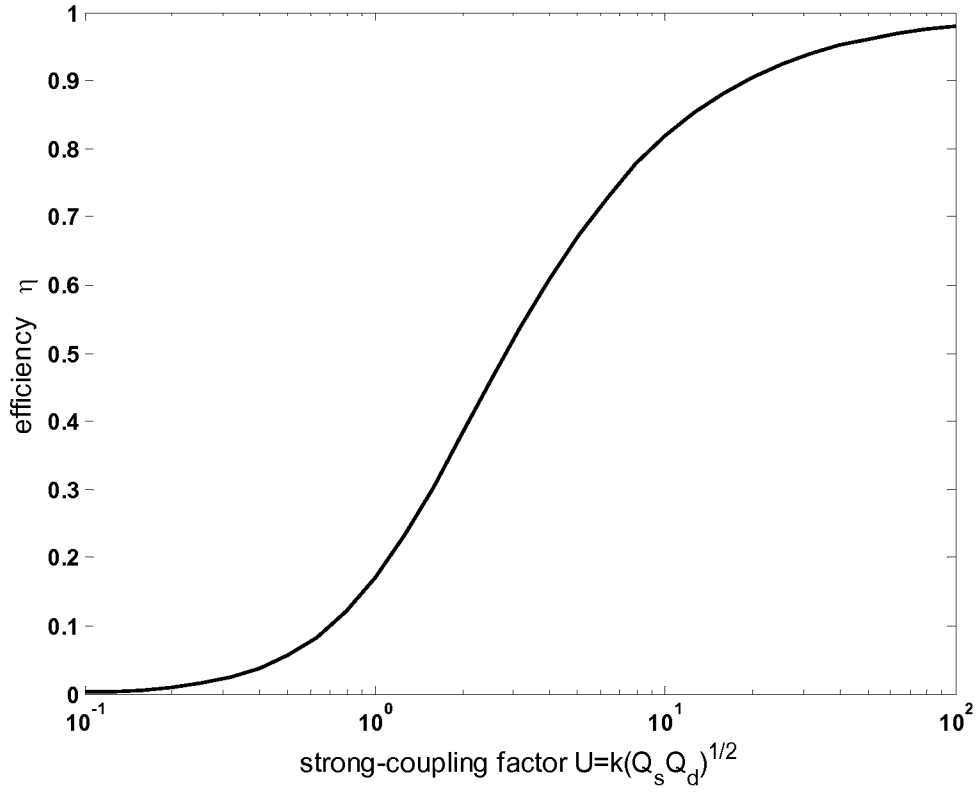
InductEV, Inc.
Exhibit 1002
Page 157

Fig. 4



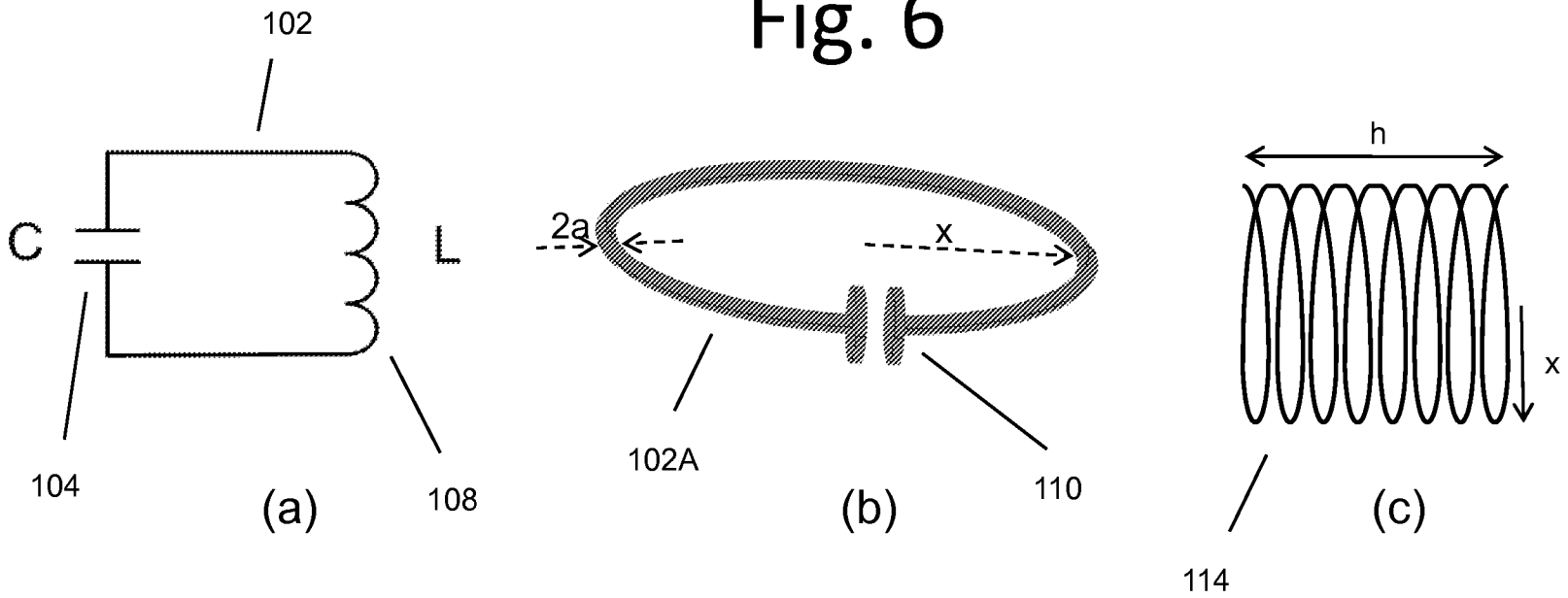
InductEV, Inc.
Exhibit 1002
Page 158

Fig. 5



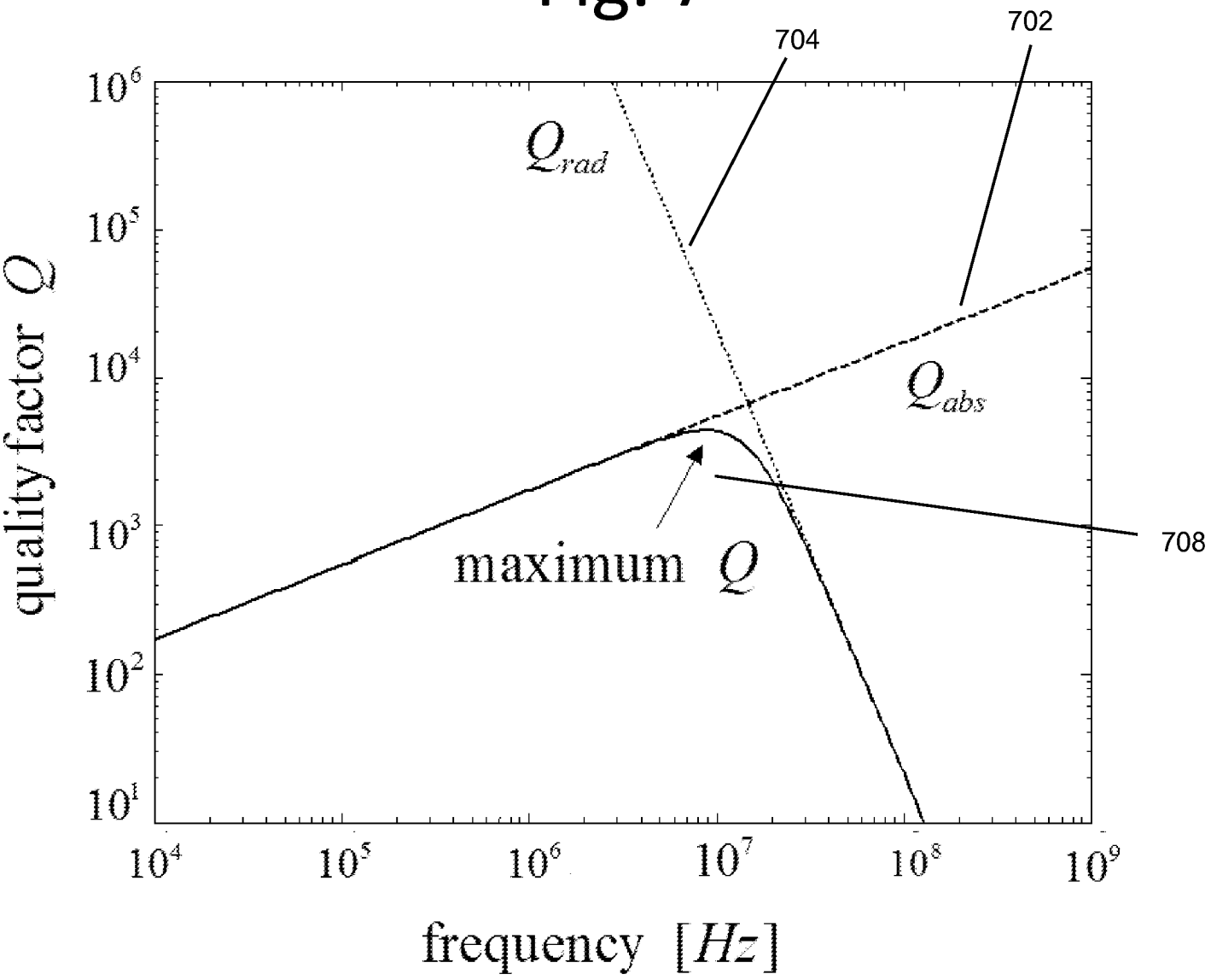
InductEV, Inc.
Exhibit 1002
Page 159

Fig. 6



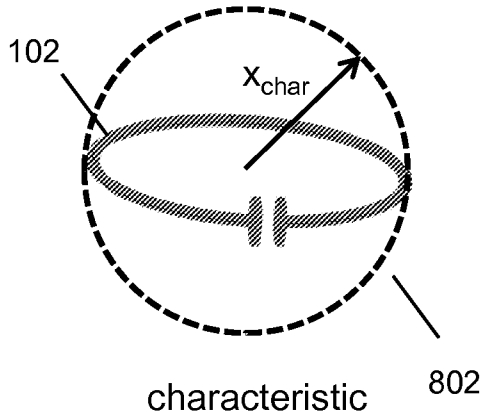
InductEV, Inc.
Exhibit 1002
Page 160

Fig. 7

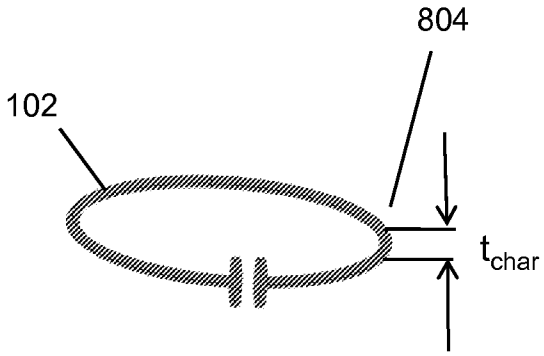


InductEV, Inc.
Exhibit 1002
Page 161

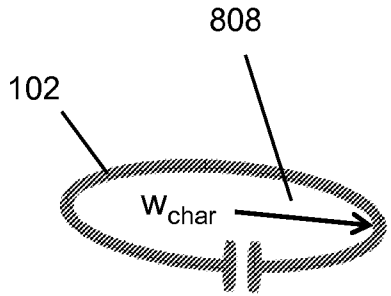
Fig. 8



characteristic size



characteristic thickness



characteristic width

InductEV, Inc.
Exhibit 1002
Page 162

Fig. 9

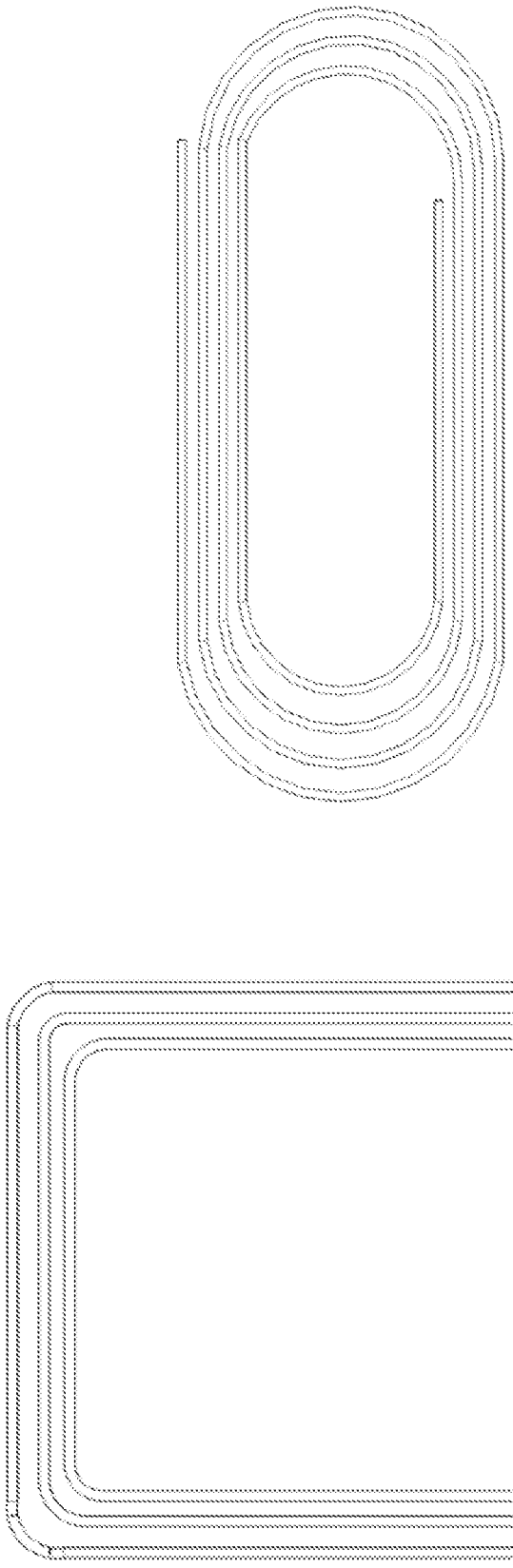


Fig. 10

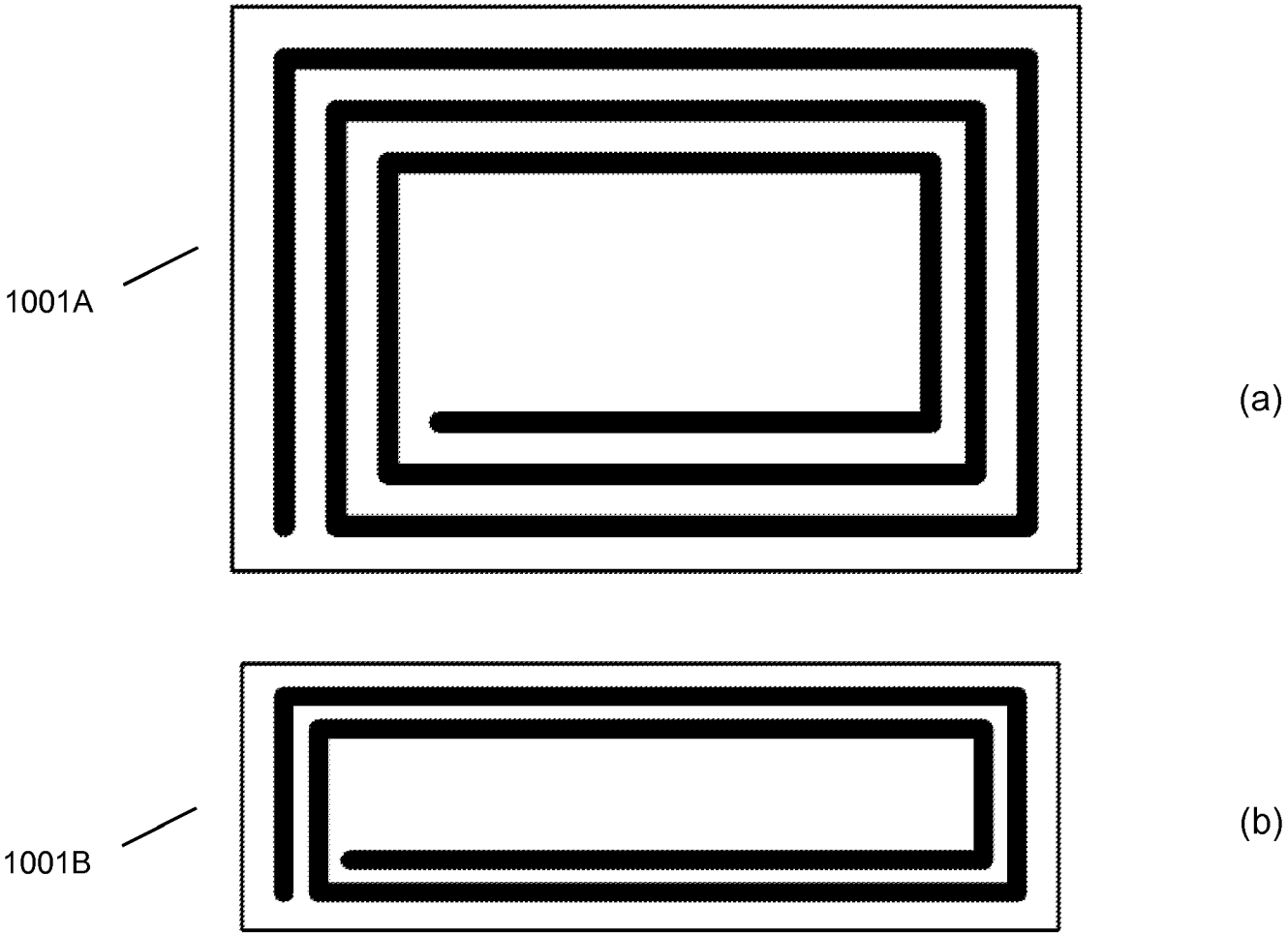
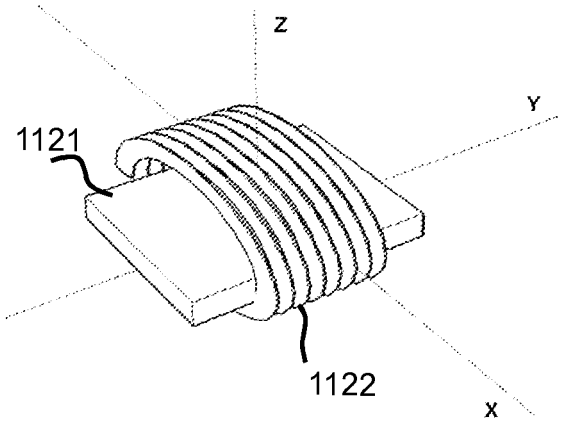
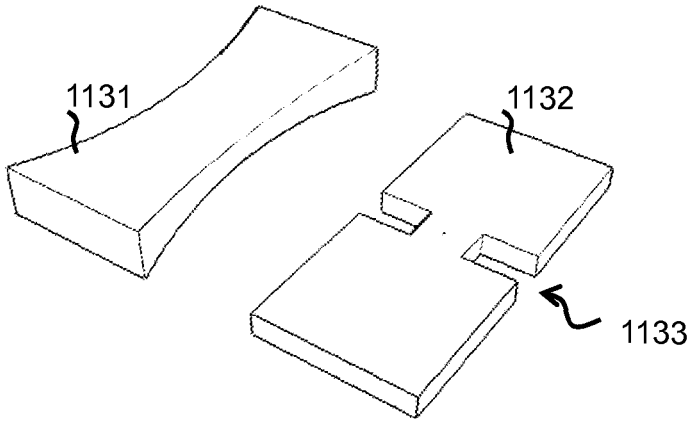


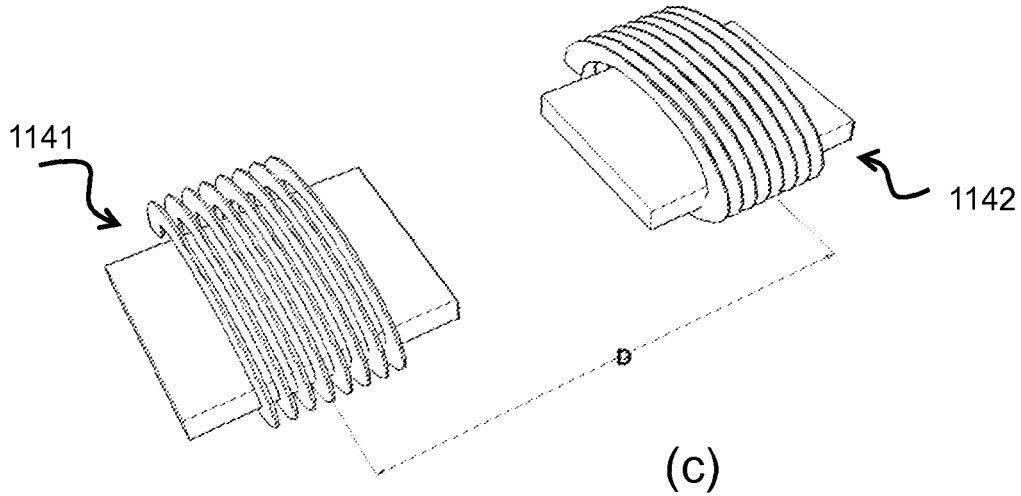
Fig. 11



(a)



(b)



(c)

InductEV, Inc.
Exhibit 1002
Page 165

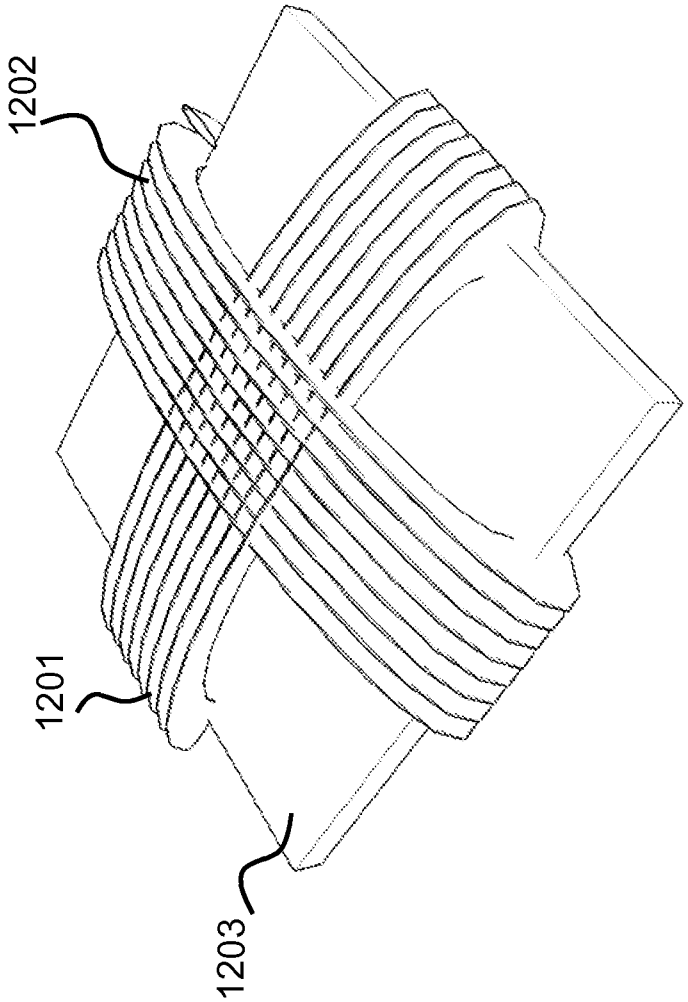


Fig. 12

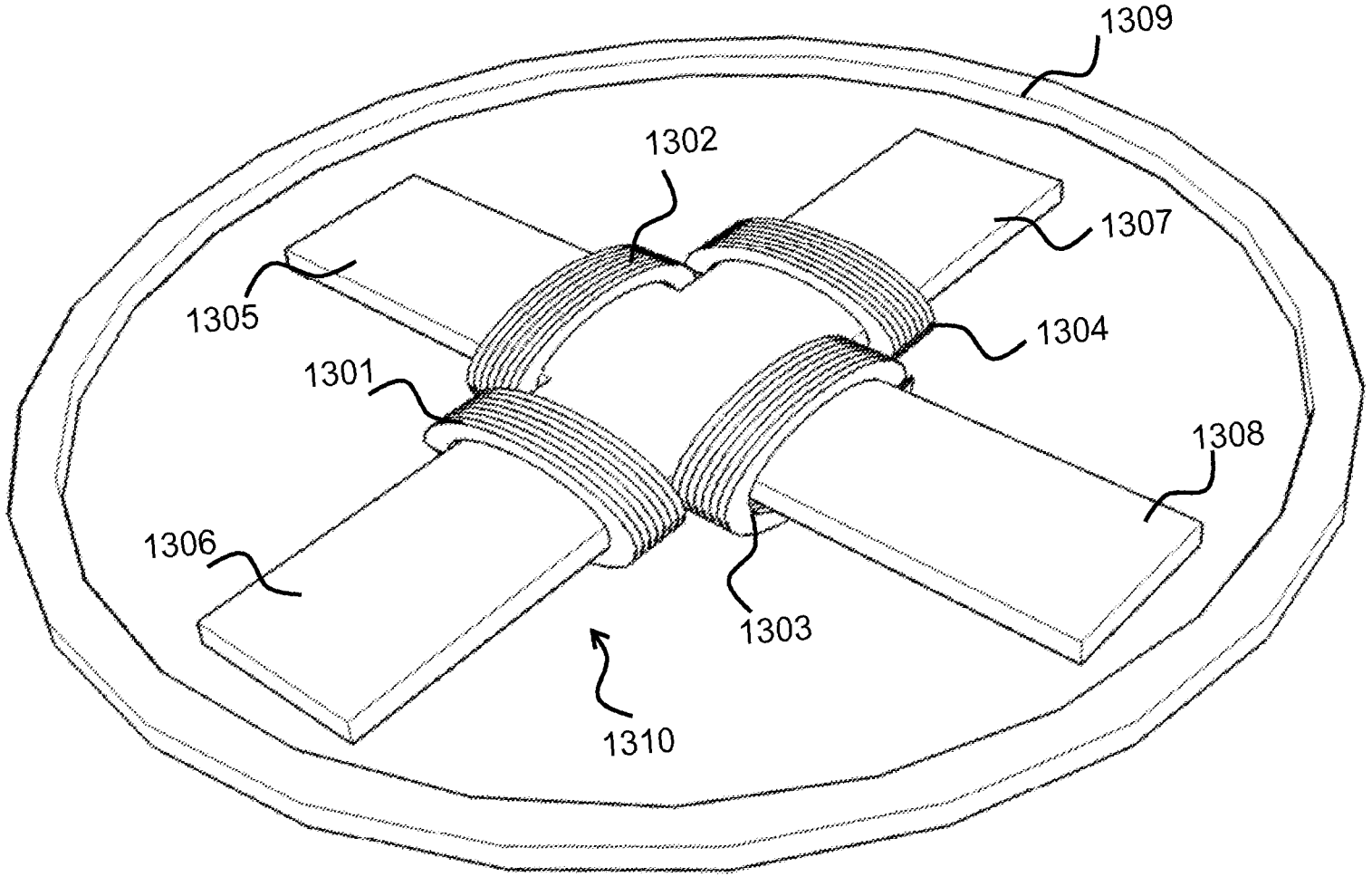


Fig. 13

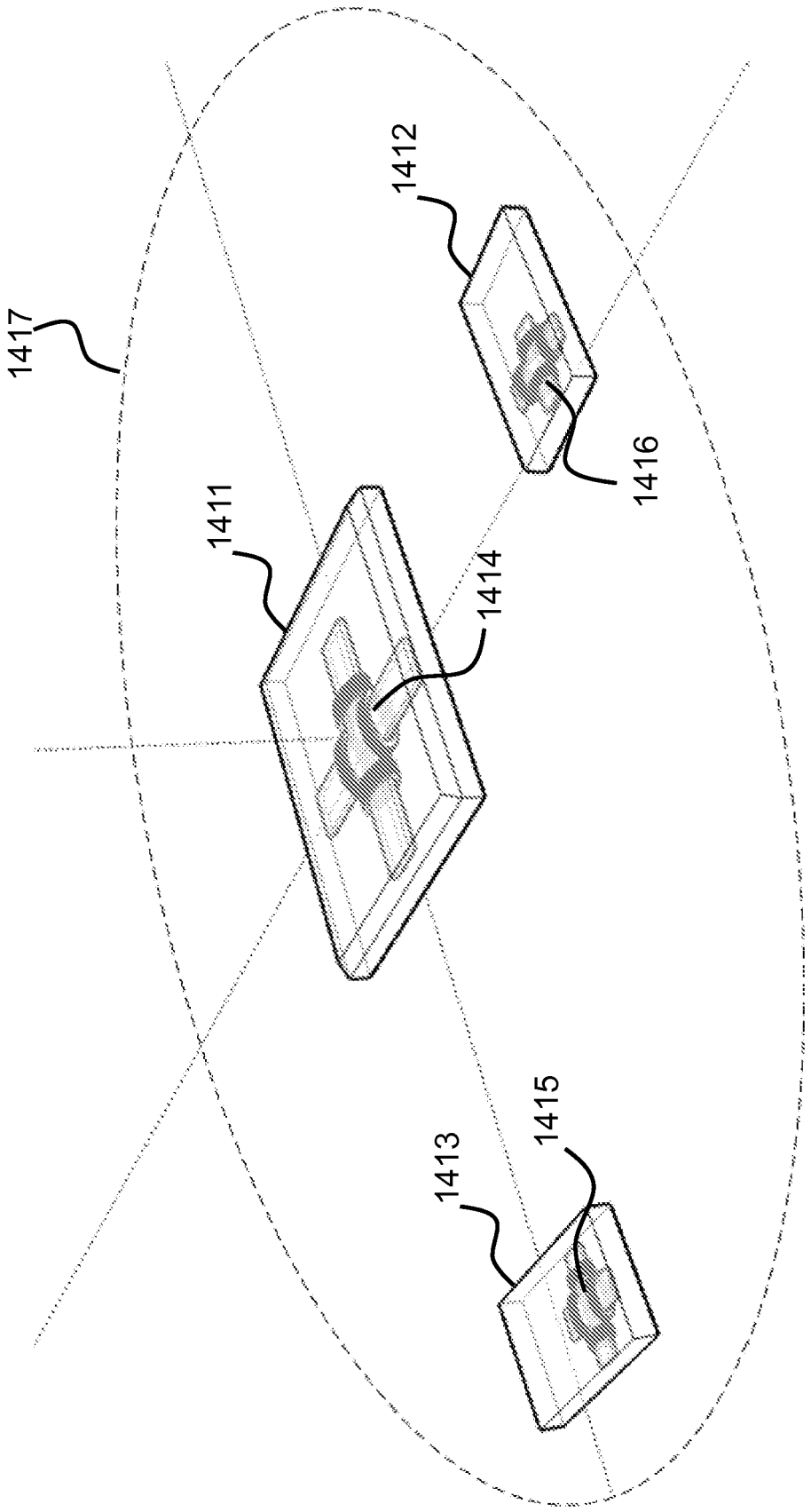


Fig. 14

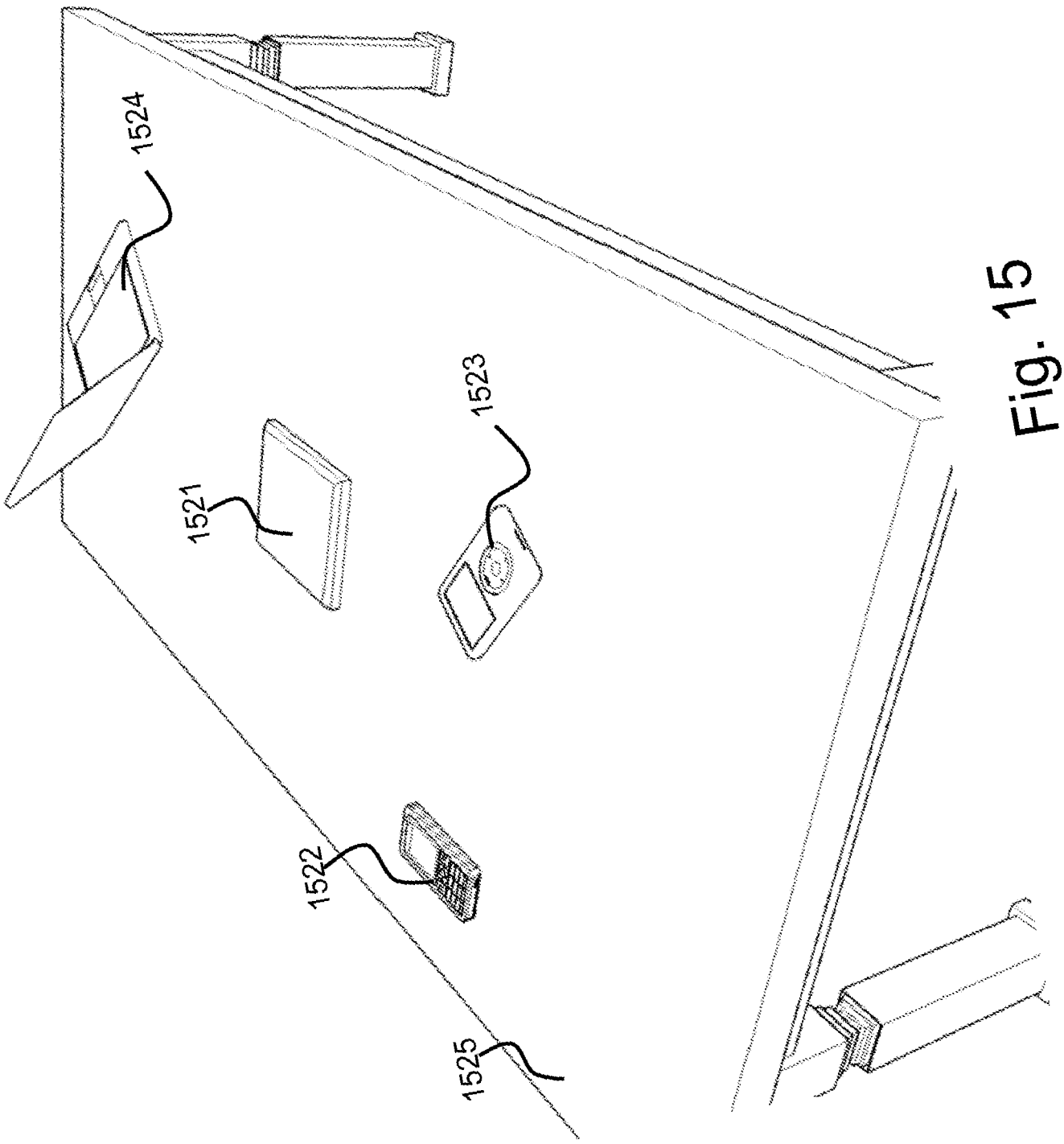
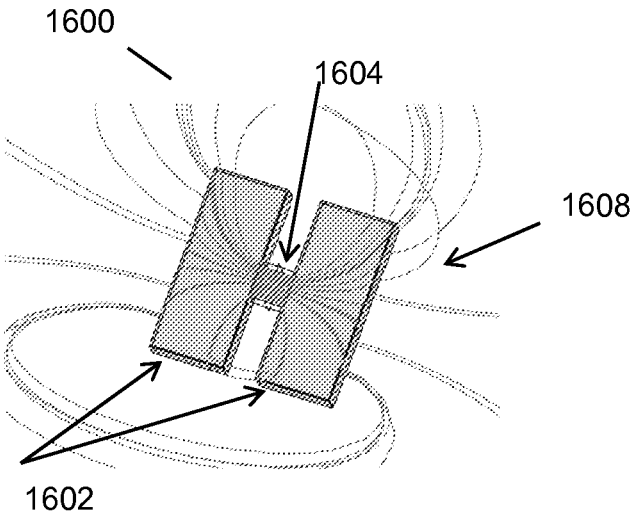
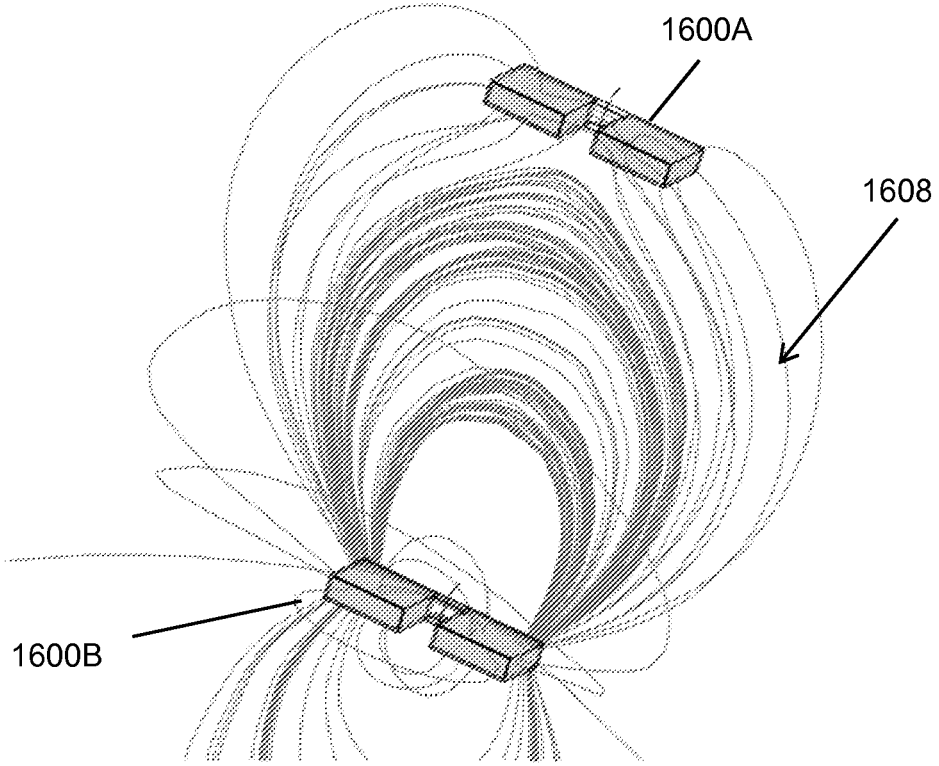


Fig. 15

Fig. 16



(a)



(b)

InductEV, Inc.
Exhibit 1002
Page 170

Fig. 17

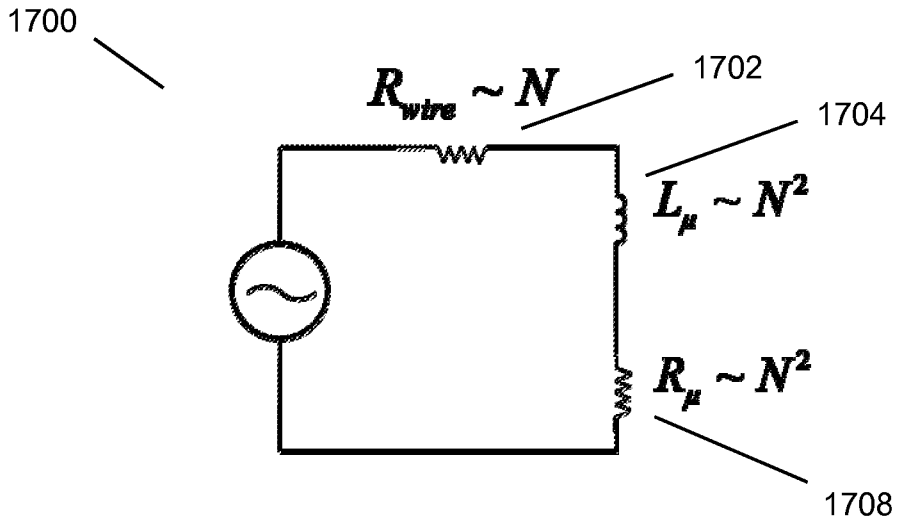


Fig. 18

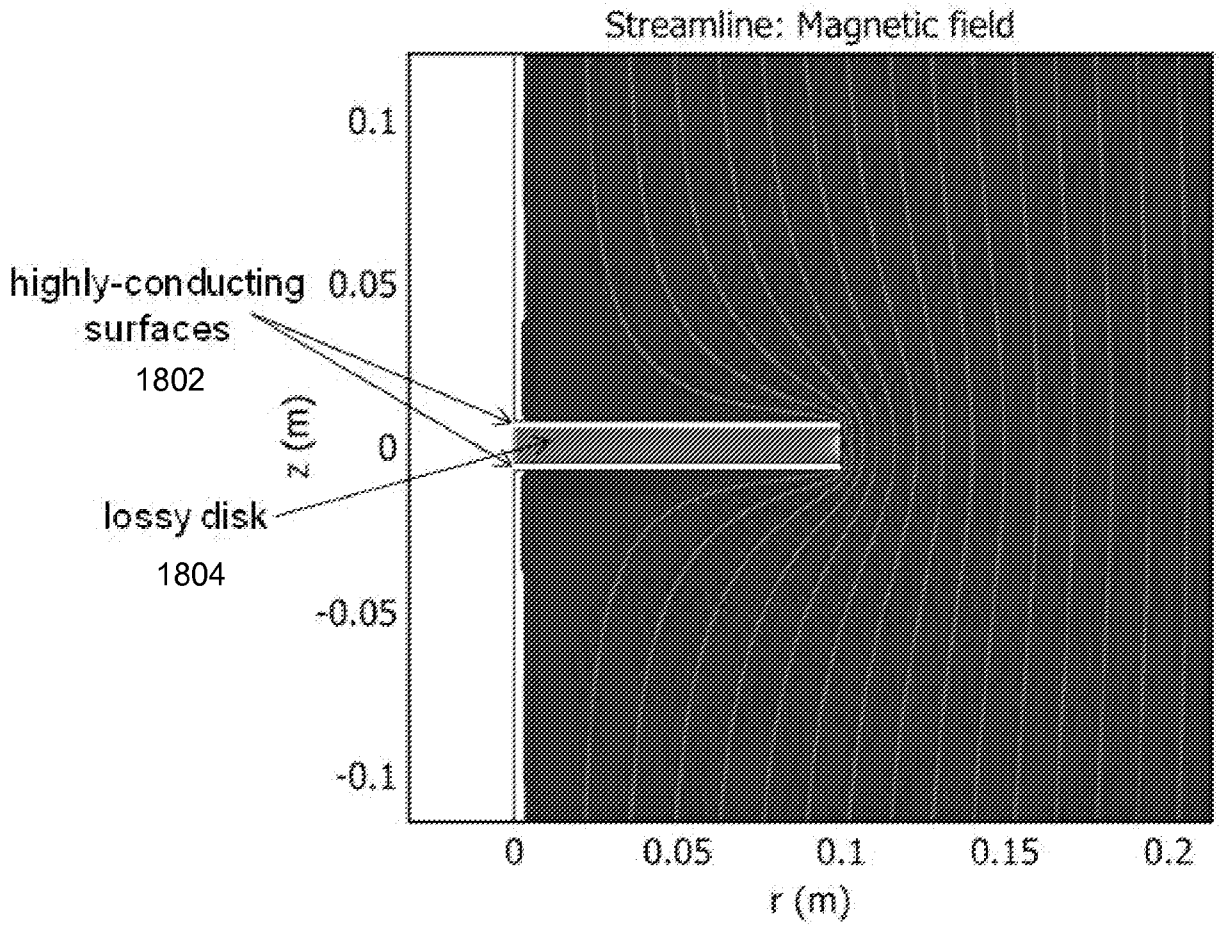

Streamline: Magnetic field
highly-conducting surfaces
1802
lossy disk
1804
z (m)
0.1
0.05
0
-0.05
-0.1
0
0.05
0.1
0.15
0.2
r (m)

Fig. 19

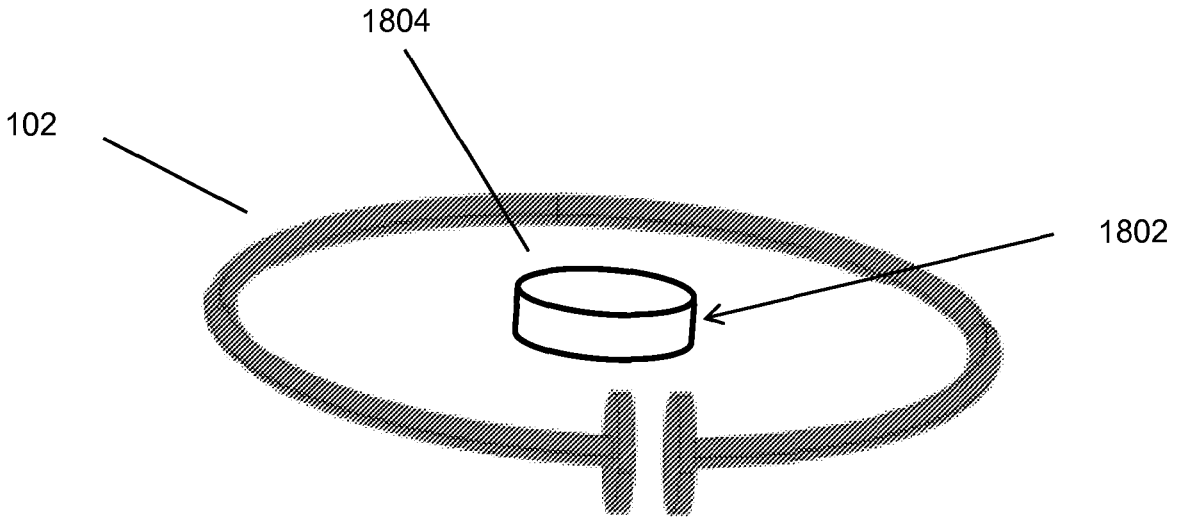


Fig. 20

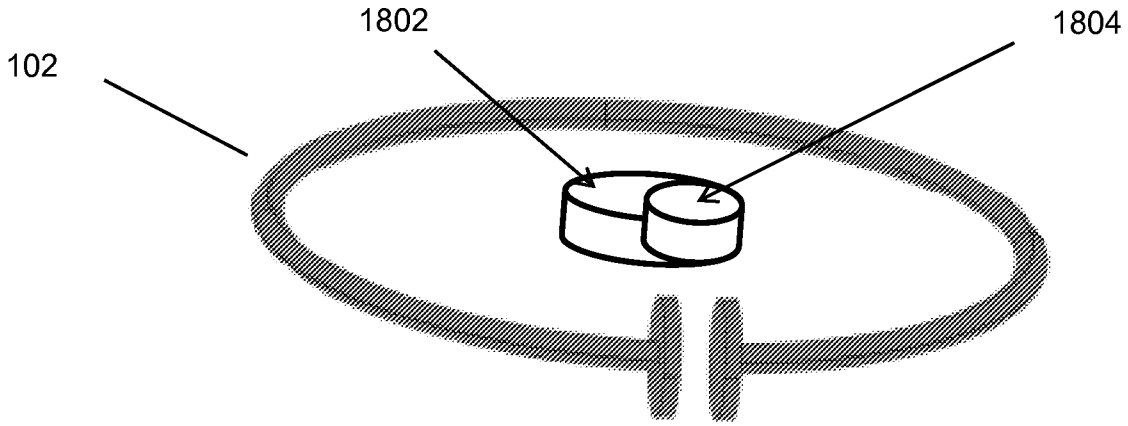


Fig. 21

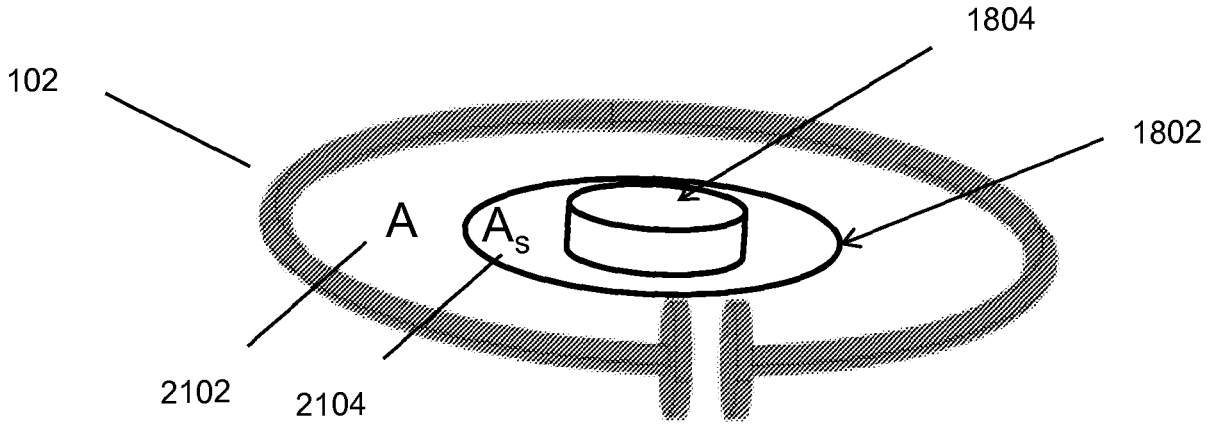


Fig. 22

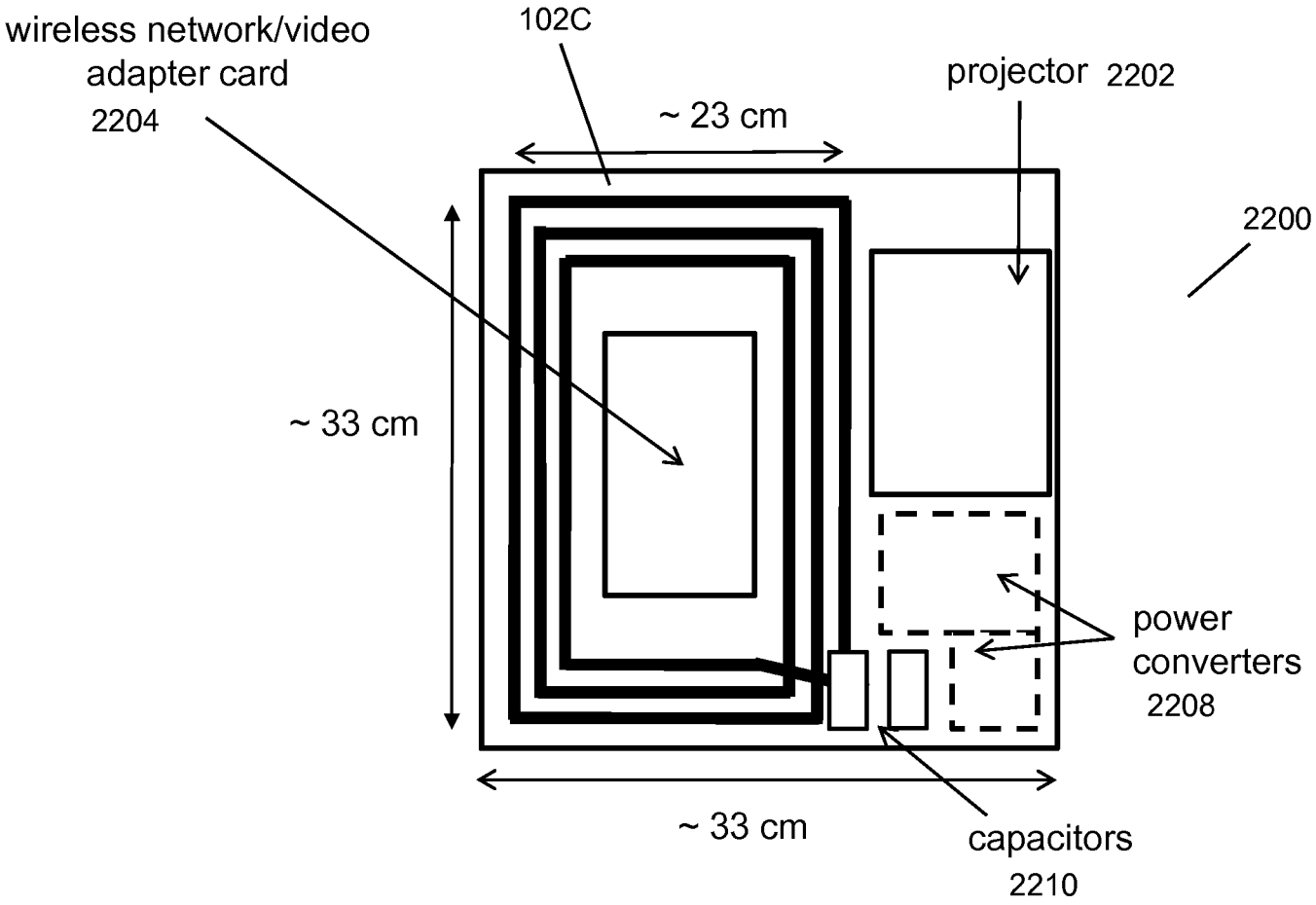
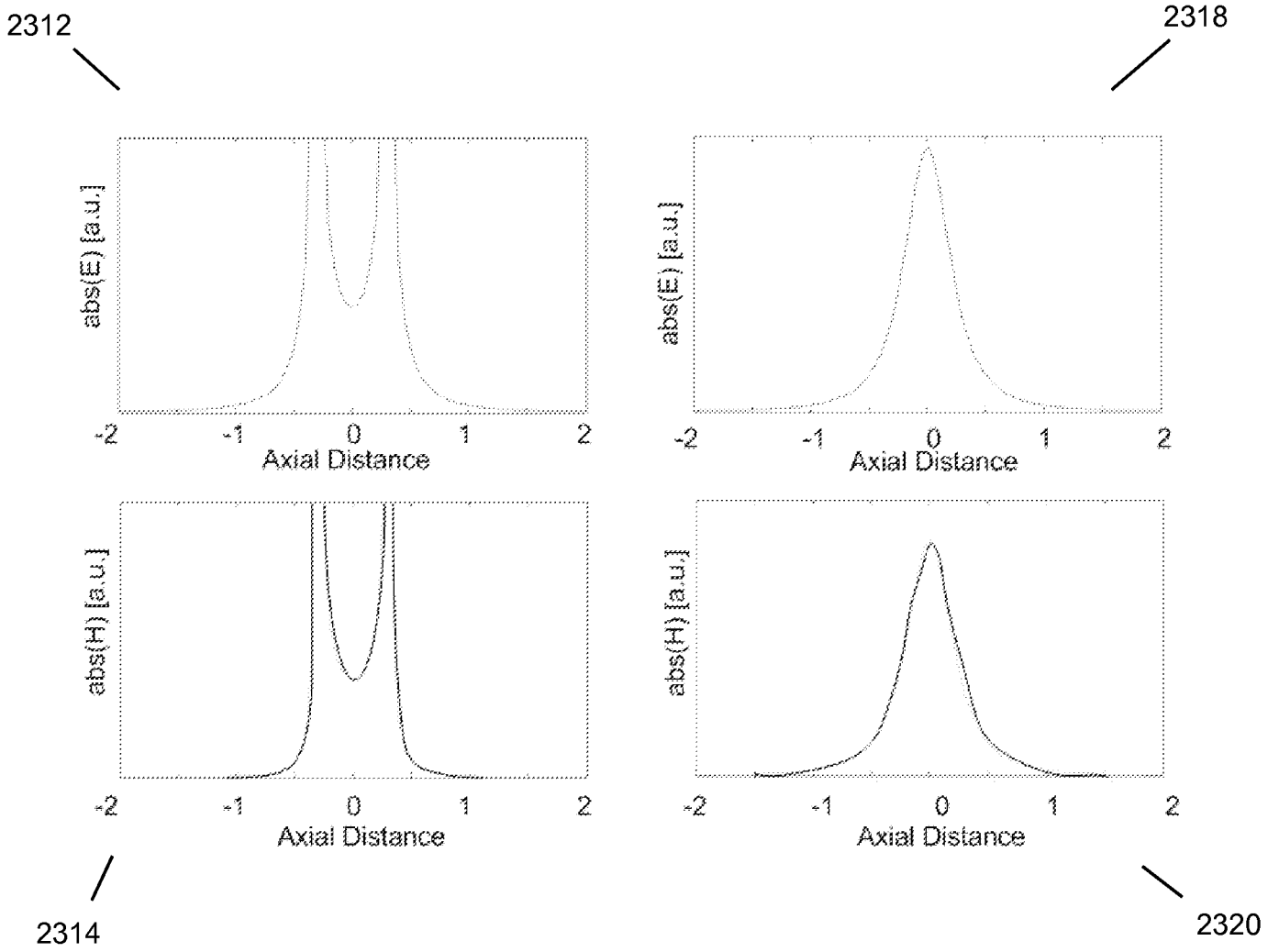
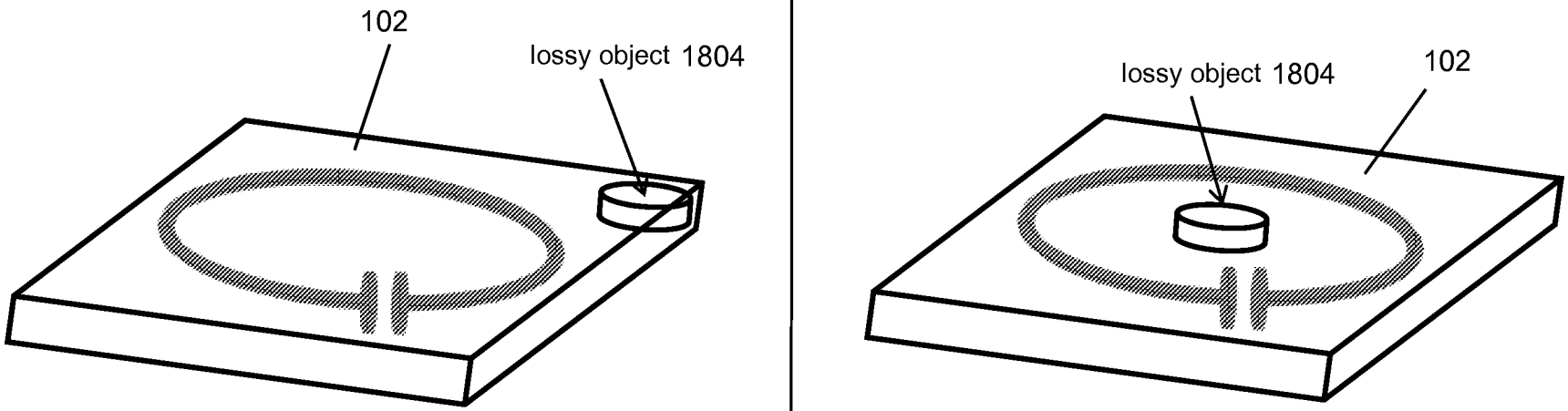

wireless network/video
adapter card
2204
102C
~ 23 cm
projector 2202
2200
~ 33 cm
power
converters
2208
~ 33 cm
capacitors
2210

Fig. 23



InductEV, Inc.
Exhibit 1002
Page 177

Fig. 24



(a)

(b)

Fig. 25

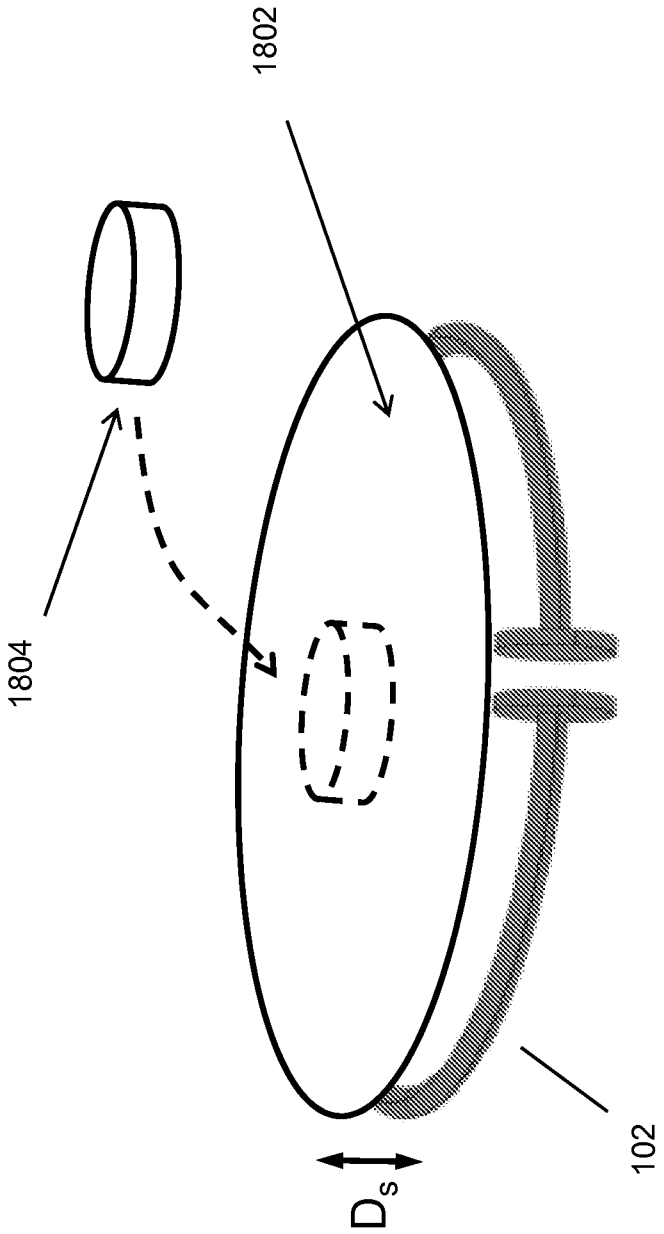


Fig. 26

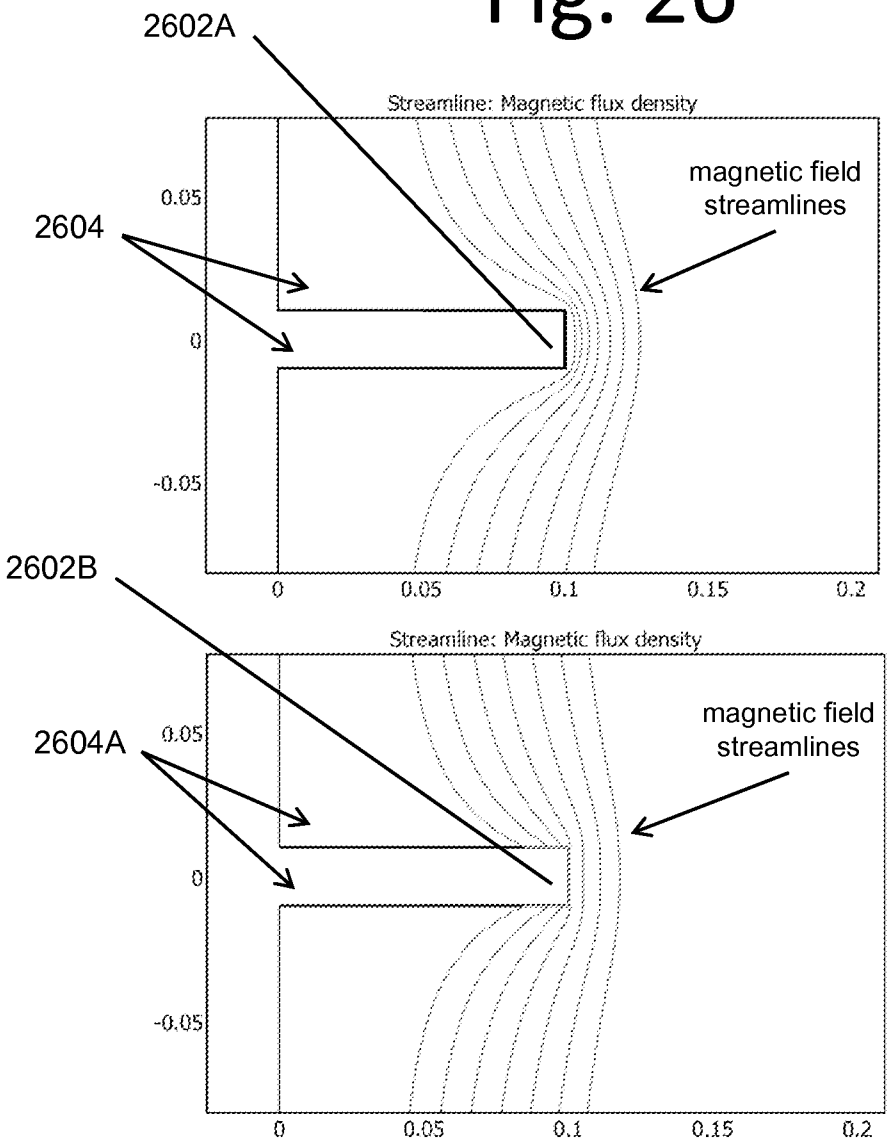

2602A
Streamline: Magnetic flux density
magnetic field streamlines
2604
0.05
0
-0.05
0
0.05
0.1
0.15
0.2
(a)
2602B
Streamline: Magnetic flux density
magnetic field streamlines
2604A
0.05
0
-0.05
0
0.05
0.1
0.15
0.2
(b)

Fig. 27

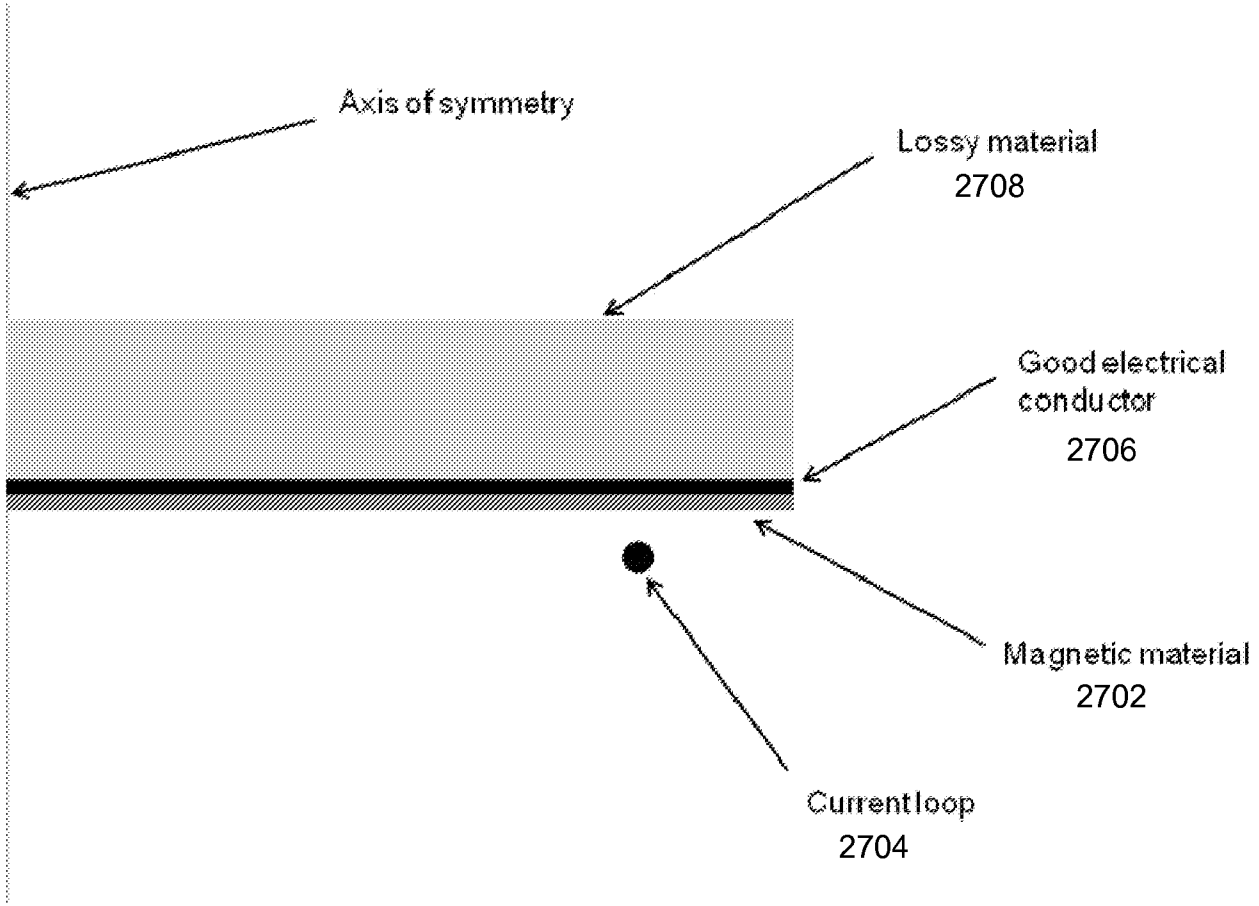

Axis of symmetry
Lossy material
2708
Good electrical conductor
2706
Magnetic material
2702
Current loop
2704

Fig. 28

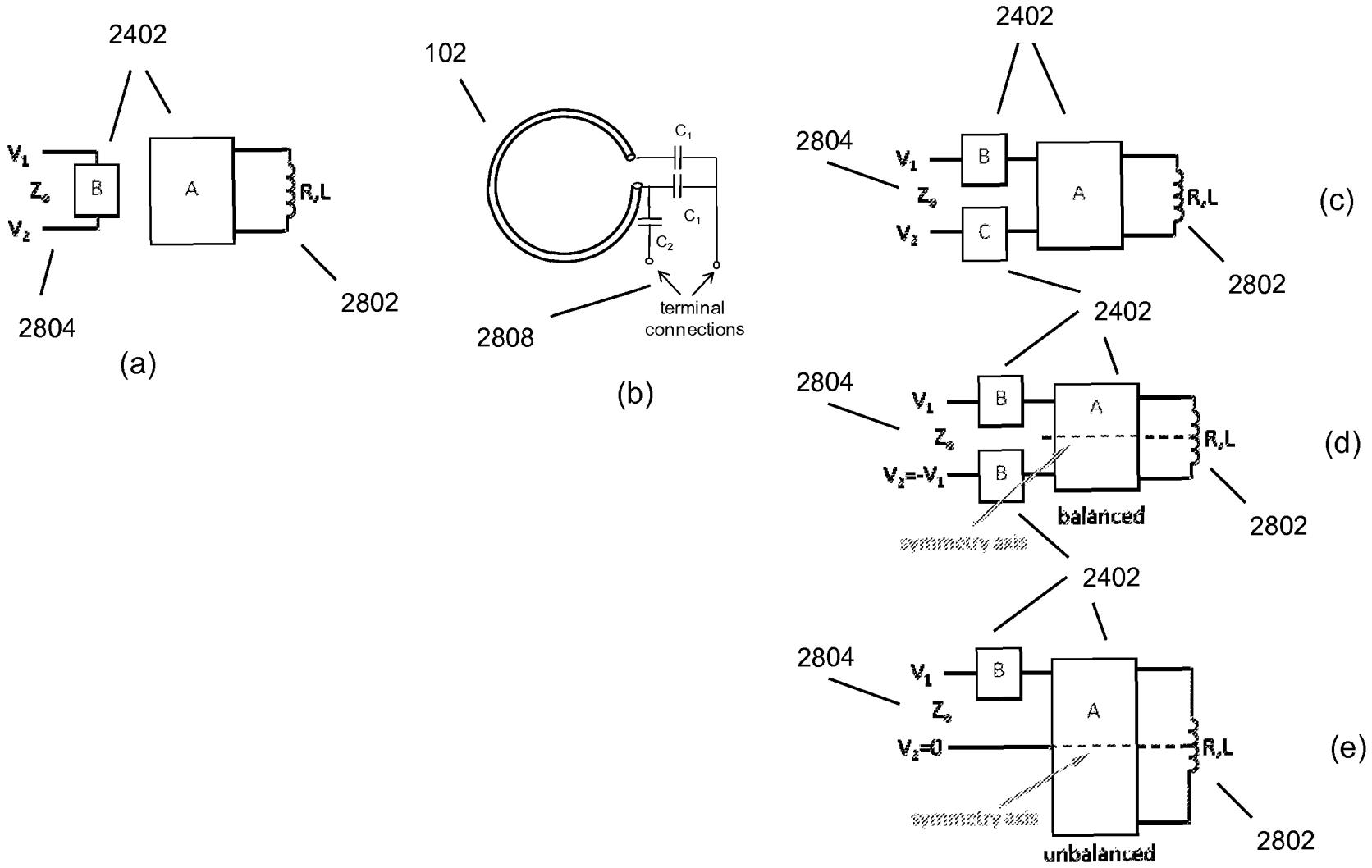

2402
V_1
Z_o
V_2
B
A
R,L
2804
2802
(a)
102
C_1
C_1
C_2
terminal connections
2808
(b)
2402
2804
V_1
Z_o
V_2
B
C
A
R,L
2802
(c)
2402
2804
V_1
Z_o
$V_2=-V_1$
B
B
A
R,L
balanced
symmetry axis
2802
(d)
2402
2804
V_1
Z_o
$V_2=0$
B
A
R,L
symmetry axis
unbalanced
2802
(e)

Fig. 29

(a)



(b)



(c)

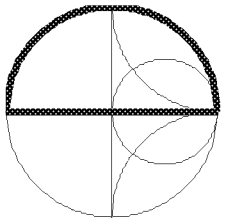
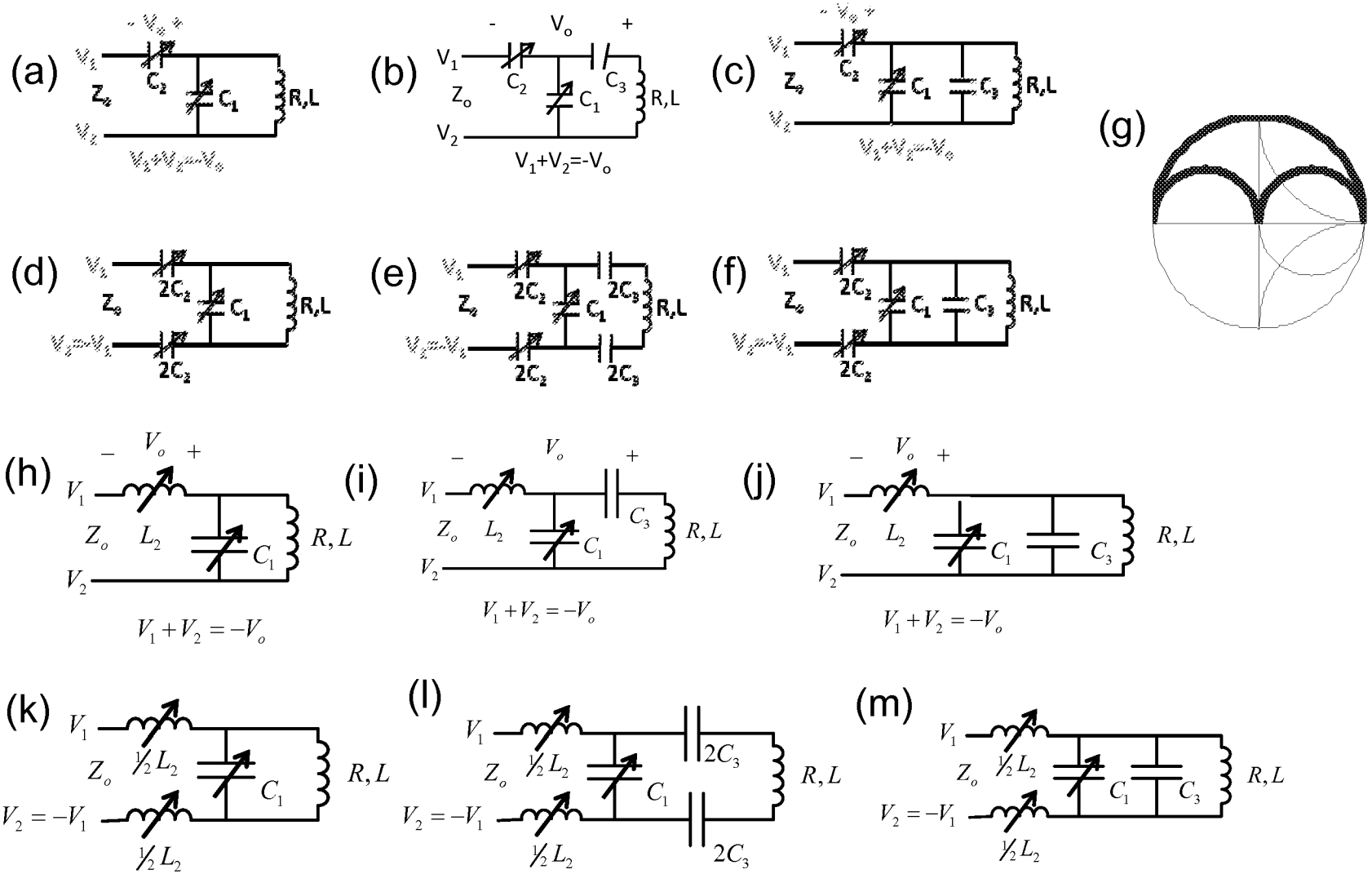


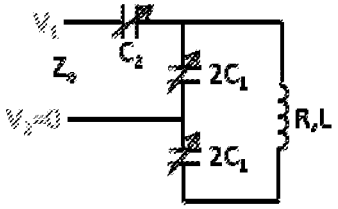
Fig. 30



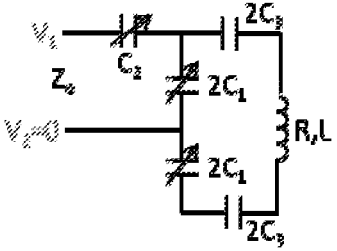
InductEV, Inc.
Exhibit 1002
Page 184

Fig. 31

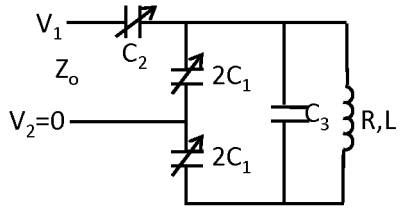
(a)



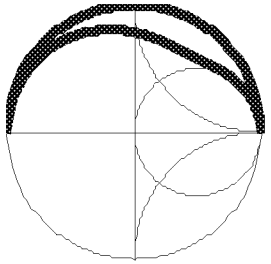
(b)



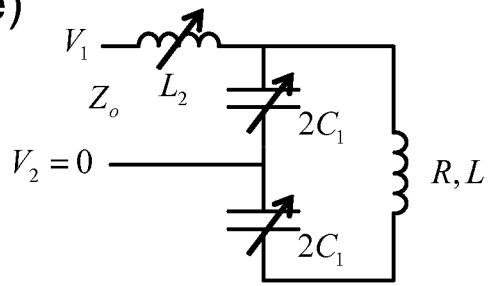
(c)



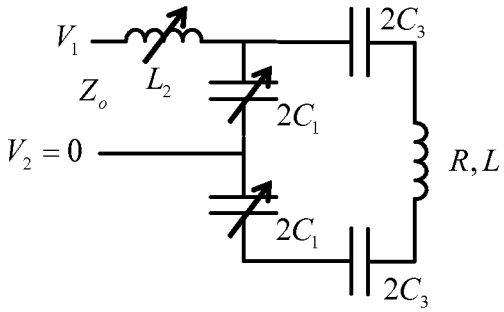
(d)



(e)



(f)



(g)

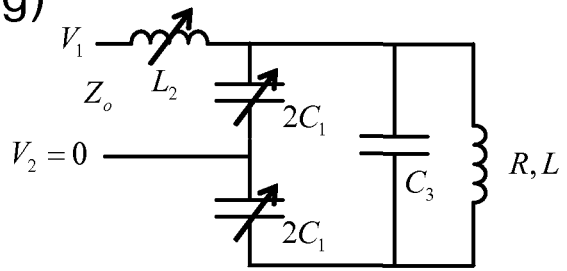
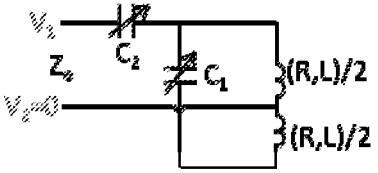
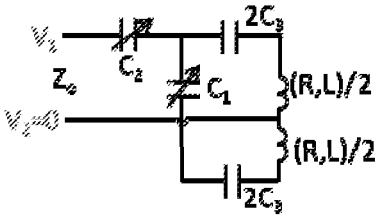


Fig. 32

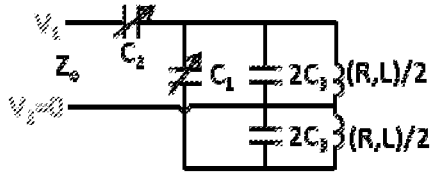
(a)



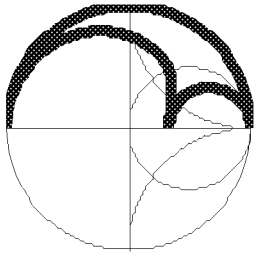
(b)



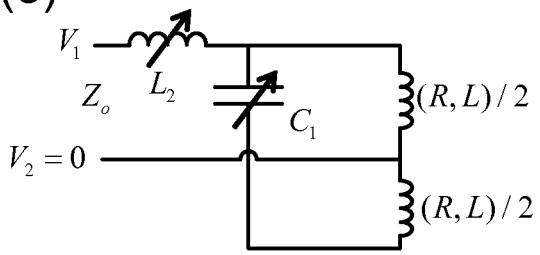
(c)



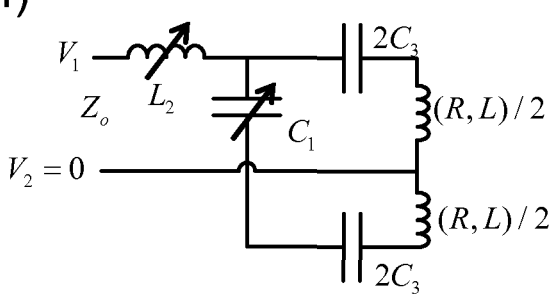
(d)



(e)



(f)



(g)

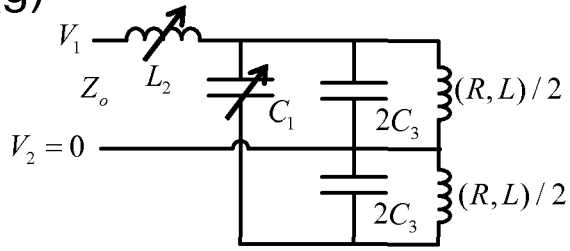
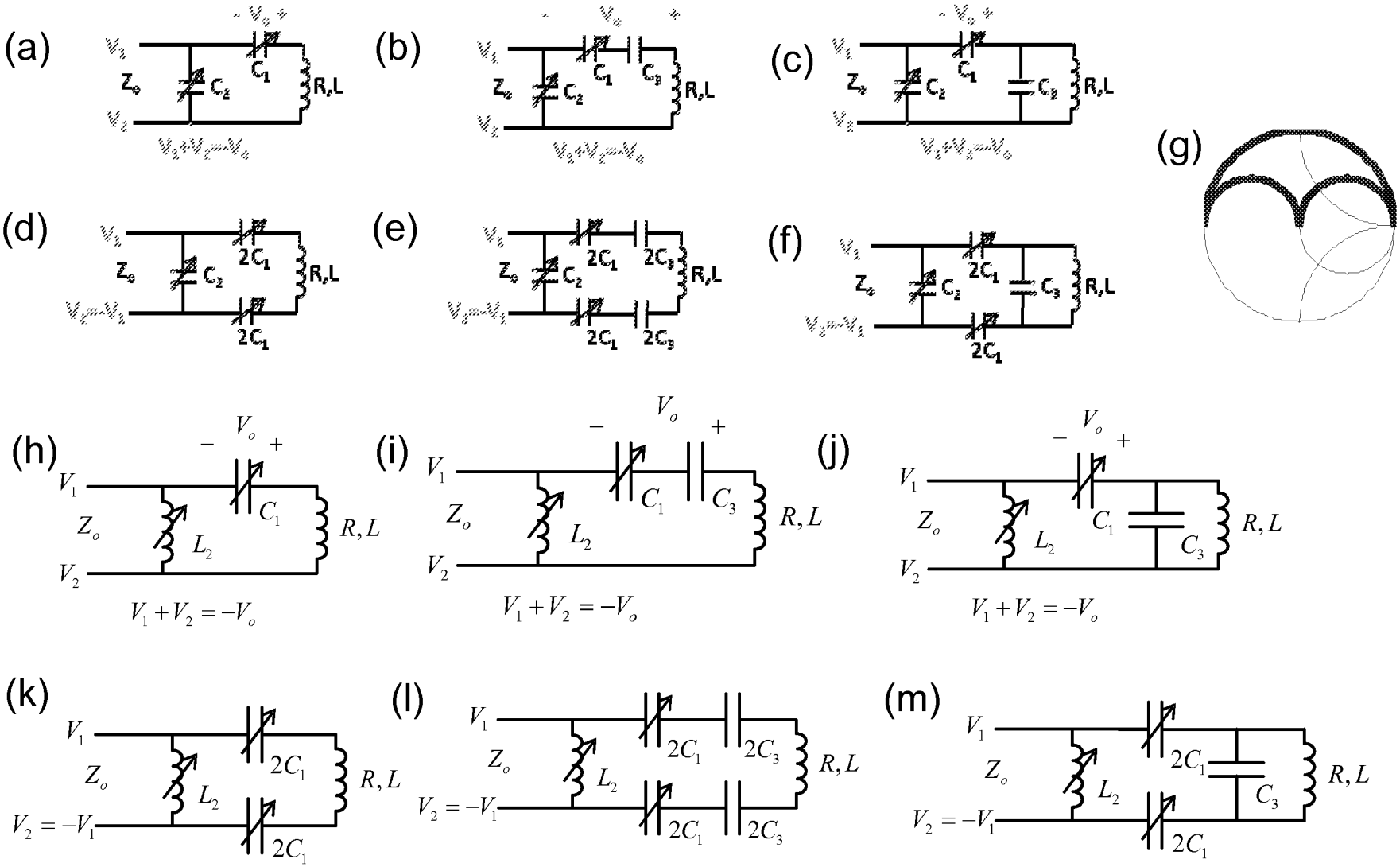
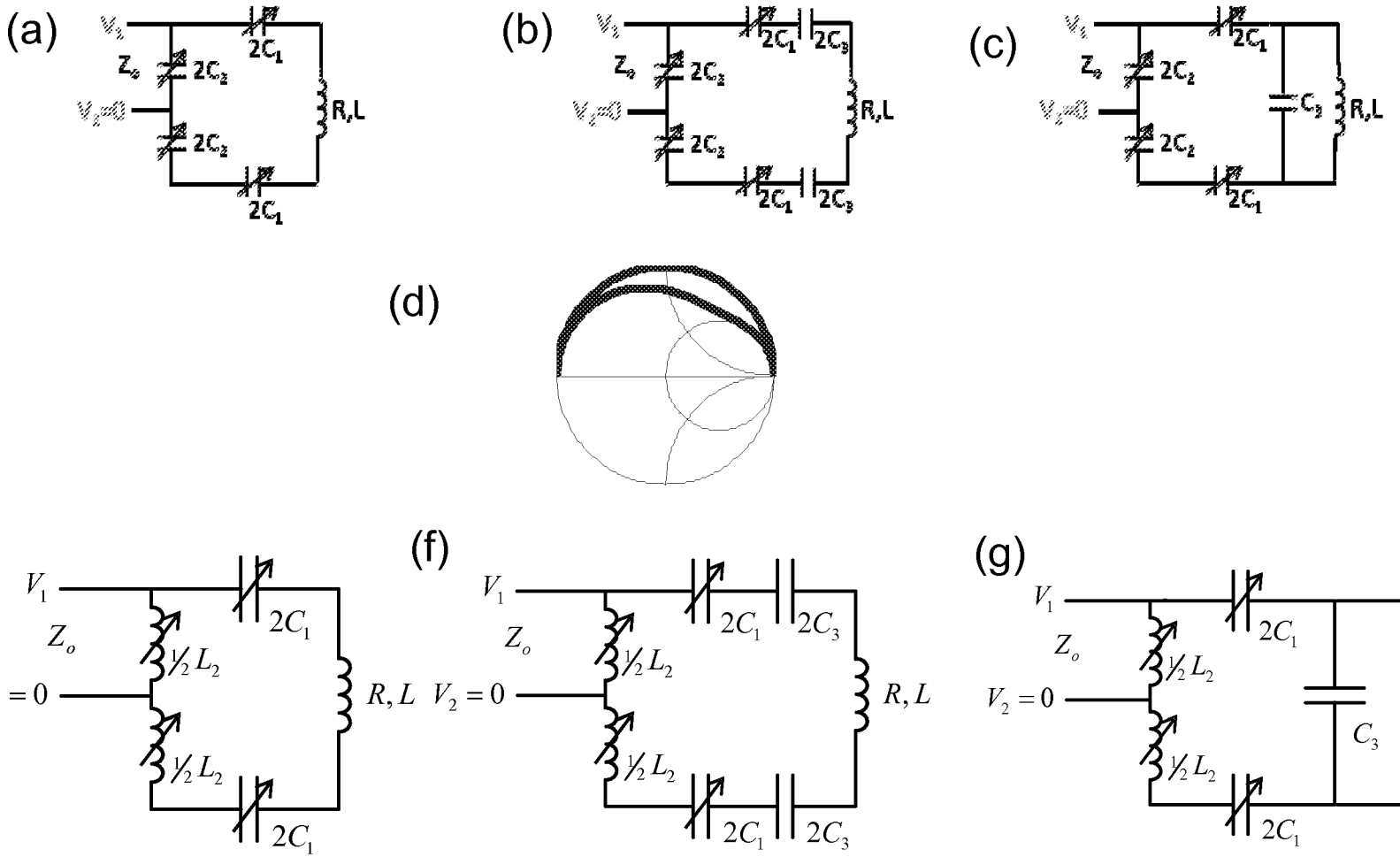


Fig. 33



InductEV, Inc.
Exhibit 1002
Page 187

Fig. 34



InductEV, Inc.
Exhibit 1002
Page 188

Fig. 35

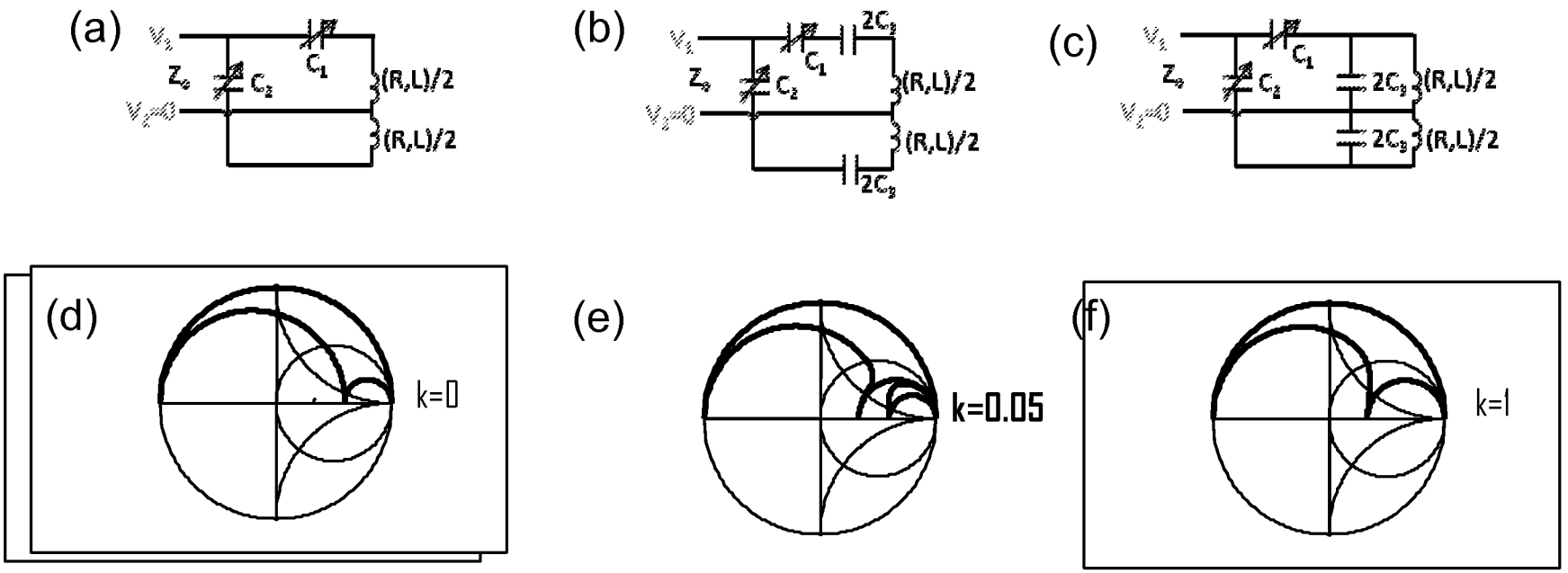
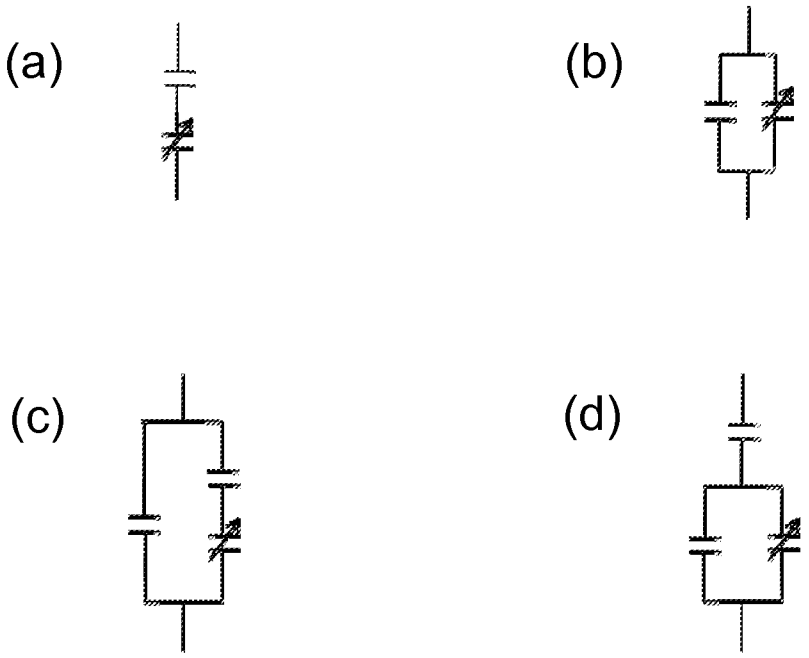


Fig. 36



InductEV, Inc.
Exhibit 1002
Page 190

Fig. 37

(a)



(b)

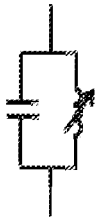


Fig. 38

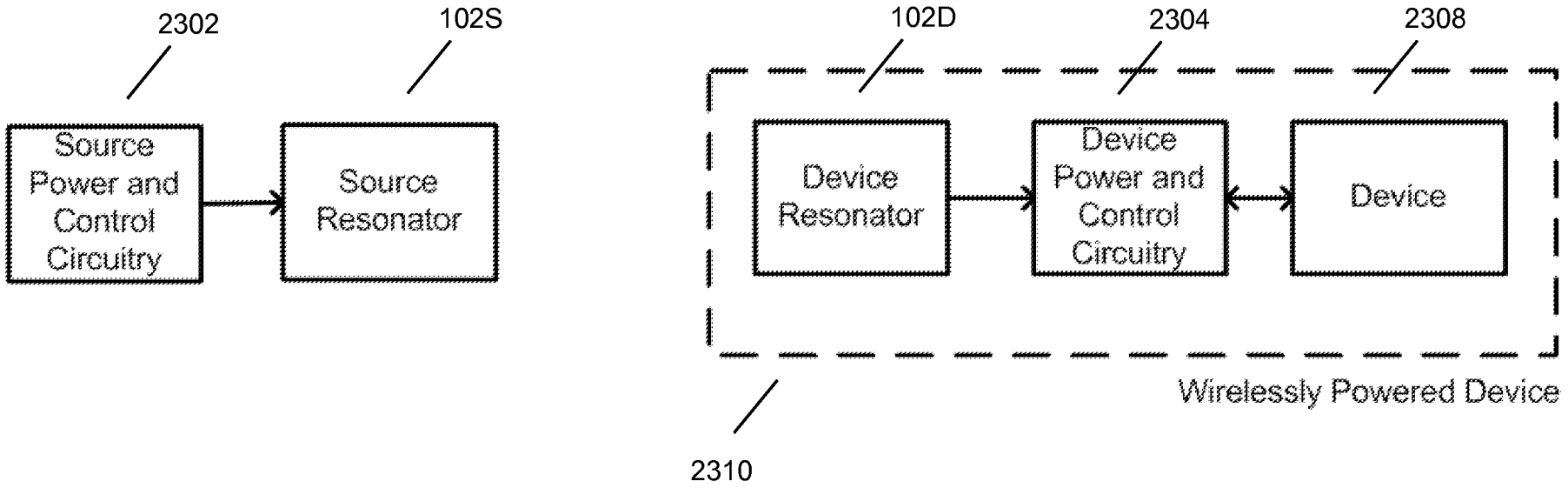

2302
102S
Source Power and Control Circuitry
Source Resonator
102D
2304
2308
Device Resonator
Device Power and Control Circuitry
Device
Wirelessly Powered Device
2310

Fig. 39

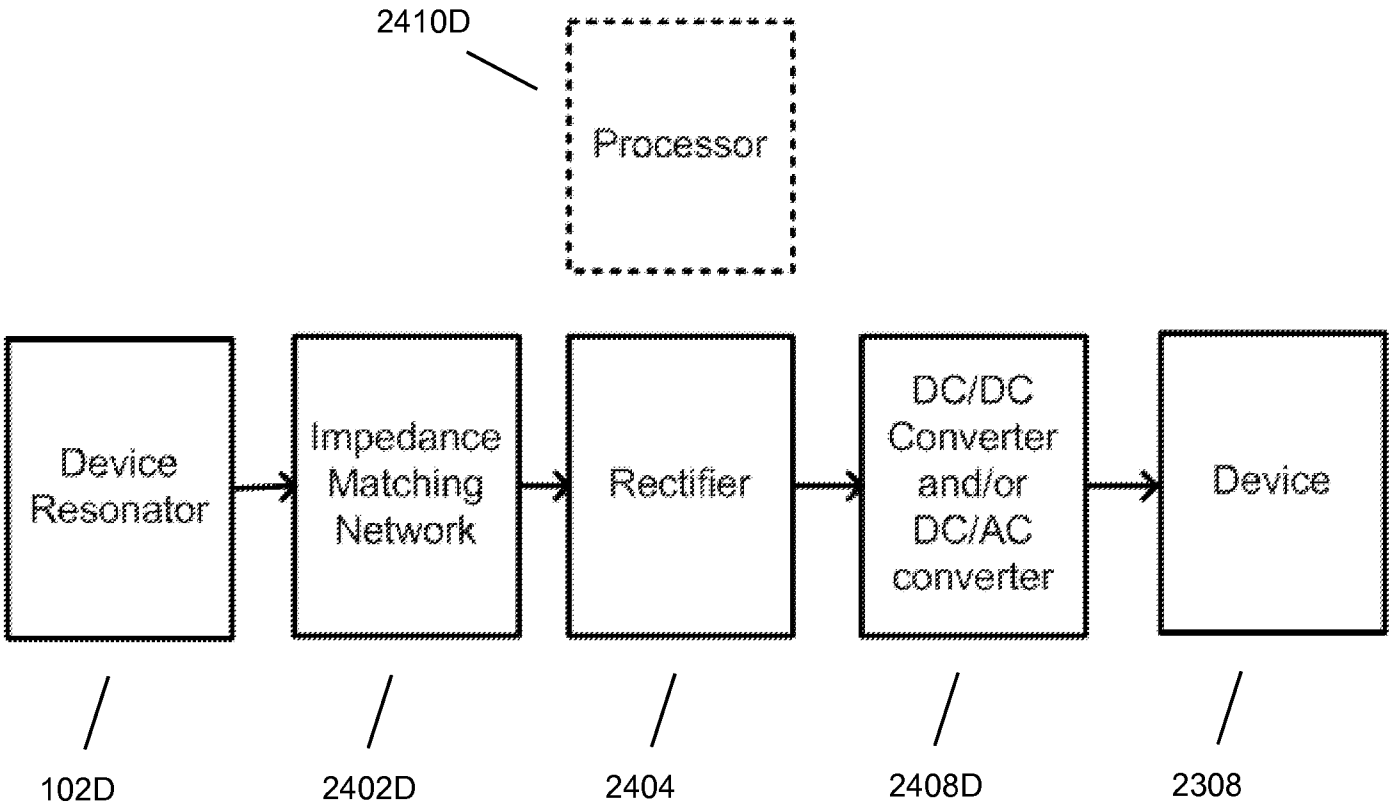

2410D
Processor
Device Resonator
Impedance Matching Network
Rectifier
DC/DC Converter and/or DC/AC converter
Device
102D
2402D
2404
2408D
2308

Fig. 40

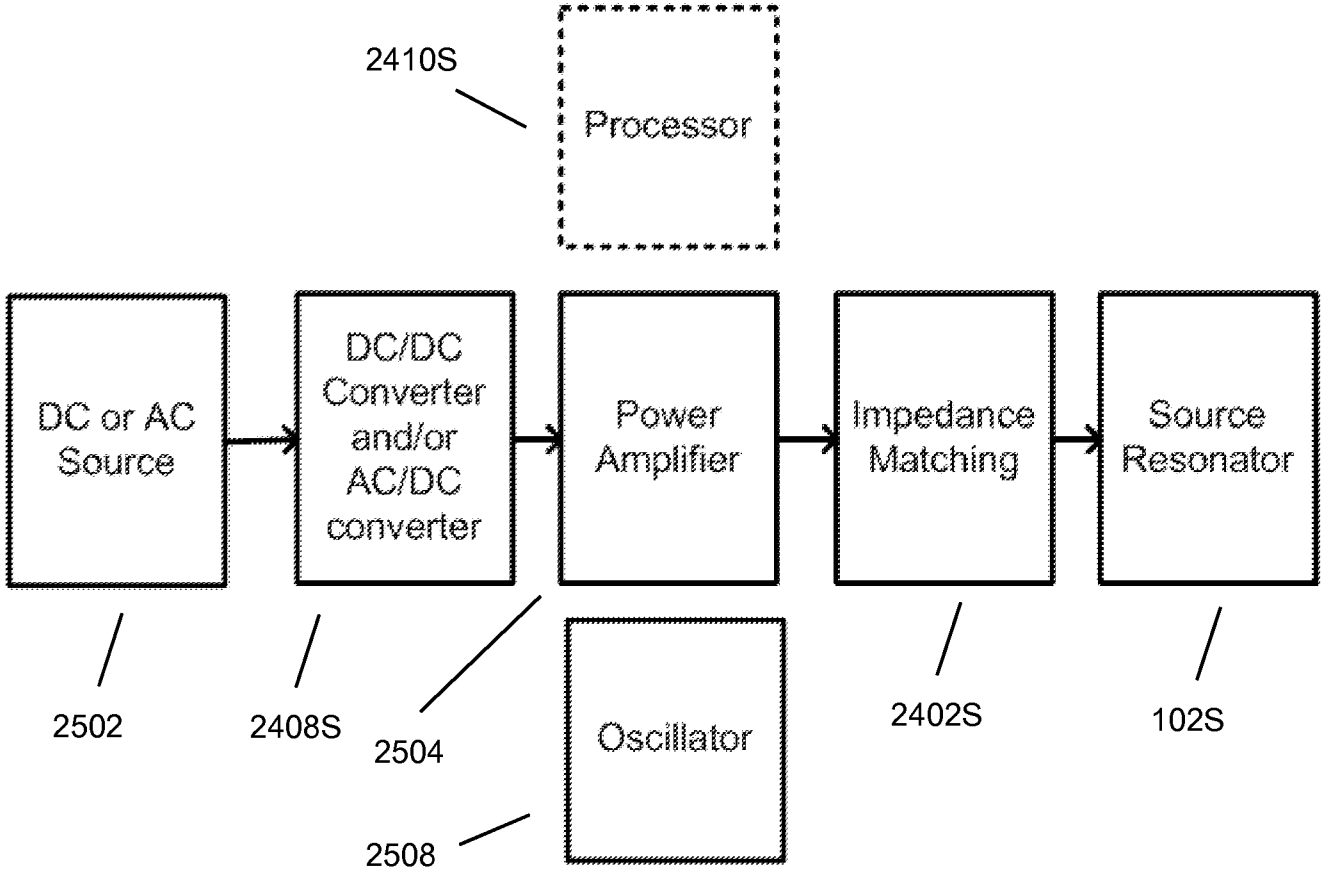

2410S
Processor
DC or AC Source
DC/DC Converter and/or AC/DC converter
Power Amplifier
Impedance Matching
Source Resonator
2502
2408S
2504
Oscillator
2402S
102S
2508

Fig. 41

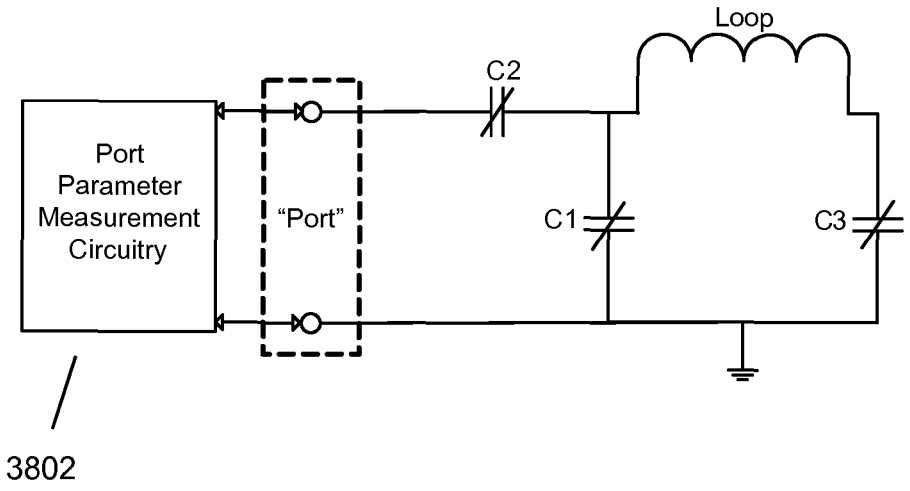

Loop
C2
Port
Parameter
Measurement
Circuitry
"Port"
C1
C3
3802

Fig. 42

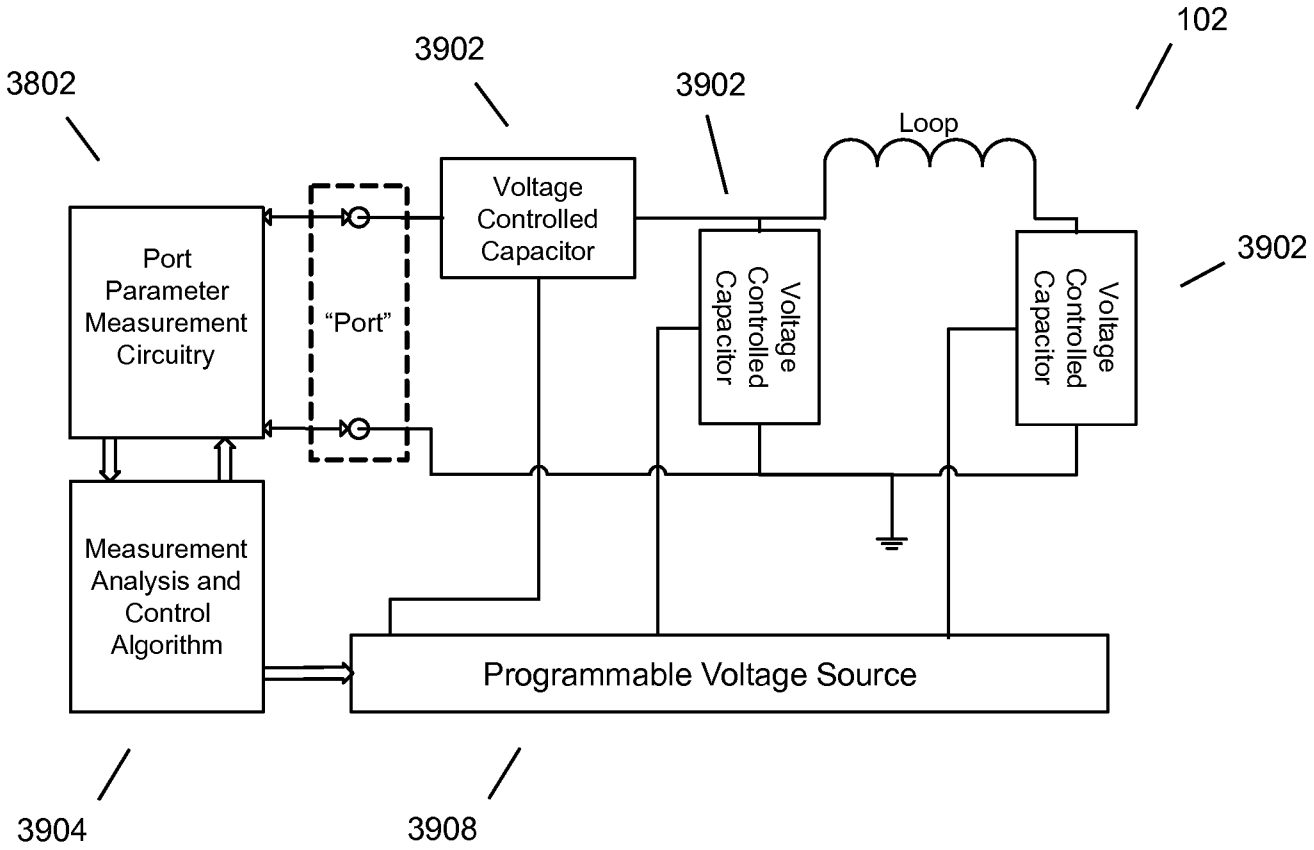

102
3902
3802
3902
Loop
3902
Voltage Controlled Capacitor
Port Parameter Measurement Circuitry
"Port"
Voltage Controlled Capacitor
Voltage Controlled Capacitor
Measurement Analysis and Control Algorithm
Programmable Voltage Source
3904
3908

Fig. 43

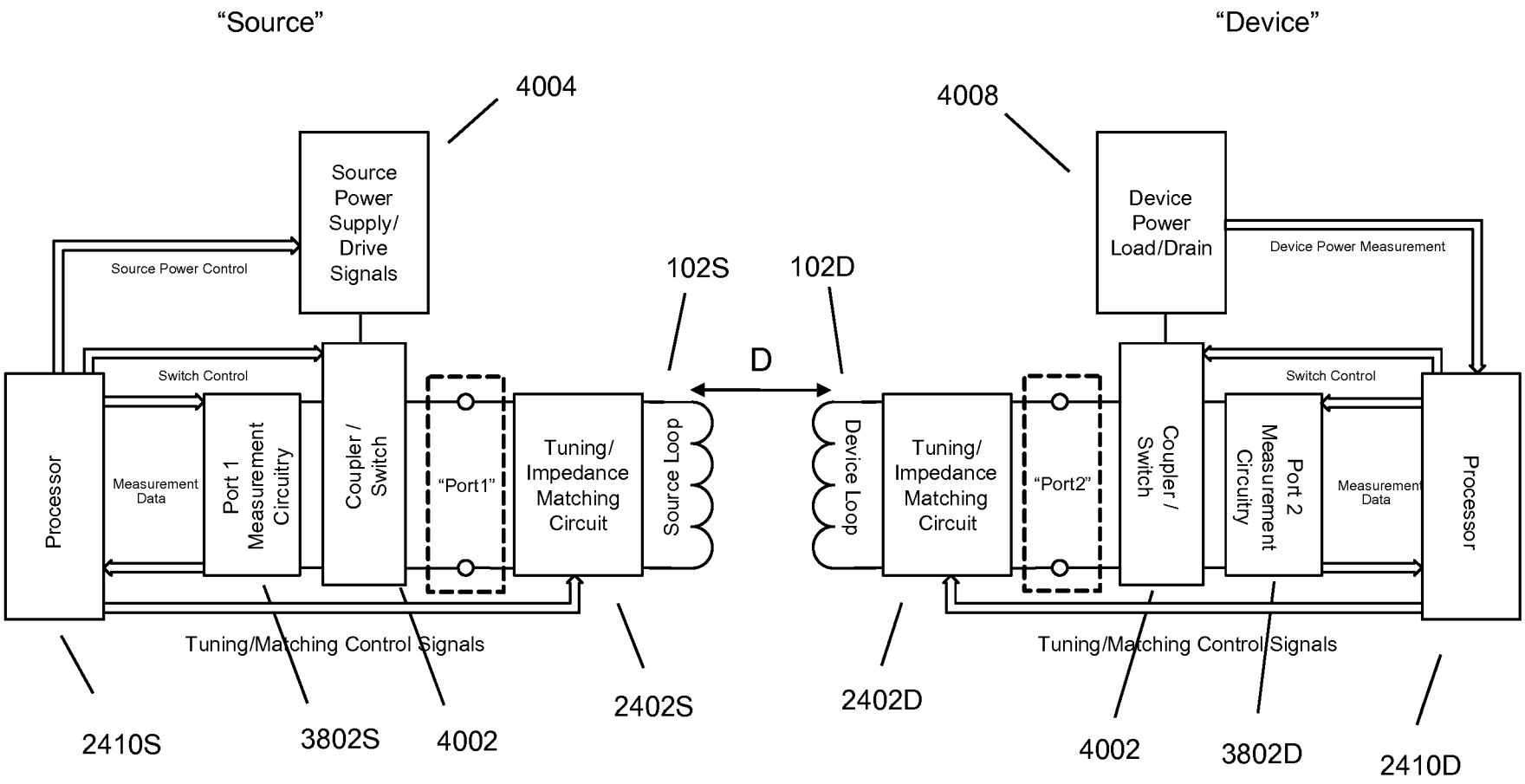

"Source"
"Device"
4004
4008
Source Power Supply/ Drive Signals
Device Power Load/Drain
Source Power Control
Device Power Measurement
102S
102D
D
Switch Control
Switch Control
Processor
Measurement Data
Port 1 Measurement Circuitry
Coupler / Switch
"Port1"
Tuning/ Impedance Matching Circuit
Source Loop
Device Loop
Tuning/ Impedance Matching Circuit
"Port2"
Coupler / Switch
Port 2 Measurement Circuitry
Measurement Data
Processor
Tuning/Matching Control Signals
Tuning/Matching Control Signals
2410S
3802S
4002
2402S
2402D
4002
3802D
2410D

Fig. 44

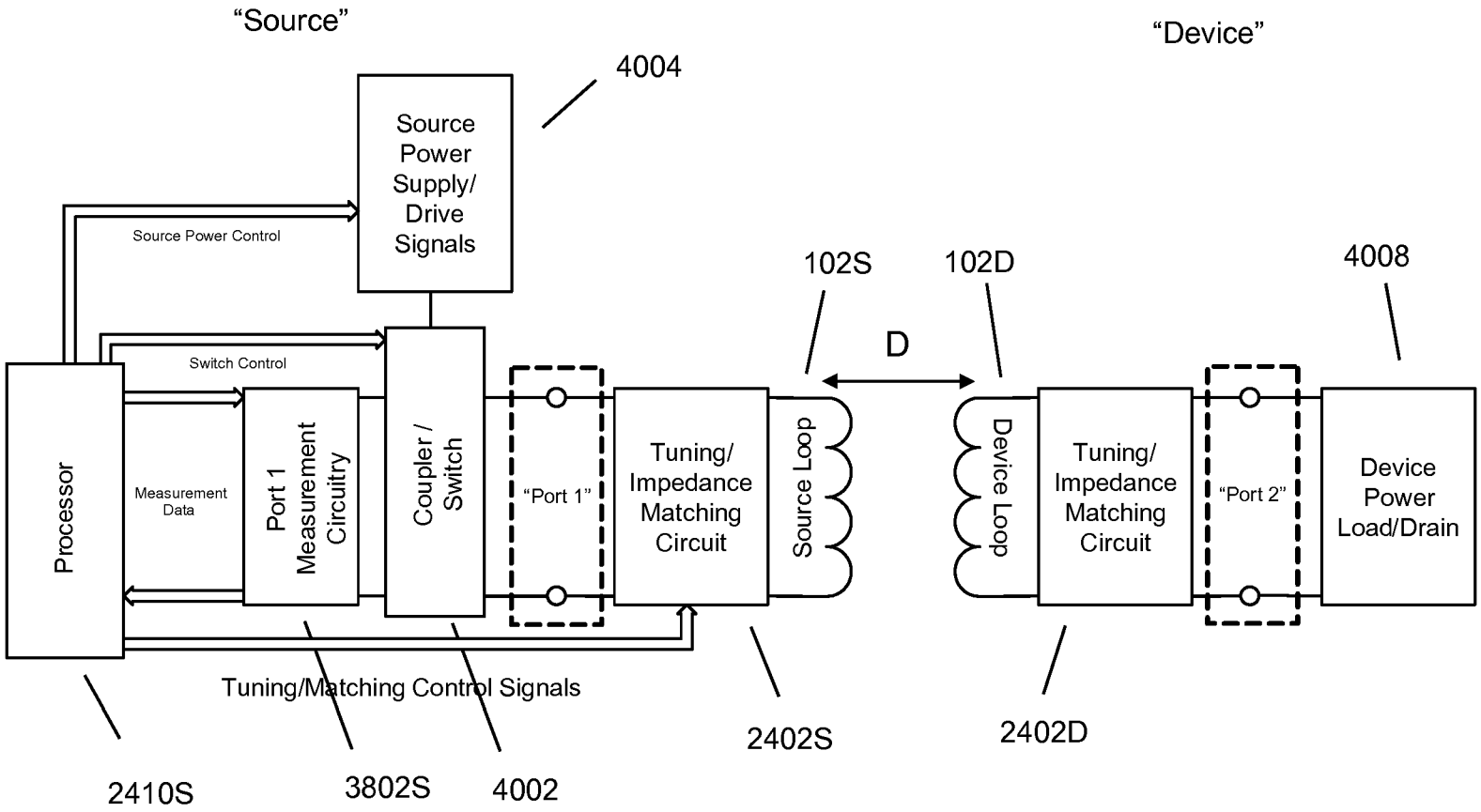

"Source"
"Device"
4004
Source Power Supply/ Drive Signals
Source Power Control
Switch Control
102S
102D
D
4008
Processor
Measurement Data
Port 1 Measurement Circuitry
Coupler / Switch
"Port 1"
Tuning/ Impedance Matching Circuit
Source Loop
Device Loop
Tuning/ Impedance Matching Circuit
"Port 2"
Device Power Load/Drain
Tuning/Matching Control Signals
2410S
3802S
4002
2402S
2402D

Fig. 45

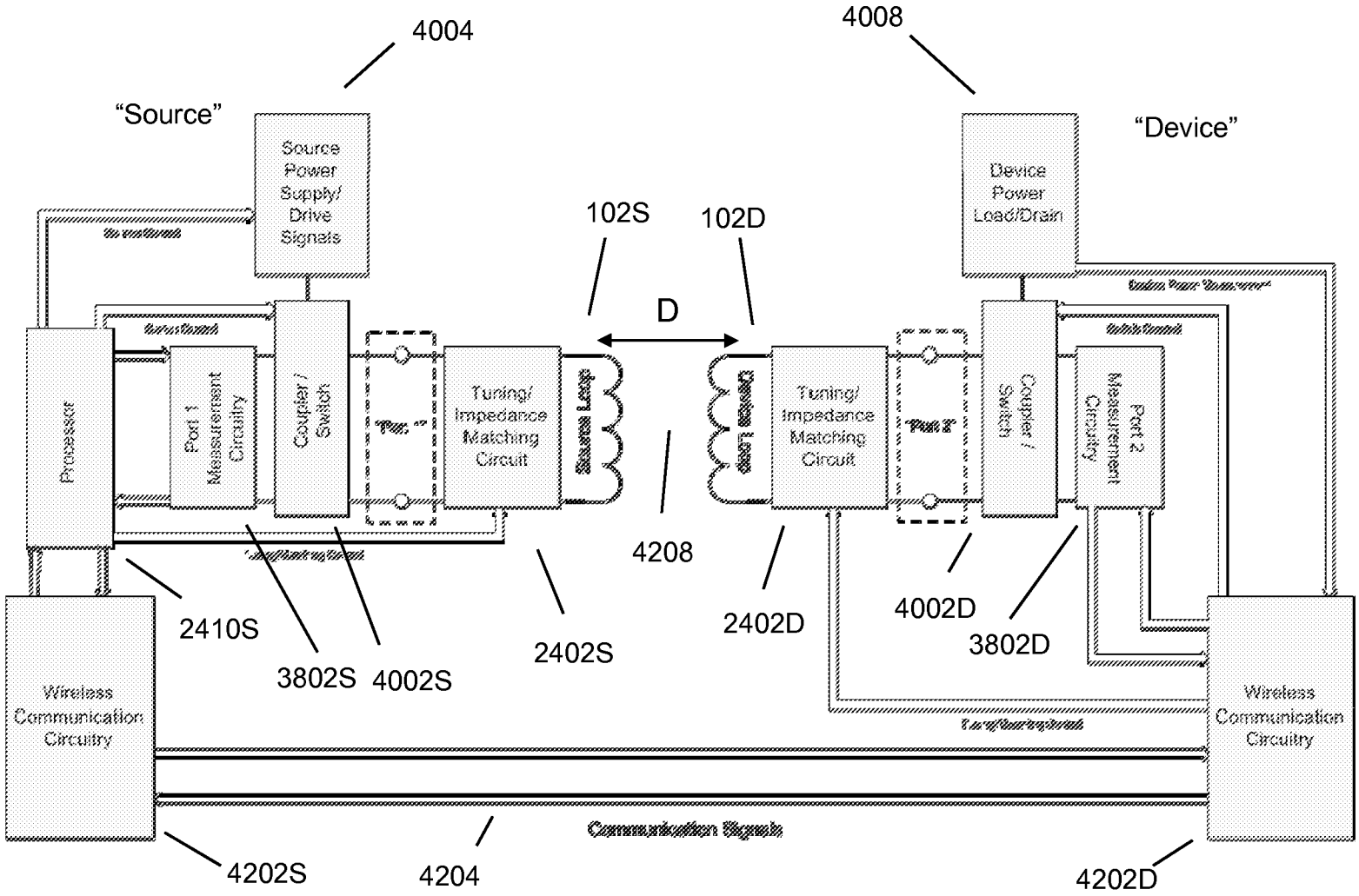

4004
4008
"Source"
"Device"
Source Power Supply/ Drive Signals
Device Power Load/Drain
102S
102D
D
Processor
Port 1 Measurement Circuitry
Coupler / Switch
Tuning/ Impedance Matching Circuit
Source Loop
Device Loop
Tuning/ Impedance Matching Circuit
Coupler / Switch
Port 2 Measurement Circuitry
4208
2410S
3802S
4002S
2402S
2402D
4002D
3802D
Wireless Communication Circuitry
Wireless Communication Circuitry
Communication Signals
4202S
4204
4202D

Fig. 46

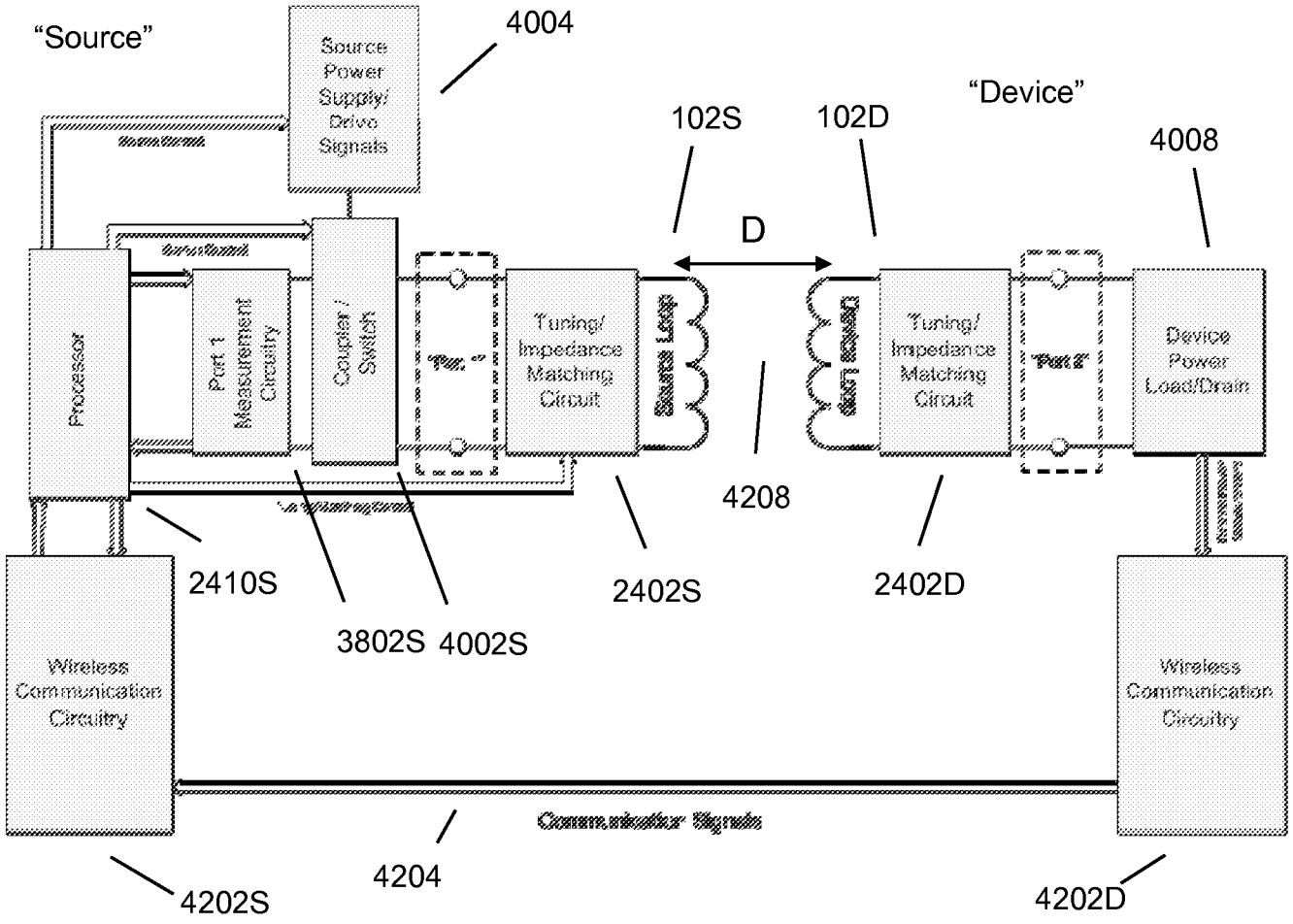
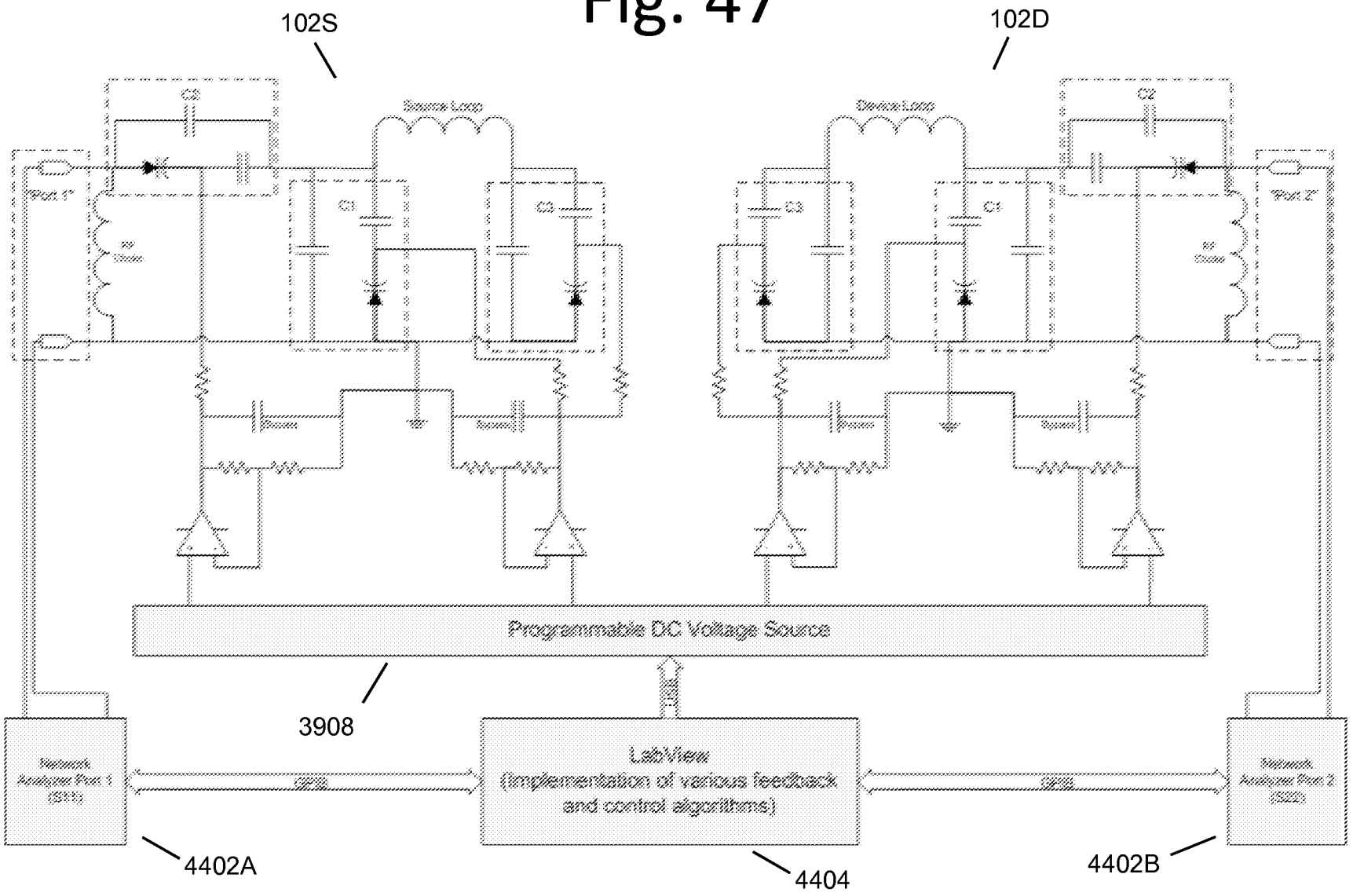
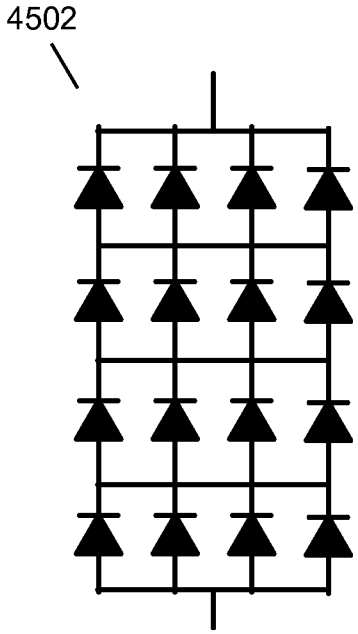

"Source"
4004
Source Power Supply/ Drive Signals
102S
102D
"Device"
4008
D
Processor
Port 1 Measurement Circuitry
Coupler / Switch
Tuning/ Impedance Matching Circuit
Source Loop
Device Loop
Tuning/ Impedance Matching Circuit
Device Power Load/Drain
4208
2410S
3802S
4002S
2402S
2402D
Wireless Communication Circuitry
Wireless Communication Circuitry
Communication Signals
4204
4202S
4202D

Fig. 47



InductEV, Inc.
Exhibit 1002
Page 201

Fig. 48



InductEV, Inc.
Exhibit 1002
Page 202

Fig. 49

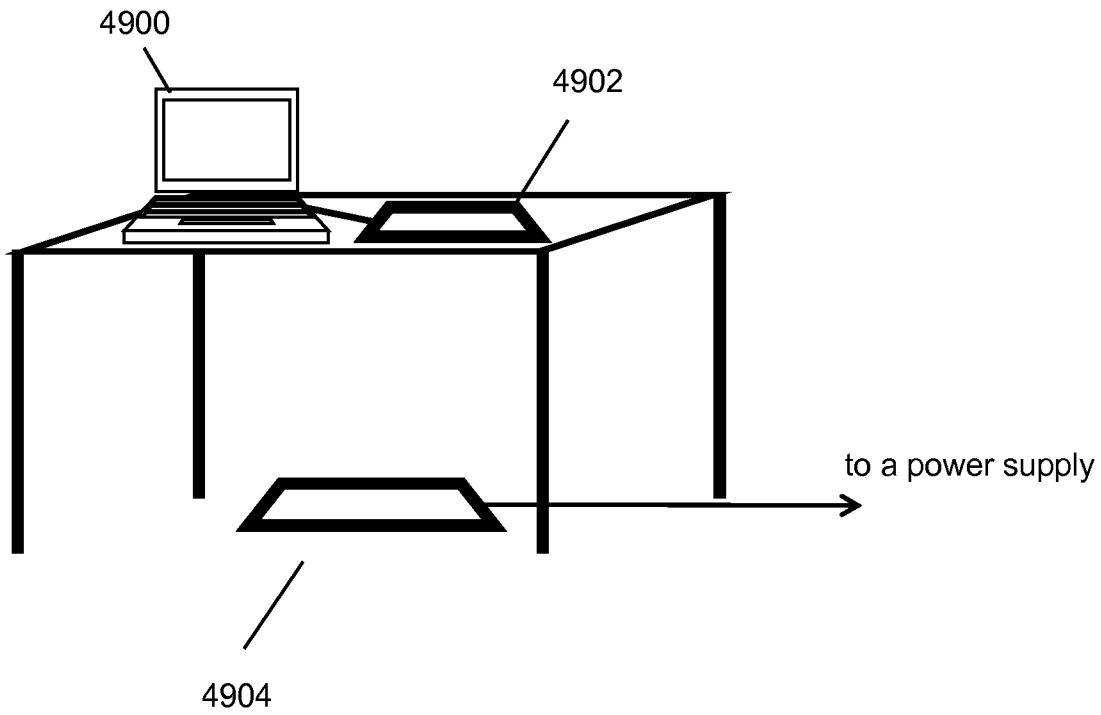


Fig. 50

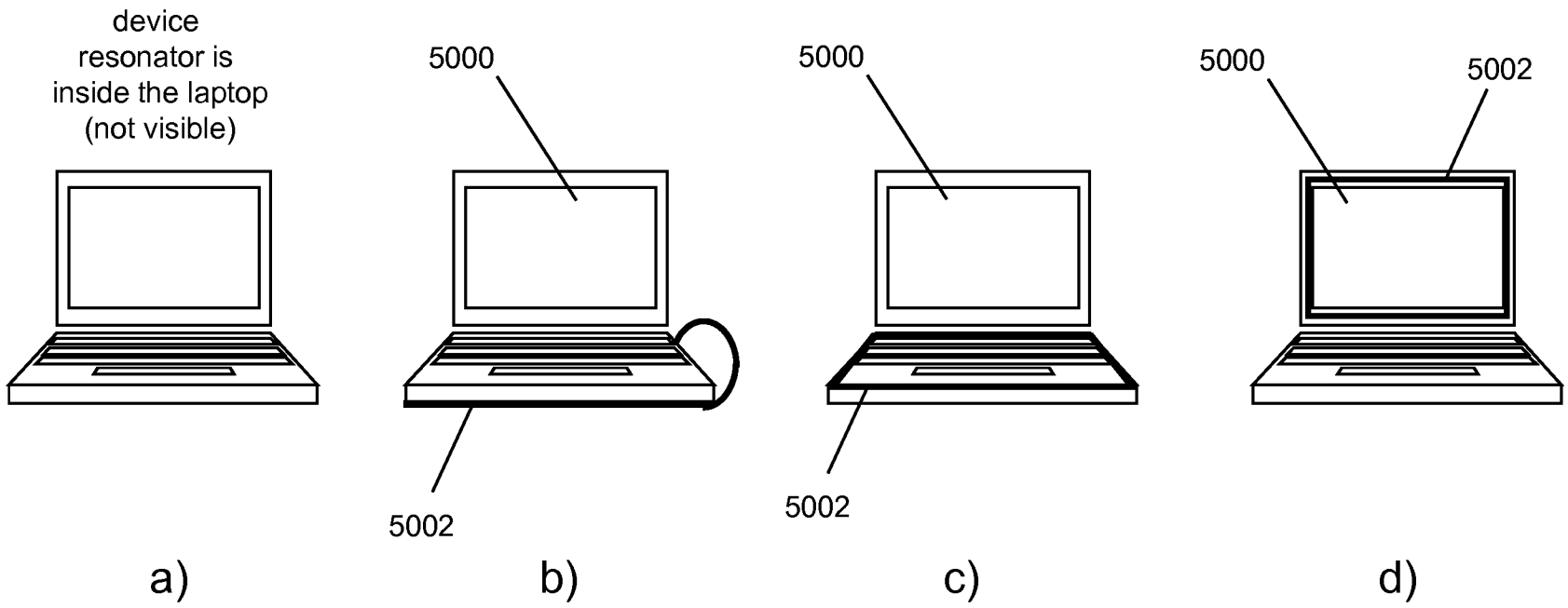
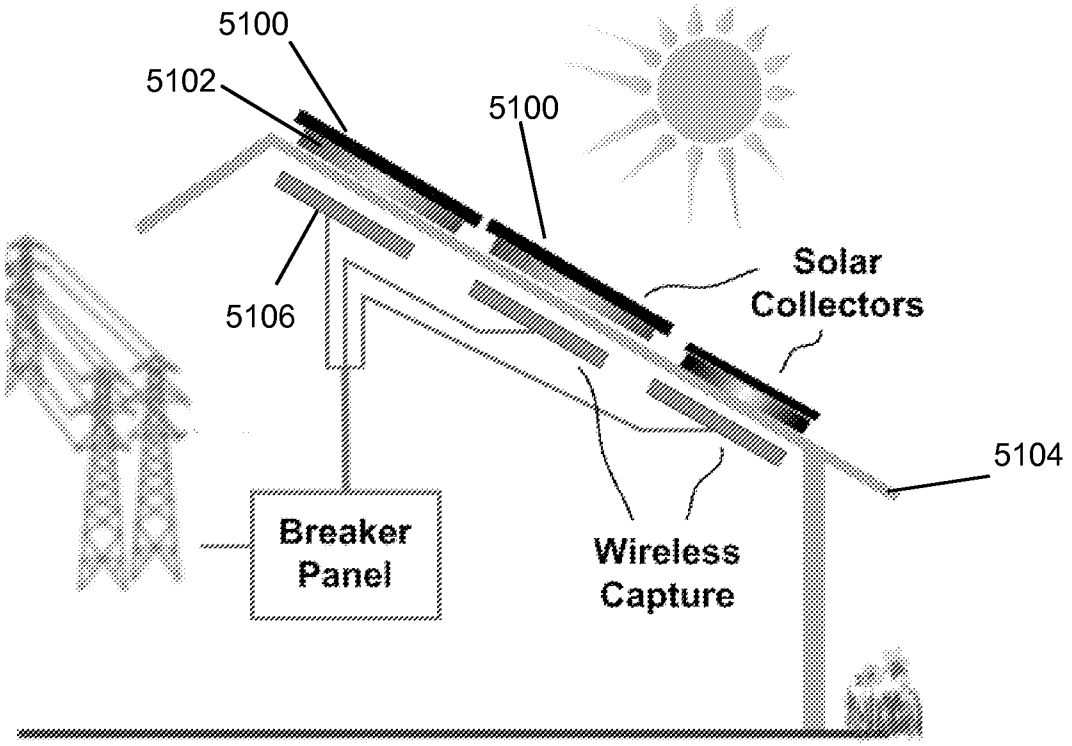

device
resonator is
inside the laptop
(not visible)
5000
5002
5000
5002
5000
5002
a)
b)
c)
d)

Fig. 51


5100
5102
5100
5106
Solar
Collectors
5104
Breaker
Panel
Wireless
Capture

Electronic Acknowledgement Receipt

EFS ID:	6152421
Application Number:	12567716
International Application Number:	
Confirmation Number:	4901
Title of Invention:	WIRELESS ENERGY TRANSFER SYSTEMS
First Named Inventor/Applicant Name:	Morris P. Kesler
Customer Number:	43520
Filer:	Robert A. Mazzarese
Filer Authorized By:	
Attorney Docket Number:	WTCY-0026-P01
Receipt Date:	25-SEP-2009
Filing Date:	
Time Stamp:	22:47:46
Application Type:	Utility under 35 USC 111(a)

Payment information:

Submitted with Payment	no

File Listing:

Document Number	Document Description	File Name	File Size(Bytes)/ Message Digest	Multi Part /.zip	Pages (if appl.)
1		WTCY-0026-P01_092509_Specification.pdf	689217 98b16a26453fdfb0293f9a3b33d446933b93eb95	yes	145

	Multipart Description/PDF files in .zip description		
	Document Description	**Start**	**End**
	Specification	1	140
	Claims	141	144
	Abstract	145	145

Warnings:					
Information:					
2	Drawings-only black and white line drawings	WTCY-0026-P01_092509_Drawings.pdf	1639445 7d0fa6f851f6ca7dbf79d4d52b900e42de9be7a0	no	51
Warnings:					
Information:					
3	Application Data Sheet	WTCY-0026-P01_092509_ADS.pdf	1358911 a83b81063374edd821d09ae6cbb5eea6f4373341	no	9
Warnings:					
Information:					
		Total Files Size (in bytes):	3687573		

This Acknowledgement Receipt evidences receipt on the noted date by the USPTO of the indicated documents, characterized by the applicant, and including page counts, where applicable. It serves as evidence of receipt similar to a Post Card, as described in MPEP 503.

New Applications Under 35 U.S.C. 111
If a new application is being filed and the application includes the necessary components for a filing date (see 37 CFR 1.53(b)-(d) and MPEP 506), a Filing Receipt (37 CFR 1.54) will be issued in due course and the date shown on this Acknowledgement Receipt will establish the filing date of the application.

National Stage of an International Application under 35 U.S.C. 371
If a timely submission to enter the national stage of an international application is compliant with the conditions of 35 U.S.C. 371 and other applicable requirements a Form PCT/DO/EO/903 indicating acceptance of the application as a national stage submission under 35 U.S.C. 371 will be issued in addition to the Filing Receipt, in due course.

New International Application Filed with the USPTO as a Receiving Office
If a new international application is being filed and the international application includes the necessary components for an international filing date (see PCT Article 11 and MPEP 1810), a Notification of the International Application Number and of the International Filing Date (Form PCT/RO/105) will be issued in due course, subject to prescriptions concerning national security, and the date shown on this Acknowledgement Receipt will establish the international filing date of the application.

SCORE Placeholder Sheet for IFW Content

Application Number: 12567716 Document Date: 9/25/2009

The presence of this form in the IFW record indicates that the following document type was received in electronic format on the date identified above. This content is stored in the SCORE database.

- Drawings – Other than Black and White Line Drawings

Since this was an electronic submission, there is no physical artifact folder, no artifact folder is recorded in PALM, and no paper documents or physical media exist. The TIFF images in the IFW record were created from the original documents that are stored in SCORE.

To access the documents in the SCORE database, refer to instructions developed by SIRA.

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- Examiners may access SCORE content via the eDAN interface.
- Other USPTO employees can bookmark the current SCORE URL (http://es/ScoreAccessWeb/).
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Form Revision Date: February 8, 2006

PTO/SB/06 (12-04)

Filing Date: 09/25/09

Approved for use through 7/31/2006. OMB 0651-0032
U.S. Patent and Trademark Office; U.S. DEPARTMENT OF COMMERCE
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PATENT APPLICATION FEE DETERMINATION RECORD Substitute for Form PTO-875	Application or Docket Number 12/567,716

APPLICATION AS FILED – PART I

	(Column 1)	(Column 2)	SMALL ENTITY		OR	OTHER THAN SMALL ENTITY	
FOR	NUMBER FILED	NUMBER EXTRA	RATE ($)	FEE ($)		RATE ($)	FEE ($)
BASIC FEE (37 CFR 1.16(a), (b), or (c))	N/A	N/A	N/A			N/A	330
SEARCH FEE (37 CFR 1.16(k), (i), or (m))	N/A	N/A	N/A			N/A	540
EXAMINATION FEE (37 CFR 1.16(o), (p), or (q))	N/A	N/A	N/A			N/A	220
TOTAL CLAIMS (37 CFR 1.16(i))	23 minus 20 =	3	x$26		OR	x$52	156
INDEPENDENT CLAIMS (37 CFR 1.16(h))	3 minus 3 =	*	x$110			x$220	
APPLICATION SIZE FEE (37 CFR 1.16(s))	If the specification and drawings exceed 100 sheets of paper, the application size fee due is $260 ($130 for small entity) for each additional 50 sheets or fraction thereof. See 35 U.S.C. 41(a)(1)(G) and 37 CFR						270
MULTIPLE DEPENDENT CLAIM PRESENT (37 CFR 1.16(j))			195			390	
* If the difference in column 1 is less than zero, enter "0" in column 2.			TOTAL			TOTAL	1516

APPLICATION AS AMENDED – PART II

		(Column 1)		(Column 2)	(Column 3)	SMALL ENTITY		OR	OTHER THAN SMALL ENTITY	
		CLAIMS REMAINING AFTER AMENDMENT		HIGHEST NUMBER PREVIOUSLY PAID FOR	PRESENT EXTRA	RATE ($)	ADDI-TIONAL FEE ($)		RATE ($)	ADDI-TIONAL FEE ($)
AMENDMENT A	Total (37 CFR 1.16(i))	*	Minus	**	=	x =		OR	x =	
	Independent (37 CFR 1.16(h))	*	Minus	***	=	x =		OR	x =	
	Application Size Fee (37 CFR 1.16(s))							OR		
	FIRST PRESENTATION OF MULTIPLE DEPENDENT CLAIM (37 CFR 1.16(j))					N/A		OR	N/A	
						TOTAL ADD'T FEE		OR	TOTAL ADD'T FEE	

		(Column 1)		(Column 2)	(Column 3)			OR		
		CLAIMS REMAINING AFTER AMENDMENT		HIGHEST NUMBER PREVIOUSLY PAID FOR	PRESENT EXTRA	RATE ($)	ADDI-TIONAL FEE ($)		RATE ($)	ADDI-TIONAL FEE ($)
AMENDMENT B	Total (37 CFR 1.16(i))	*	Minus	**	=	x =		OR	x =	
	Independent (37 CFR 1.16(h))	*	Minus	***	=	x =		OR	x =	
	Application Size Fee (37 CFR 1.16(s))							OR		
	FIRST PRESENTATION OF MULTIPLE DEPENDENT CLAIM (37 CFR 1.16(j))					N/A		OR	N/A	
						TOTAL ADD'T FEE		OR	TOTAL ADD'T FEE	

* If the entry in column 1 is less than the entry in column 2, write "0" in column 3.
** If the "Highest Number Previously Paid For" IN THIS SPACE is less than 20, enter "20".
*** If the "Highest Number Previously Paid For" IN THIS SPACE is less than 3, enter "3".
The "Highest Number Previously Paid For" (Total or Independent) is the highest number found in the appropriate box in column 1.

This collection of information is required by 37 CFR 1.16. The information is required to obtain or retain a benefit by the public which is to file (and by the USPTO to process) an application. Confidentiality is governed by 35 U.S.C. 122 and 37 CFR 1.14. This collection is estimated to take 12 minutes to complete, including gathering, preparing, and submitting the completed application form to the USPTO. Time will vary depending upon the individual case. Any comments on the amount of time you require to complete this form and/or suggestions for reducing this burden, should be sent to the Chief Information Officer, U.S. Patent and Trademark Office, U.S. Department of Commerce, P.O. Box 1450, Alexandria, VA 22313-1450. DO NOT SEND FEES OR COMPLETED FORMS TO THIS ADDRESS. **SEND TO: Commissioner for Patents, P.O. Box 1450, Alexandria, VA 22313-1450.**

If you need assistance in completing the form, call 1-800-PTO-9199 and select option 2.

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APPLICATION NUMBER	FILING or 371(c) DATE	GRP ART UNIT	FIL FEE REC'D	ATTY.DOCKET.NO	TOT CLAIMS	IND CLAIMS
12/567,716	09/25/2009	2828	0.00	WTCY-0026-P01	23	3

CONFIRMATION NO. 4901

43520
STRATEGIC PATENTS P.C..
C/O PORTFOLIOIP
P.O. BOX 52050
MINNEAPOLIS, MN 55402

FILING RECEIPT

OC000000038208596

Date Mailed: 10/14/2009

Receipt is acknowledged of this non-provisional patent application. The application will be taken up for examination in due course. Applicant will be notified as to the results of the examination. Any correspondence concerning the application must include the following identification information: the U.S. APPLICATION NUMBER, FILING DATE, NAME OF APPLICANT, and TITLE OF INVENTION. Fees transmitted by check or draft are subject to collection. Please verify the accuracy of the data presented on this receipt. **If an error is noted on this Filing Receipt, please submit a written request for a Filing Receipt Correction. Please provide a copy of this Filing Receipt with the changes noted thereon. If you received a "Notice to File Missing Parts" for this application, please submit any corrections to this Filing Receipt with your reply to the Notice. When the USPTO processes the reply to the Notice, the USPTO will generate another Filing Receipt incorporating the requested corrections**

Applicant(s)

Morris P. Kessler, Bedford, MA;
Aristeidis Karalis, Boston, MA;
Andre B. Kurs, Chestnut Hill, MA;
Andrew J. Campanella, Waltham, MA;
Ron Fiorello, Tewksbury, MA;
Qiang Li, Malden, MA;
Konrad Kulikowski, Somerville, MA;
Eric G. Giler, Wellesley, MA;
Frank J. Pergal, Gloucester, MA;
David A. Schatz, Needham, MA;
Katherine L. Hall, Westford, MA;
Marin Soljacic, Belmont, MA;

Power of Attorney: None

Domestic Priority data as claimed by applicant

This appln claims benefit of 61/100,721 09/27/2008
and claims benefit of 61/108,743 10/27/2008
and claims benefit of 61/147,386 01/26/2009
and claims benefit of 61/152,086 02/12/2009
and claims benefit of 61/178,508 05/15/2009
and claims benefit of 61/182,768 06/01/2009
and claims benefit of 61/121,159 12/09/2008
and claims benefit of 61/142,977 01/07/2009
and claims benefit of 61/142,885 01/06/2009
and claims benefit of 61/142,796 01/06/2009

and claims benefit of 61/142,889 01/06/2009
and claims benefit of 61/142,880 01/06/2009
and claims benefit of 61/142,818 01/06/2009
and claims benefit of 61/142,887 01/06/2009
and claims benefit of 61/156,764 03/02/2009
and claims benefit of 61/143,058 01/07/2009
and claims benefit of 61/152,390 02/13/2009
and claims benefit of 61/163,695 03/26/2009
and claims benefit of 61/172,633 04/24/2009
and claims benefit of 61/169,240 04/14/2009
and claims benefit of 61/173,747 04/29/2009

Foreign Applications

Projected Publication Date: To Be Determined - pending completion of Missing Parts

Non-Publication Request: No

Early Publication Request: No

Title

WIRELESS ENERGY TRANSFER SYSTEMS

Preliminary Class

372

PROTECTING YOUR INVENTION OUTSIDE THE UNITED STATES

Since the rights granted by a U.S. patent extend only throughout the territory of the United States and have no effect in a foreign country, an inventor who wishes patent protection in another country must apply for a patent in a specific country or in regional patent offices. Applicants may wish to consider the filing of an international application under the Patent Cooperation Treaty (PCT). An international (PCT) application generally has the same effect as a regular national patent application in each PCT-member country. The PCT process **simplifies** the filing of patent applications on the same invention in member countries, but **does not result** in a grant of "an international patent" and does not eliminate the need of applicants to file additional documents and fees in countries where patent protection is desired.

Almost every country has its own patent law, and a person desiring a patent in a particular country must make an application for patent in that country in accordance with its particular laws. Since the laws of many countries differ in various respects from the patent law of the United States, applicants are advised to seek guidance from specific foreign countries to ensure that patent rights are not lost prematurely.

Applicants also are advised that in the case of inventions made in the United States, the Director of the USPTO must issue a license before applicants can apply for a patent in a foreign country. The filing of a U.S. patent application serves as a request for a foreign filing license. The application's filing receipt contains further information and guidance as to the status of applicant's license for foreign filing.

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patent applications. The guide is available either by contacting the USPTO Contact Center at 800-786-9199, or it can be viewed on the USPTO website at http://www.uspto.gov/web/offices/pac/doc/general/index.html.

For information on preventing theft of your intellectual property (patents, trademarks and copyrights), you may wish to consult the U.S. Government website, http://www.stopfakes.gov. Part of a Department of Commerce initiative, this website includes self-help "toolkits" giving innovators guidance on how to protect intellectual property in specific countries such as China, Korea and Mexico. For questions regarding patent enforcement issues, applicants may call the U.S. Government hotline at 1-866-999-HALT (1-866-999-4158).

LICENSE FOR FOREIGN FILING UNDER

Title 35, United States Code, Section 184

Title 37, Code of Federal Regulations, 5.11 & 5.15

GRANTED

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This license is to be retained by the licensee and may be used at any time on or after the effective date thereof unless it is revoked. This license is automatically transferred to any related applications(s) filed under 37 CFR 1.53(d). This license is not retroactive.

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NOT GRANTED

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United States Patent and Trademark Office
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Alexandria, Virginia 22313-1450
www.uspto.gov

APPLICATION NUMBER	FILING OR 371(C) DATE	FIRST NAMED APPLICANT	ATTY. DOCKET NO./TITLE
12/567,716	09/25/2009	Morris P. Kessler	WTCY-0026-P01

CONFIRMATION NO. 4901

43520
STRATEGIC PATENTS P.C..
C/O PORTFOLIOIP
P.O. BOX 52050
MINNEAPOLIS, MN 55402

FORMALITIES LETTER

OC000000038208597

Date Mailed: 10/14/2009

NOTICE TO FILE MISSING PARTS OF NONPROVISIONAL APPLICATION

FILED UNDER 37 CFR 1.53(b)

Filing Date Granted

Items Required To Avoid Abandonment:

An application number and filing date have been accorded to this application. The item(s) indicated below, however, are missing. Applicant is given **TWO MONTHS** from the date of this Notice within which to file all required items and pay any fees required below to avoid abandonment. Extensions of time may be obtained by filing a petition accompanied by the extension fee under the provisions of 37 CFR 1.136(a).

- The statutory basic filing fee is missing.
  *Applicant must submit $**330** to complete the basic filing fee for a non-small entity. If appropriate, applicant may make a written assertion of entitlement to small entity status and pay the small entity filing fee (37 CFR 1.27).*
- The oath or declaration is missing.
  A properly signed oath or declaration in compliance with 37 CFR 1.63, identifying the application by the above Application Number and Filing Date, is required.
  Note: If a petition under 37 CFR 1.47 is being filed, an oath or declaration in compliance with 37 CFR 1.63 signed by all available joint inventors, or if no inventor is available by a party with sufficient proprietary interest, is required.

The application is informal since it does not comply with the regulations for the reason(s) indicated below.

The required item(s) identified below must be timely submitted to avoid abandonment:

- Replacement drawings in compliance with 37 CFR 1.84 and 37 CFR 1.121(d) are required. The drawings submitted are not acceptable because:
  - The drawings have a line quality that is too light to be reproduced (weight of all lines and letters must be heavy enough to permit adequate reproduction) or text that is illegible (reference characters, sheet numbers, and view numbers must be plain and legible) see 37 CFR 1.84(l) and (p)(1)); See Figure(s) 23.
  - More than one figure is present and each figure is not labeled "Fig." with a consecutive Arabic numeral (1, 2, etc.) or an Arabic numeral and capital letter in the English alphabet (A, B, etc.)(see 37 CFR 1.84(u)(1)). See Figure(s) 9a &9b. A brief description of the several views of the drawings (see 37 CFR 1.74) should be added or amended to correspond to the corrected numbering of the figures. See also 37 CFR 1.77(b)(7).
  - The drawings submitted to the Office are not electronically reproducible because portions of figures 45-47 are missing and/or blurry.

Applicant is cautioned that correction of the above items may cause the specification and drawings page count to exceed 100 pages. If the specification and drawings exceed 100 pages, applicant will need to submit the required application size fee.

The applicant needs to satisfy supplemental fees problems indicated below.

The required item(s) identified below must be timely submitted to avoid abandonment:

- Additional claim fees of $**156** as a non-small entity, including any required multiple dependent claim fee, are required. Applicant must submit the additional claim fees or cancel the additional claims for which fees are due.
- To avoid abandonment, a surcharge (for late submission of filing fee, search fee, examination fee or oath or declaration) as set forth in 37 CFR 1.16(f) of $**130** for a non-small entity, must be submitted with the missing items identified in this notice.

SUMMARY OF FEES DUE:

Total additional fee(s) required for this application is $**1646** for a non-small entity

- $**330** Statutory basic filing fee.
- $**130** Surcharge.
- The application search fee has not been paid. Applicant must submit $**540** to complete the search fee.
- The application examination fee has not been paid. Applicant must submit $**220** to complete the examination fee for a non-small entity.
- The specification and drawings submitted electronically contain the equivalent of more than 100 pages. Applicant owes $**270** for **47** pages in excess of **100** pages for a non-small entity.
- Total additional claim fee(s) for this application is $**156**
  - $**156** for **3** total claims over 20.

Replies should be mailed to:

Mail Stop Missing Parts
Commissioner for Patents
P.O. Box 1450
Alexandria VA 22313-1450

Registered users of EFS-Web may alternatively submit their reply to this notice via EFS-Web.
https://sportal.uspto.gov/authenticate/AuthenticateUserLocalEPF.html

For more information about EFS-Web please call the USPTO Electronic Business Center at **1-866-217-9197** or visit our website at http://www.uspto.gov/ebc.

If you are not using EFS-Web to submit your reply, you must include a copy of this notice.

/aabranyos/

Office of Data Management, Application Assistance Unit (571) 272-4000, or (571) 272-4200, or 1-888-786-0101

Electronic Patent Application Fee Transmittal

Application Number:	12567716
Filing Date:	25-Sep-2009
Title of Invention:	WIRELESS ENERGY TRANSFER SYSTEMS
First Named Inventor/Applicant Name:	Morris P. Kessler
Filer:	John H. Nortrop
Attorney Docket Number:	WTCY-0026-P01

Filed as Large Entity

Utility under 35 USC 111(a) Filing Fees

Description	Fee Code	Quantity	Amount	Sub-Total in USD($)
Basic Filing:				
Utility application filing	1011	1	330	330
Utility Search Fee	1111	1	540	540
Utility Examination Fee	1311	1	220	220
Pages:				
Utility Appl Size fee per 50 sheets >100	1081	1	270	270
Claims:				
Claims in excess of 20	1202	3	52	156
Miscellaneous-Filing:				

Description	Fee Code	Quantity	Amount	Sub-Total in USD($)
Late filing fee for oath or declaration	1051	1	130	130
Petition:				
Patent-Appeals-and-Interference:				
Post-Allowance-and-Post-Issuance:				
Extension-of-Time:				
Miscellaneous:				
			Total in USD ($)	**1646**

United States Patent Application

COMBINED DECLARATION AND POWER OF ATTORNEY

As a below named inventor I hereby declare with respect to the U.S. patent application entitled

WIRELESS ENERGY TRANSFER SYSTEMS

the specification of which was filed on September 25, 2009 as application serial no. 12/567,716, that:

(a) my residence, post office address, and citizenship are as stated below next to my name;
(b) I believe I am the original, first and joint inventor of the subject matter which is claimed and for which a patent is sought; and
(c) I have reviewed and understood the contents of the specification, including the claims, as amended by any amendment referred to above.

I acknowledge the duty to disclose information which is material to the patentability of this application as defined in 37 C.F.R. § 1.56 (attached hereto). I also acknowledge my duty to disclose all information known to be material to patentability which became available between a filing date of a prior application and the national or PCT international filing date in the event this is a Continuation-In-Part application in accordance with 37 C.F.R. § 1.63(e).

I hereby appoint the following attorney(s) and/or patent agent(s) to prosecute this application and to transact all business in the Patent and Trademark Office connected herewith, I hereby authorize them to act and rely on instructions from and communicate directly with the person/assignee/attorney/agent/firm/organization who/which first sends/sent this case to them and by whom/which I hereby declare that I have consented after full disclosure to be represented:

All Attorneys and Agents Associated With:
Customer Number: 43520
(Strategic Patents, P.C.)

Please direct all correspondence in this case to:

Customer No. 43520
(Strategic Patents, P.C.)
Telephone No. (781) 453-9993

I hereby declare that all statements made herein of my own knowledge are true and that all statements made on information and belief are believed to be true; and further that these statements were made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under Section 1001 of Title 18 of the United States Code and that such willful false statements may jeopardize the validity of the application or any patent issued thereon.

Full Name of joint inventor number 1 : **Morris P. Kesler**
Citizenship: **United States of America** Residence: **Bedford, MA**
Post Office Address: 95 Hancock Street
Bedford, MA 01730

Signature: _____ Date: Nov. 6, 2009
Morris P. Kesler

Full Name of joint inventor number 2 : **Aristeidis Karalis**
Citizenship: **Greece (Hellenic Republic)** Residence: **Boston, MA**
Post Office Address: 151 Tremont Street
Apt. 21F
Boston, MA 02111

Signature: _____ Date: Nov 10, 2009
Aristeidis Karalis

Full Name of joint inventor number 3 : **Andre B. Kurs**
Citizenship: **Brazil** Residence: **Chestnut Hill, MA**
Post Office Address: 250 Hammond Pond Parkway
Apt. 1203S
Chestnut Hill, MA 02467

Signature: _____ Date: Nov. 06'09
Andre B. Kurs

Full Name of joint inventor number 4 : **Andrew J. Campanella**
Citizenship: **United States of America** Residence: **Waltham, MA**
Post Office Address: 30 Orange Street
Waltham, MA 02453

Signature: _____ Date: 11/6/2009
Andrew J. Campanella

Full Name of joint inventor number 5 : **Ron Fiorello**
Citizenship: **United States of America** Residence: **Tewksbury, MA**
Post Office Address: 20 Scotland Drive
Tewksbury, MA 01876

Signature: _____ Date: nov 6, 2009
Ron Fiorello

Full Name of joint inventor number 6 : **Qiang Li**
Citizenship: **China** Residence: **Malden, MA**
Post Office Address: 654 Main Street
Malden, MA 02148

Signature: Li Qiang Date: 11/6/09
Qiang Li

Full Name of joint inventor number 7 : **Konrad J. Kulikowski**
Citizenship: **United States of America** Residence: **Somerville, MA**
Post Office Address: 91 Pearson Avenue
Apartment 1
Somerville, MA 02144

Signature: Date: 11/09/09
Konrad J. Kulikowski

Full Name of joint inventor number 8 : **Eric R. Giler**
Citizenship: **United States of America** Residence: **Wellesley, MA**
Post Office Address: 105 Benvenue Street
Wellesley, MA 02482

Signature: Date: 11/6/09
Eric R. Giler

Full Name of joint inventor number 9 : **Frank J. Pergal**
Citizenship: **United States of America** Residence: **Gloucester, MA**
Post Office Address: 14 Norrock Road
Gloucester, MA 01930

Signature: Date:
Frank J. Pergal

Full Name of joint inventor number 10 : **David A. Schatz**
Citizenship: **United States of America** Residence: **Needham, MA**
Post Office Address: 37 White Pine Rd
Needham, MA 02492

Signature: Date: 11/6/09
David A. Schatz

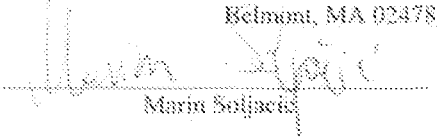
Full Name of joint inventor number 11 : **Katherine L. Hall**
Citizenship: **United States of America** Residence: **Westford, MA**
Post Office Address: 21 Griffin Road
Westford, MA 01886

Signature: Date: 11/6/09
Katherine L. Hall

Full Name of joint inventor number 12 : **Marin Soljacic**

Citizenship: **Croatia** Residence: **Belmont, MA**

Post Office Address: 44 Westlund Road
Belmont, MA 02478

Signature:  Date: 6 NOV 09

Marin Soljacic

Full Name of joint inventor number 6 : **Qiang Li**
Citizenship: **China** Residence: **Malden, MA**
Post Office Address: 654 Main Street
Malden, MA 02148

Signature: ..... Date: .....
Qiang Li

Full Name of joint inventor number 7 : **Konrad J. Kulikowski**
Citizenship: **United States of America** Residence: **Somerville, MA**
Post Office Address: 91 Pearson Avenue
Apartment 1
Somerville, MA 02144

Signature: ..... Date: .....
Konrad J. Kulikowski

Full Name of joint inventor number 8 : **Eric R. Giler**
Citizenship: **United States of America** Residence: **Wellesley, MA**
Post Office Address: 105 Benvenue Street
Wellesley, MA 02482

Signature: ..... Date: .....
Eric R. Giler

Full Name of joint inventor number 9 : **Frank J. Pergal**
Citizenship: **United States of America** Residence: **Gloucester, MA**
Post Office Address: 14 Norrock Road
Gloucester, MA 01930

Signature: Frank J. Pergal Date: 11-24-09
Frank J. Pergal

Full Name of joint inventor number 10 : **David A. Schatz**
Citizenship: **United States of America** Residence: **Needham, MA**
Post Office Address: 37 White Pine Rd.
Needham, MA 02492

Signature: ..... Date: .....
David A. Schatz

Full Name of joint inventor number 11 : **Katherine L. Hall**
Citizenship: **United States of America** Residence: **Westford, MA**
Post Office Address: 21 Griffin Road
Westford, MA 01886

Signature: ..... Date: .....
Katherine L. Hall

---

§ 1.56 Duty to disclose information material to patentability.

(a) A patent by its very nature is affected with a public interest. The public interest is best served, and the most effective patent examination occurs when, at the time an application is being examined, the Office is aware of and evaluates the teachings of all information material to patentability. Each individual associated with the filing and prosecution of a patent application has a duty of candor and good faith in dealing with the Office, which includes a duty to disclose to the Office all information known to that individual to be material to patentability as defined in this section. The duty to disclose information exists with respect to each pending claim until the claim is canceled or withdrawn from consideration, or the application becomes abandoned. Information material to the patentability of a claim that is canceled or withdrawn from consideration need not be submitted if the information is not material to the patentability of any claim remaining under consideration in the application. There is no duty to submit information which is not material to the patentability of any existing claim. The duty to disclose all information known to be material to patentability is deemed to be satisfied if all information known to be material to patentability of any claim issued in a patent was cited by the Office or submitted to the Office in the manner prescribed by §§ 1.97(b)-(d) and 1.98. However, no patent will be granted on an application in connection with which fraud on the Office was practiced or attempted or the duty of disclosure was violated through bad faith or intentional misconduct. The Office encourages applicants to carefully examine:

(1) prior art cited in search reports of a foreign patent office in a counterpart application, and

(2) the closest information over which individuals associated with the filing or prosecution of a patent application believe any pending claim patentably defines, to make sure that any material information contained therein is disclosed to the Office.

(b) Under this section, information is material to patentability when it is not cumulative to information already of record or being made of record in the application, and

(1) It establishes, by itself or in combination with other information, a prima facie case of unpatentability of a claim; or

(2) It refutes, or is inconsistent with, a position the applicant takes in:

(i) Opposing an argument of unpatentability relied on by the Office, or

(ii) Asserting an argument of patentability.

A prima facie case of unpatentability is established when the information compels a conclusion that a claim is unpatentable under the preponderance of evidence, burden-of-proof standard, giving each term in the claim its broadest reasonable construction consistent with the specification, and before any consideration is given to evidence which may be submitted in an attempt to establish a contrary conclusion of patentability.

(c) Individuals associated with the filing or prosecution of a patent application within the meaning of this section are:

(1) Each inventor named in the application;

(2) Each attorney or agent who prepares or prosecutes the application; and

(3) Every other person who is substantively involved in the preparation or prosecution of the application and who is associated with the inventor, with the assignee or with anyone to whom there is an obligation to assign the application.

(d) Individuals other than the attorney, agent or inventor may comply with this section by disclosing information to the attorney, agent, or inventor.

Electronic Acknowledgement Receipt

EFS ID:	6625781
Application Number:	12567716
International Application Number:	
Confirmation Number:	4901
Title of Invention:	WIRELESS ENERGY TRANSFER SYSTEMS
First Named Inventor/Applicant Name:	Morris P. Kessler
Customer Number:	43520
Filer:	John H. Nortrop
Filer Authorized By:	
Attorney Docket Number:	WTCY-0026-P01
Receipt Date:	14-DEC-2009
Filing Date:	25-SEP-2009
Time Stamp:	10:48:19
Application Type:	Utility under 35 USC 111(a)

Payment information:

Submitted with Payment	yes
Payment Type	Deposit Account
Payment was successfully received in RAM	$1646
RAM confirmation Number	7687
Deposit Account	505087
Authorized User	

The Director of the USPTO is hereby authorized to charge indicated fees and credit any overpayment as follows:

Charge any Additional Fees required under 37 C.F.R. Section 1.16 (National application filing, search, and examination fees)

Charge any Additional Fees required under 37 C.F.R. Section 1.17 (Patent application and reexamination processing fees)

File Listing:

Document Number	Document Description	File Name	File Size(Bytes)/ Message Digest	Multi Part /.zip	Pages (if appl.)
1	Applicant Response to Pre-Exam Formalities Notice	WTCY-0026-P01_121409_MissingParts.pdf	116771 0a485bb298c72c22e9e95e52c23f29d4a7143a58	no	2
Warnings:					
Information:					
2	Oath or Declaration filed	WTCY-0026-P01_121409_ExecutedDecPOA.pdf	841322 218089bf99abdc5b1e5dbd2d6198e326cdf3dfb2	no	6
Warnings:					
Information:					
3	Application Data Sheet	WTCY-0026-P01_121409_SupplementalADS.pdf	1361852 d648398f84595b5f40b8b5d06c7439629dcaf2e4	no	9
Warnings:					
Information:					
4		WTCY-0026-P01_121409_PreliminaryAmendment.pdf	80456 526a25a2b2e3102292884ca1e9837e6892c8a60d	yes	3

Multipart Description/PDF files in .zip description

Document Description	Start	End
Preliminary Amendment	1	1
Drawings-only black and white line drawings	2	2
Applicant Arguments/Remarks Made in an Amendment	3	3

Warnings:					
Information:					
5	Request for Corrected Filing Receipt	WTCY-0026-P01_121409_MarkedFR_Filed.pdf	820352 e7e0f671ee1936ef59f788a4b3be43e3f8cf7a22	no	3
Warnings:					
Information:					
6	Drawings-only black and white line drawings	WTCY-0026-P01_121409_FormalDrawings_Filed.pdf	7597033 68b2d4399729fe75343e0a1812dad9618968cf47	no	53
Warnings:					
Information:					
7	Fee Worksheet (PTO-875)	fee-info.pdf	39972 279b2ddbb04a3d8509faac4a9e98bfad9419136e	no	2

Warnings:	
Information:	
Total Files Size (in bytes):	10857758

This Acknowledgement Receipt evidences receipt on the noted date by the USPTO of the indicated documents, characterized by the applicant, and including page counts, where applicable. It serves as evidence of receipt similar to a Post Card, as described in MPEP 503.

New Applications Under 35 U.S.C. 111

If a new application is being filed and the application includes the necessary components for a filing date (see 37 CFR 1.53(b)-(d) and MPEP 506), a Filing Receipt (37 CFR 1.54) will be issued in due course and the date shown on this Acknowledgement Receipt will establish the filing date of the application.

National Stage of an International Application under 35 U.S.C. 371

If a timely submission to enter the national stage of an international application is compliant with the conditions of 35 U.S.C. 371 and other applicable requirements a Form PCT/DO/EO/903 indicating acceptance of the application as a national stage submission under 35 U.S.C. 371 will be issued in addition to the Filing Receipt, in due course.

New International Application Filed with the USPTO as a Receiving Office

If a new international application is being filed and the international application includes the necessary components for an international filing date (see PCT Article 11 and MPEP 1810), a Notification of the International Application Number and of the International Filing Date (Form PCT/RO/105) will be issued in due course, subject to prescriptions concerning national security, and the date shown on this Acknowledgement Receipt will establish the international filing date of the application.

UNITED STATES PATENT AND TRADEMARK OFFICE

UNITED STATES DEPARTMENT OF COMMERCE
United States Patent and Trademark Office
Address: COMMISSIONER FOR PATENTS
P.O. Box 1450
Alexandria, Virginia 22313-1450
www.uspto.gov

APPLICATION NUMBER	FILING or 371(c) DATE	GRP ART UNIT	FIL FEE REC'D	ATTY.DOCKET.NO	TOT CLAIMS	IND CLAIMS
12/567,716	09/25/2009	2828	0.00	WTCY-0026-P01	23	3

CONFIRMATION NO. 4901

43520
STRATEGIC PATENTS P.C..
C/O PORTFOLIOIP
P.O. BOX 52050
MINNEAPOLIS, MN 55402

FILING RECEIPT

OC000000038208596

Date Mailed: 10/14/2009

Receipt is acknowledged of this non-provisional patent application. The application will be taken up for examination in due course. Applicant will be notified as to the results of the examination. Any correspondence concerning the application must include the following identification information: the U.S. APPLICATION NUMBER, FILING DATE, NAME OF APPLICANT, and TITLE OF INVENTION. Fees transmitted by check or draft are subject to collection. Please verify the accuracy of the data presented on this receipt. **If an error is noted on this Filing Receipt, please submit a written request for a Filing Receipt Correction. Please provide a copy of this Filing Receipt with the changes noted thereon. If you received a "Notice to File Missing Parts" for this application, please submit any corrections to this Filing Receipt with your reply to the Notice. When the USPTO processes the reply to the Notice, the USPTO will generate another Filing Receipt incorporating the requested corrections**

Applicant(s)

Morris P. Kesler

~~Morris P. Kessler~~, Bedford, MA;
Aristeidis Karalis, Boston, MA;
Andre B. Kurs, Chestnut Hill, MA;
Andrew J. Campanella, Waltham, MA;
Ron Fiorello, Tewksbury, MA;
Qiang Li, Malden, MA;
Konrad Kulikowski, Somerville, MA;
~~Eric G. Giler~~, Wellesley, MA;
Frank J. Pergal, Gloucester, MA;
David A. Schatz, Needham, MA;
Katherine L. Hall, Westford, MA;
Marin Soljacic, Belmont, MA;

Eric R. Giler

Power of Attorney: None

Domestic Priority data as claimed by applicant

This appln claims benefit of 61/100,721 09/27/2008
and claims benefit of 61/108,743 10/27/2008
and claims benefit of 61/147,386 01/26/2009
and claims benefit of 61/152,086 02/12/2009
and claims benefit of 61/178,508 05/15/2009
and claims benefit of 61/182,768 06/01/2009
and claims benefit of 61/121,159 12/09/2008
and claims benefit of 61/142,977 01/07/2009
and claims benefit of 61/142,885 01/06/2009
and claims benefit of 61/142,796 01/06/2009

CPA GLOBAL
OCT 2 2 2009
RECEIVED
Coded _____ Verified _____

and claims benefit of 61/142,889 01/06/2009
and claims benefit of 61/142,880 01/06/2009
and claims benefit of 61/142,818 01/06/2009
and claims benefit of 61/142,887 01/06/2009
and claims benefit of 61/156,764 03/02/2009
and claims benefit of 61/143,058 01/07/2009
and claims benefit of 61/152,390 02/13/2009
and claims benefit of 61/163,695 03/26/2009
and claims benefit of 61/172,633 04/24/2009
and claims benefit of 61/169,240 04/14/2009
and claims benefit of 61/173,747 04/29/2009

Foreign Applications

Projected Publication Date: To Be Determined - pending completion of Missing Parts

Non-Publication Request: No

Early Publication Request: No

Title

WIRELESS ENERGY TRANSFER SYSTEMS

Preliminary Class

372

PROTECTING YOUR INVENTION OUTSIDE THE UNITED STATES

Since the rights granted by a U.S. patent extend only throughout the territory of the United States and have no effect in a foreign country, an inventor who wishes patent protection in another country must apply for a patent in a specific country or in regional patent offices. Applicants may wish to consider the filing of an international application under the Patent Cooperation Treaty (PCT). An international (PCT) application generally has the same effect as a regular national patent application in each PCT-member country. The PCT process **simplifies** the filing of patent applications on the same invention in member countries, but **does not result** in a grant of "an international patent" and does not eliminate the need of applicants to file additional documents and fees in countries where patent protection is desired.

Almost every country has its own patent law, and a person desiring a patent in a particular country must make an application for patent in that country in accordance with its particular laws. Since the laws of many countries differ in various respects from the patent law of the United States, applicants are advised to seek guidance from specific foreign countries to ensure that patent rights are not lost prematurely.

Applicants also are advised that in the case of inventions made in the United States, the Director of the USPTO must issue a license before applicants can apply for a patent in a foreign country. The filing of a U.S. patent application serves as a request for a foreign filing license. The application's filing receipt contains further information and guidance as to the status of applicant's license for foreign filing.

Applicants may wish to consult the USPTO booklet, "General Information Concerning Patents" (specifically, the section entitled "Treaties and Foreign Patents") for more information on timeframes and deadlines for filing foreign

patent applications. The guide is available either by contacting the USPTO Contact Center at 800-786-9199, or it can be viewed on the USPTO website at http://www.uspto.gov/web/offices/pac/doc/general/index.html.

For information on preventing theft of your intellectual property (patents, trademarks and copyrights), you may wish to consult the U.S. Government website, http://www.stopfakes.gov. Part of a Department of Commerce initiative, this website includes self-help "toolkits" giving innovators guidance on how to protect intellectual property in specific countries such as China, Korea and Mexico. For questions regarding patent enforcement issues, applicants may call the U.S. Government hotline at 1-866-999-HALT (1-866-999-4158).

LICENSE FOR FOREIGN FILING UNDER

Title 35, United States Code, Section 184

Title 37, Code of Federal Regulations, 5.11 & 5.15

GRANTED

The applicant has been granted a license under 35 U.S.C. 184, if the phrase "IF REQUIRED, FOREIGN FILING LICENSE GRANTED" followed by a date appears on this form. Such licenses are issued in all applications where the conditions for issuance of a license have been met, regardless of whether or not a license may be required as set forth in 37 CFR 5.15. The scope and limitations of this license are set forth in 37 CFR 5.15(a) unless an earlier license has been issued under 37 CFR 5.15(b). The license is subject to revocation upon written notification. The date indicated is the effective date of the license, unless an earlier license of similar scope has been granted under 37 CFR 5.13 or 5.14.

This license is to be retained by the licensee and may be used at any time on or after the effective date thereof unless it is revoked. This license is automatically transferred to any related applications(s) filed under 37 CFR 1.53(d). This license is not retroactive.

The grant of a license does not in any way lessen the responsibility of a licensee for the security of the subject matter as imposed by any Government contract or the provisions of existing laws relating to espionage and the national security or the export of technical data. Licensees should apprise themselves of current regulations especially with respect to certain countries, of other agencies, particularly the Office of Defense Trade Controls, Department of State (with respect to Arms, Munitions and Implements of War (22 CFR 121-128)); the Bureau of Industry and Security, Department of Commerce (15 CFR parts 730-774); the Office of Foreign AssetsControl, Department of Treasury (31 CFR Parts 500+) and the Department of Energy.

NOT GRANTED

No license under 35 U.S.C. 184 has been granted at this time, if the phrase "IF REQUIRED, FOREIGN FILING LICENSE GRANTED" DOES NOT appear on this form. Applicant may still petition for a license under 37 CFR 5.12, if a license is desired before the expiration of 6 months from the filing date of the application. If 6 months has lapsed from the filing date of this application and the licensee has not received any indication of a secrecy order under 35 U.S.C. 181, the licensee may foreign file the application pursuant to 37 CFR 5.15(b).

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

In re application of Morris P. Kesler et al	: Group Art Unit: 2828
Serial No. 12/567,716	: Confirmation No. 4901
Filed: September 25, 2009	: Examiner: Not yet known

PRELIMINARY AMENDMENT

Mail Stop Missing Parts
Commissioner for Patents
P.O. Box 1450
Alexandria, VA 22313-1450

Sir/Madam:

Please enter the following amendments prior to examination on the merits:

Amendments to the Drawings begin on page 2 of this paper.

Remarks begin on page 3 of this paper.

InductEV, Inc.
Exhibit 1002
Page 229

PTO/SB/14 (07-07)
Approved for use through 06/30/2010. OMB 0651-0032
U.S. Patent and Trademark Office; U.S. DEPARTMENT OF COMMERCE
Under the Paperwork Reduction Act of 1995, no persons are required to respond to a collection of information unless it contains a valid OMB control number.

Application Data Sheet 37 CFR 1.76	Attorney Docket Number	WTCY-0026-P01
	Application Number	
Title of Invention	WIRELESS ENERGY TRANSFER SYSTEMS	

The application data sheet is part of the provisional or nonprovisional application for which it is being submitted. The following form contains the bibliographic data arranged in a format specified by the United States Patent and Trademark Office as outlined in 37 CFR 1.76.
This document may be completed electronically and submitted to the Office in electronic format using the Electronic Filing System (EFS) or the document may be printed and included in a paper filed application.

Secrecy Order 37 CFR 5.2

☐ Portions or all of the application associated with this Application Data Sheet may fall under a Secrecy Order pursuant to 37 CFR 5.2 (Paper filers only. Applications that fall under Secrecy Order may not be filed electronically.)

Applicant Information:

Applicant 1 Remove

Applicant Authority ◉ Inventor ○ Legal Representative under 35 U.S.C. 117 ○ Party of Interest under 35 U.S.C. 118

Prefix	Given Name	Middle Name	Family Name	Suffix
	Morris	P.	Kesler	

Residence Information (Select One) ◉ US Residency ○ Non US Residency ○ Active US Military Service

City	Bedford	State/Province	MA	Country of Residence[i]	US

Citizenship under 37 CFR 1.41(b)[i] US

Mailing Address of Applicant:

Address 1	95 Hancock Street		
Address 2			
City	Bedford	State/Province	MA
Postal Code	01730	Country[i]	US

Applicant 2 Remove

Applicant Authority ◉ Inventor ○ Legal Representative under 35 U.S.C. 117 ○ Party of Interest under 35 U.S.C. 118

Prefix	Given Name	Middle Name	Family Name	Suffix
	Aristeidis		Karalis	

Residence Information (Select One) ◉ US Residency ○ Non US Residency ○ Active US Military Service

City	Boston	State/Province	MA	Country of Residence[i]	US

Citizenship under 37 CFR 1.41(b)[i] GR

Mailing Address of Applicant:

Address 1	151 Tremont Street		
Address 2	Apartment 21F		
City	Boston	State/Province	MA
Postal Code	02111	Country[i]	US

Applicant 3 Remove

Applicant Authority ◉ Inventor ○ Legal Representative under 35 U.S.C. 117 ○ Party of Interest under 35 U.S.C. 118

Prefix	Given Name	Middle Name	Family Name	Suffix
	Andre	B.	Kurs	

Residence Information (Select One) ◉ US Residency ○ Non US Residency ○ Active US Military Service

City	Chestnut Hill	State/Province	MA	Country of Residence[i]	US

Application Data Sheet 37 CFR 1.76	Attorney Docket Number	WTCY-0026-P01
	Application Number	
Title of Invention	WIRELESS ENERGY TRANSFER SYSTEMS	

Citizenship under 37 CFR 1.41(b) i	BR				
Mailing Address of Applicant:					
Address 1	250 Hammond Pond Parkway				
Address 2	Apartment 1203S				
City	Chestnut Hill	**State/Province**	MA		
Postal Code	02467	**Country**i	US		

Applicant 4 Remove

Applicant Authority (•) Inventor ( ) Legal Representative under 35 U.S.C. 117 ( ) Party of Interest under 35 U.S.C. 118

Prefix	Given Name	Middle Name	Family Name	Suffix
	Andrew	J.	Campanella	

Residence Information (Select One) (•) US Residency ( ) Non US Residency ( ) Active US Military Service

City	Waltham	**State/Province**	MA	**Country of Residence** i	US
Citizenship under 37 CFR 1.41(b) i	US				
Mailing Address of Applicant:					
Address 1	30 Orange Street				
Address 2					
City	Waltham	**State/Province**	MA		
Postal Code	02453	**Country**i	US		

Applicant 5 Remove

Applicant Authority (•) Inventor ( ) Legal Representative under 35 U.S.C. 117 ( ) Party of Interest under 35 U.S.C. 118

Prefix	Given Name	Middle Name	Family Name	Suffix
	Ron		Fiorello	

Residence Information (Select One) (•) US Residency ( ) Non US Residency ( ) Active US Military Service

City	Tewksbury	**State/Province**	MA	**Country of Residence** i	US
Citizenship under 37 CFR 1.41(b) i	US				
Mailing Address of Applicant:					
Address 1	20 Scotland Drive				
Address 2					
City	Tewksbury	**State/Province**	MA		
Postal Code	01876	**Country**i	US		

Applicant 6 Remove

Applicant Authority (•) Inventor ( ) Legal Representative under 35 U.S.C. 117 ( ) Party of Interest under 35 U.S.C. 118

Prefix	Given Name	Middle Name	Family Name	Suffix
	Qiang		Li	

Residence Information (Select One) (•) US Residency ( ) Non US Residency ( ) Active US Military Service

City	Malden	**State/Province**	MA	**Country of Residence** i	US
Citizenship under 37 CFR 1.41(b) i	CN				

Application Data Sheet 37 CFR 1.76	Attorney Docket Number	WTCY-0026-P01
	Application Number	
Title of Invention	WIRELESS ENERGY TRANSFER SYSTEMS	

Mailing Address of Applicant:					
Address 1	654 Main Street				
Address 2					
City	Malden	**State/Province**	MA		
Postal Code	02148	**Country**[i]	US		
Applicant 7				Remove	
Applicant Authority ◉ Inventor	○ Legal Representative under 35 U.S.C. 117	○ Party of Interest under 35 U.S.C. 118			
Prefix	**Given Name**	**Middle Name**	**Family Name**	**Suffix**	
	Konrad		Kulikowski		
Residence Information (Select One) ◉ US Residency	○ Non US Residency	○ Active US Military Service			
City	Somerville	**State/Province**	MA	**Country of Residence** [i]	US
Citizenship under 37 CFR 1.41(b) [i]	US				

Mailing Address of Applicant:					
Address 1	91 Pearson Avenue				
Address 2	Apartment 1				
City	Somerville	**State/Province**	MA		
Postal Code	02144	**Country**[i]	US		
Applicant 8				Remove	
Applicant Authority ◉ Inventor	○ Legal Representative under 35 U.S.C. 117	○ Party of Interest under 35 U.S.C. 118			
Prefix	**Given Name**	**Middle Name**	**Family Name**	**Suffix**	
	Eric	R.	Giler		
Residence Information (Select One) ◉ US Residency	○ Non US Residency	○ Active US Military Service			
City	Wellesley	**State/Province**	MA	**Country of Residence** [i]	US
Citizenship under 37 CFR 1.41(b) [i]	US				

Mailing Address of Applicant:					
Address 1	105 Benvenue Street				
Address 2					
City	Wellesley	**State/Province**	MA		
Postal Code	02482	**Country**[i]	US		
Applicant 9				Remove	
Applicant Authority ◉ Inventor	○ Legal Representative under 35 U.S.C. 117	○ Party of Interest under 35 U.S.C. 118			
Prefix	**Given Name**	**Middle Name**	**Family Name**	**Suffix**	
	Frank	J.	Pergal		
Residence Information (Select One) ◉ US Residency	○ Non US Residency	○ Active US Military Service			
City	Gloucester	**State/Province**	MA	**Country of Residence** [i]	US
Citizenship under 37 CFR 1.41(b) [i]	US				

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Application Data Sheet 37 CFR 1.76	Attorney Docket Number	WTCY-0026-P01
	Application Number	
Title of Invention	WIRELESS ENERGY TRANSFER SYSTEMS	

Mailing Address of Applicant:					
Address 1	14 Norrock Road				
Address 2					
City	Gloucester	**State/Province**	MA		
Postal Code	01930	**Country**[i]	US		
Applicant 10				Remove	
Applicant Authority	(•) Inventor	( ) Legal Representative under 35 U.S.C. 117		( ) Party of Interest under 35 U.S.C. 118	
Prefix	**Given Name**	**Middle Name**	**Family Name**		**Suffix**
	David	A.	Schatz		
Residence Information (Select One)	(•) US Residency	( ) Non US Residency	( ) Active US Military Service		
City	Needham	**State/Province**	MA	**Country of Residence**[i]	US
Citizenship under 37 CFR 1.41(b)[i]	US				

Mailing Address of Applicant:					
Address 1	37 White Pine Road				
Address 2					
City	Needham	**State/Province**	MA		
Postal Code	02492	**Country**[i]	US		
Applicant 11				Remove	
Applicant Authority	(•) Inventor	( ) Legal Representative under 35 U.S.C. 117		( ) Party of Interest under 35 U.S.C. 118	
Prefix	**Given Name**	**Middle Name**	**Family Name**		**Suffix**
	Katherine	L.	Hall		
Residence Information (Select One)	(•) US Residency	( ) Non US Residency	( ) Active US Military Service		
City	Westford	**State/Province**	MA	**Country of Residence**[i]	US
Citizenship under 37 CFR 1.41(b)[i]	US				

Mailing Address of Applicant:					
Address 1	21 Griffin Road				
Address 2					
City	Westford	**State/Province**	MA		
Postal Code	01886	**Country**[i]	US		
Applicant 12				Remove	
Applicant Authority	(•) Inventor	( ) Legal Representative under 35 U.S.C. 117		( ) Party of Interest under 35 U.S.C. 118	
Prefix	**Given Name**	**Middle Name**	**Family Name**		**Suffix**
	Marin		Soljacic		
Residence Information (Select One)	(•) US Residency	( ) Non US Residency	( ) Active US Military Service		
City	Belmont	**State/Province**	MA	**Country of Residence**[i]	US
Citizenship under 37 CFR 1.41(b)[i]	HR				

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Application Data Sheet 37 CFR 1.76	Attorney Docket Number	WTCY-0026-P01
	Application Number	
Title of Invention	WIRELESS ENERGY TRANSFER SYSTEMS	

Mailing Address of Applicant:			
Address 1	44 Westlund Road		
Address 2			
City	Belmont	State/Province	MA
Postal Code	02478	Country[i]	US

All Inventors Must Be Listed - Additional Inventor Information blocks may be generated within this form by selecting the **Add** button. Add

Correspondence Information:

Enter either Customer Number or complete the Correspondence Information section below. For further information see 37 CFR 1.33(a).

☐ **An Address is being provided for the correspondence Information of this application.**

Customer Number	43520		
Email Address	patents@strategic-patents.com	Add Email	Remove Email

Application Information:

Title of the Invention	WIRELESS ENERGY TRANSFER SYSTEMS		
Attorney Docket Number	WTCY-0026-P01	**Small Entity Status Claimed**	☐
Application Type	Nonprovisional		
Subject Matter	Utility		
Suggested Class (if any)		**Sub Class (if any)**	
Suggested Technology Center (if any)			
Total Number of Drawing Sheets (if any)	51	**Suggested Figure for Publication (if any)**	

Publication Information:

☐ Request Early Publication (Fee required at time of Request 37 CFR 1.219)

☐ **Request Not to Publish.** I hereby request that the attached application not be published under 35 U.S.C. 122(b) and certify that the invention disclosed in the attached application **has not and will not** be the subject of an application filed in another country, or under a multilateral international agreement, that requires publication at eighteen months after filing.

Representative Information:

Representative information should be provided for all practitioners having a power of attorney in the application. Providing this information in the Application Data Sheet does not constitute a power of attorney in the application (see 37 CFR 1.32). Enter either Customer Number or complete the Representative Name section below. If both sections are completed the Customer Number will be used for the Representative Information during processing.

Please Select One:	◉ Customer Number	○ US Patent Practitioner	○ Limited Recognition (37 CFR 11.9)
Customer Number	43520		

Application Data Sheet 37 CFR 1.76	Attorney Docket Number	WTCY-0026-P01
	Application Number	
Title of Invention	WIRELESS ENERGY TRANSFER SYSTEMS	

Domestic Benefit/National Stage Information:

This section allows for the applicant to either claim benefit under 35 U.S.C. 119(e), 120, 121, or 365(c) or indicate National Stage entry from a PCT application. Providing this information in the application data sheet constitutes the specific reference required by 35 U.S.C. 119(e) or 120, and 37 CFR 1.78(a)(2) or CFR 1.78(a)(4), and need not otherwise be made part of the specification.

Prior Application Status	Pending		Remove
Application Number	Continuity Type	Prior Application Number	Filing Date (YYYY-MM-DD)
	non provisional of	61/100721	2008-09-27
Prior Application Status	Pending		Remove
Application Number	Continuity Type	Prior Application Number	Filing Date (YYYY-MM-DD)
	non provisional of	61/108743	2008-10-27
Prior Application Status	Pending		Remove
Application Number	Continuity Type	Prior Application Number	Filing Date (YYYY-MM-DD)
	non provisional of	61/147386	2009-01-26
Prior Application Status	Pending		Remove
Application Number	Continuity Type	Prior Application Number	Filing Date (YYYY-MM-DD)
	non provisional of	61/152086	2009-02-12
Prior Application Status	Pending		Remove
Application Number	Continuity Type	Prior Application Number	Filing Date (YYYY-MM-DD)
	non provisional of	61/178508	2009-05-15
Prior Application Status	Pending		Remove
Application Number	Continuity Type	Prior Application Number	Filing Date (YYYY-MM-DD)
	non provisional of	61/182768	2009-06-01
Prior Application Status	Pending		Remove
Application Number	Continuity Type	Prior Application Number	Filing Date (YYYY-MM-DD)
	non provisional of	61/121159	2008-12-09
Prior Application Status	Pending		Remove
Application Number	Continuity Type	Prior Application Number	Filing Date (YYYY-MM-DD)
	non provisional of	61/142977	2009-01-07
Prior Application Status	Pending		Remove
Application Number	Continuity Type	Prior Application Number	Filing Date (YYYY-MM-DD)
	non provisional of	61/142885	2009-01-06
Prior Application Status	Pending		Remove
Application Number	Continuity Type	Prior Application Number	Filing Date (YYYY-MM-DD)
	non provisional of	61/142796	2009-01-06
Prior Application Status	Pending		Remove

Application Data Sheet 37 CFR 1.76	Attorney Docket Number	WTCY-0026-P01
	Application Number	
Title of Invention	WIRELESS ENERGY TRANSFER SYSTEMS	

Application Number	Continuity Type	Prior Application Number	Filing Date (YYYY-MM-DD)
	non provisional of	61/142889	2009-01-06
Prior Application Status	Pending		Remove
Application Number	Continuity Type	Prior Application Number	Filing Date (YYYY-MM-DD)
	non provisional of	61/142880	2009-01-06
Prior Application Status	Pending		Remove
Application Number	Continuity Type	Prior Application Number	Filing Date (YYYY-MM-DD)
	non provisional of	61/142818	2009-01-06
Prior Application Status	Pending		Remove
Application Number	Continuity Type	Prior Application Number	Filing Date (YYYY-MM-DD)
	non provisional of	61/142887	2009-01-06
Prior Application Status	Pending		Remove
Application Number	Continuity Type	Prior Application Number	Filing Date (YYYY-MM-DD)
	non provisional of	61/156764	2009-03-02
Prior Application Status	Pending		Remove
Application Number	Continuity Type	Prior Application Number	Filing Date (YYYY-MM-DD)
	non provisional of	61/143058	2009-01-07
Prior Application Status	Pending		Remove
Application Number	Continuity Type	Prior Application Number	Filing Date (YYYY-MM-DD)
	non provisional of	61/152390	2009-02-13
Prior Application Status	Pending		Remove
Application Number	Continuity Type	Prior Application Number	Filing Date (YYYY-MM-DD)
	non provisional of	61/163695	2009-03-26
Prior Application Status	Pending		Remove
Application Number	Continuity Type	Prior Application Number	Filing Date (YYYY-MM-DD)
	non provisional of	61/172633	2009-04-24
Prior Application Status	Pending		Remove
Application Number	Continuity Type	Prior Application Number	Filing Date (YYYY-MM-DD)
	non provisional of	61/169240	2009-04-14
Prior Application Status	Pending		Remove
Application Number	Continuity Type	Prior Application Number	Filing Date (YYYY-MM-DD)
	non provisional of	61/173747	2009-04-29
Additional Domestic Benefit/National Stage Data may be generated within this form by selecting the **Add** button.			Add

Foreign Priority Information:

PTO/SB/14 (07-07)
Approved for use through 06/30/2010. OMB 0651-0032
U.S. Patent and Trademark Office; U.S. DEPARTMENT OF COMMERCE
Under the Paperwork Reduction Act of 1995, no persons are required to respond to a collection of information unless it contains a valid OMB control number.

Application Data Sheet 37 CFR 1.76	Attorney Docket Number	WTCY-0026-P01
	Application Number	
Title of Invention	WIRELESS ENERGY TRANSFER SYSTEMS	

This section allows for the applicant to claim benefit of foreign priority and to identify any prior foreign application for which priority is not claimed. Providing this information in the application data sheet constitutes the claim for priority as required by 35 U.S.C. 119(b) and 37 CFR 1.55(a).

Remove

Application Number	Country [i]	Parent Filing Date (YYYY-MM-DD)	Priority Claimed
			(•) Yes ( ) No

Additional Foreign Priority Data may be generated within this form by selecting the **Add** button. Add

Assignee Information:

Providing this information in the application data sheet does not substitute for compliance with any requirement of part 3 of Title 37 of the CFR to have an assignment recorded in the Office.

Assignee 1 Remove

If the Assignee is an Organization check here. ☐

Prefix	**Given Name**	Middle Name	**Family Name**	Suffix

Mailing Address Information:

Address 1			
Address 2			
City		**State/Province**	
Country [i]		Postal Code	
Phone Number		Fax Number	
Email Address			

Additional Assignee Data may be generated within this form by selecting the **Add** button. Add

Signature:

A signature of the applicant or representative is required in accordance with 37 CFR 1.33 and 10.18. Please see 37 CFR 1.4(d) for the form of the signature.

Signature	/John Nortrup/			Date (YYYY-MM-DD)	2009-12-14
First Name	John	Last Name	Nortrup	Registration Number	59063

This collection of information is required by 37 CFR 1.76. The information is required to obtain or retain a benefit by the public which is to file (and by the USPTO to process) an application. Confidentiality is governed by 35 U.S.C. 122 and 37 CFR 1.14. This collection is estimated to take 23 minutes to complete, including gathering, preparing, and submitting the completed application data sheet form to the USPTO. Time will vary depending upon the individual case. Any comments on the amount of time you require to complete this form and/or suggestions for reducing this burden, should be sent to the Chief Information Officer, U.S. Patent and Trademark Office, U.S. Department of Commerce, P.O. Box 1450, Alexandria, VA 22313-1450. DO NOT SEND FEES OR COMPLETED FORMS TO THIS ADDRESS. **SEND TO: Commissioner for Patents, P.O. Box 1450, Alexandria, VA 22313-1450.**

Privacy Act Statement

The Privacy Act of 1974 (P.L. 93-579) requires that you be given certain information in connection with your submission of the attached form related to a patent application or patent. Accordingly, pursuant to the requirements of the Act, please be advised that: (1) the general authority for the collection of this information is 35 U.S.C. 2(b)(2); (2) furnishing of the information solicited is voluntary; and (3) the principal purpose for which the information is used by the U.S. Patent and Trademark Office is to process and/or examine your submission related to a patent application or patent. If you do not furnish the requested information, the U.S. Patent and Trademark Office may not be able to process and/or examine your submission, which may result in termination of proceedings or abandonment of the application or expiration of the patent.

The information provided by you in this form will be subject to the following routine uses:

1. The information on this form will be treated confidentially to the extent allowed under the Freedom of Information Act (5 U.S.C. 552) and the Privacy Act (5 U.S.C. 552a). Records from this system of records may be disclosed to the Department of Justice to determine whether the Freedom of Information Act requires disclosure of these records.

2. A record from this system of records may be disclosed, as a routine use, in the course of presenting evidence to a court, magistrate, or administrative tribunal, including disclosures to opposing counsel in the course of settlement negotiations.

3. A record in this system of records may be disclosed, as a routine use, to a Member of Congress submitting a request involving an individual, to whom the record pertains, when the individual has requested assistance from the Member with respect to the subject matter of the record.

4. A record in this system of records may be disclosed, as a routine use, to a contractor of the Agency having need for the information in order to perform a contract. Recipients of information shall be required to comply with the requirements of the Privacy Act of 1974, as amended, pursuant to 5 U.S.C. 552a(m).

5. A record related to an International Application filed under the Patent Cooperation Treaty in this system of records may be disclosed, as a routine use, to the International Bureau of the World Intellectual Property Organization, pursuant to the Patent Cooperation Treaty.

6. A record in this system of records may be disclosed, as a routine use, to another federal agency for purposes of National Security review (35 U.S.C. 181) and for review pursuant to the Atomic Energy Act (42 U.S.C. 218(c)).

7. A record from this system of records may be disclosed, as a routine use, to the Administrator, General Services, or his/her designee, during an inspection of records conducted by GSA as part of that agency's responsibility to recommend improvements in records management practices and programs, under authority of 44 U.S.C. 2904 and 2906. Such disclosure shall be made in accordance with the GSA regulations governing inspection of records for this purpose, and any other relevant (i.e., GSA or Commerce) directive. Such disclosure shall not be used to make determinations about individuals.

8. A record from this system of records may be disclosed, as a routine use, to the public after either publication of the application pursuant to 35 U.S.C. 122(b) or issuance of a patent pursuant to 35 U.S.C. 151. Further, a record may be disclosed, subject to the limitations of 37 CFR 1.14, as a routine use, to the public if the record was filed in an application which became abandoned or in which the proceedings were terminated and which application is referenced by either a published application, an application open to public inspections or an issued patent.

9. A record from this system of records may be disclosed, as a routine use, to a Federal, State, or local law enforcement agency, if the USPTO becomes aware of a violation or potential violation of law or regulation.

Amendments to the Drawings

The attached drawing sheets replace the original fifty-one drawing sheets containing Figs. 1-51.

Attachment: Replacement Sheets (53)

InductEV, Inc.
Exhibit 1002
Page 239

UNITED STATES PATENT AND TRADEMARK OFFICE

P 80157 · E 92451

UNITED STATES DEPARTMENT OF COMMERCE
United States Patent and Trademark Office
Address: COMMISSIONER FOR PATENTS
P.O. Box 1450
Alexandria, Virginia 22313-1450
www.uspto.gov

APPLICATION NUMBER	FILING OR 371(C) DATE	FIRST NAMED APPLICANT	ATTY. DOCKET NO./TITLE
12/567,716	09/25/2009	Morris P. Kessler	WTCY-0026-P01

CONFIRMATION NO. 4901

43520
STRATEGIC PATENTS P.C..
C/O PORTFOLIOIP
P.O. BOX 52050
MINNEAPOLIS, MN 55402

FORMALITIES LETTER

OC000000038208597

Date Mailed: 10/14/2009

NOTICE TO FILE MISSING PARTS OF NONPROVISIONAL APPLICATION

FILED UNDER 37 CFR 1.53(b)

Filing Date Granted

Items Required To Avoid Abandonment:

An application number and filing date have been accorded to this application. The item(s) indicated below, however, are missing. Applicant is given **TWO MONTHS** from the date of this Notice within which to file all required items and pay any fees required below to avoid abandonment. Extensions of time may be obtained by filing a petition accompanied by the extension fee under the provisions of 37 CFR 1.136(a).

- The statutory basic filing fee is missing.
  *Applicant must submit $**330** to complete the basic filing fee for a non-small entity. If appropriate, applicant may make a written assertion of entitlement to small entity status and pay the small entity filing fee (37 CFR 1.27).*
- The oath or declaration is missing.
  A properly signed oath or declaration in compliance with 37 CFR 1.63, identifying the application by the above Application Number and Filing Date, is required.
  Note: If a petition under 37 CFR 1.47 is being filed, an oath or declaration in compliance with 37 CFR 1.63 signed by all available joint inventors, or if no inventor is available by a party with sufficient proprietary interest, is required.

The application is informal since it does not comply with the regulations for the reason(s) indicated below.

The required item(s) identified below must be timely submitted to avoid abandonment:

- Replacement drawings in compliance with 37 CFR 1.84 and 37 CFR 1.121(d) are required. The drawings submitted are not acceptable because:
  - The drawings have a line quality that is too light to be reproduced (weight of all lines and letters must be heavy enough to permit adequate reproduction) or text that is illegible (reference characters, sheet numbers, and view numbers must be plain and legible) see 37 CFR 1.84(l) and (p)(1)); See Figure(s) 23.
  - More than one figure is present and each figure is not labeled "Fig." with a consecutive Arabic numeral (1, 2, etc.) or an Arabic numeral and capital letter in the English alphabet (A, B, etc.)(see 37 CFR 1.84(u)(1)). See Figure(s) 9a &9b. A brief description of the several views of the drawings (see 37 CFR 1.74) should be added or amended to correspond to the corrected numbering of the figures. See also 37 CFR 1.77(b)(7).
  - The drawings submitted to the Office are not electronically reproducible because portions of figures 45-47 are missing and/or blurry.

CPA GLOBAL
OCT 2 2 2009
Coded _____ Verified _____

Applicant is cautioned that correction of the above items may cause the specification and drawings page count to exceed 100 pages. If the specification and drawings exceed 100 pages, applicant will need to submit the required application size fee.

The applicant needs to satisfy supplemental fees problems indicated below.

The required item(s) identified below must be timely submitted to avoid abandonment:

- Additional claim fees of **$156** as a non-small entity, including any required multiple dependent claim fee, are required. Applicant must submit the additional claim fees or cancel the additional claims for which fees are due.
- To avoid abandonment, a surcharge (for late submission of filing fee, search fee, examination fee or oath or declaration) as set forth in 37 CFR 1.16(f) of **$130** for a non-small entity, must be submitted with the missing items identified in this notice.

SUMMARY OF FEES DUE:

Total additional fee(s) required for this application is **$1646** for a non-small entity

- **$330** Statutory basic filing fee.
- **$130** Surcharge.
- The application search fee has not been paid. Applicant must submit **$540** to complete the search fee.
- The application examination fee has not been paid. Applicant must submit **$220** to complete the examination fee for a non-small entity.
- The specification and drawings submitted electronically contain the equivalent of more than 100 pages. Applicant owes **$270** for **47** pages in excess of **100** pages for a non-small entity.
- Total additional claim fee(s) for this application is **$156**
  - **$156** for **3** total claims over 20.

Replies should be mailed to:

Mail Stop Missing Parts
Commissioner for Patents
P.O. Box 1450
Alexandria VA 22313-1450

Registered users of EFS-Web may alternatively submit their reply to this notice via EFS-Web.
https://sportal.uspto.gov/authenticate/AuthenticateUserLocalEPF.html

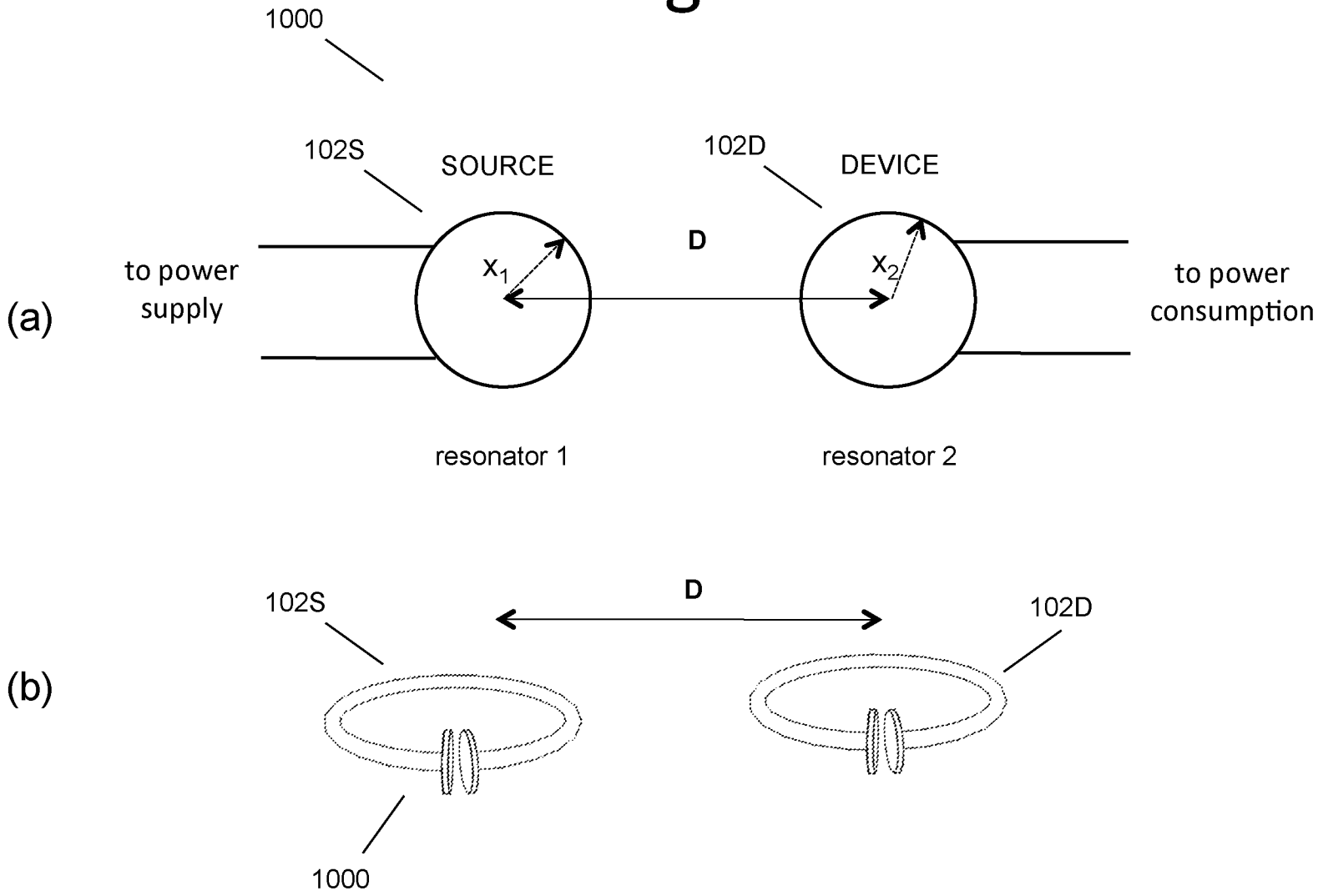
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If you are not using EFS-Web to submit your reply, you must include a copy of this notice.

/aabranyos/

Office of Data Management, Application Assistance Unit (571) 272-4000, or (571) 272-4200, or 1-888-786-0101

Fig. 1



Replacement Sheet

InductEV, Inc.
Exhibit 1002
Page 242

Fig. 2

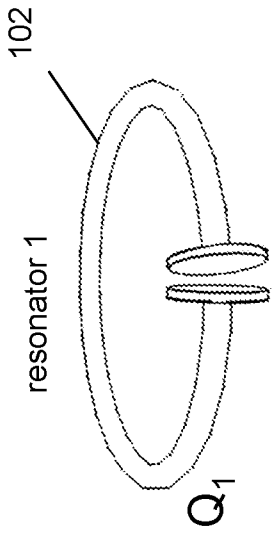


Fig. 3

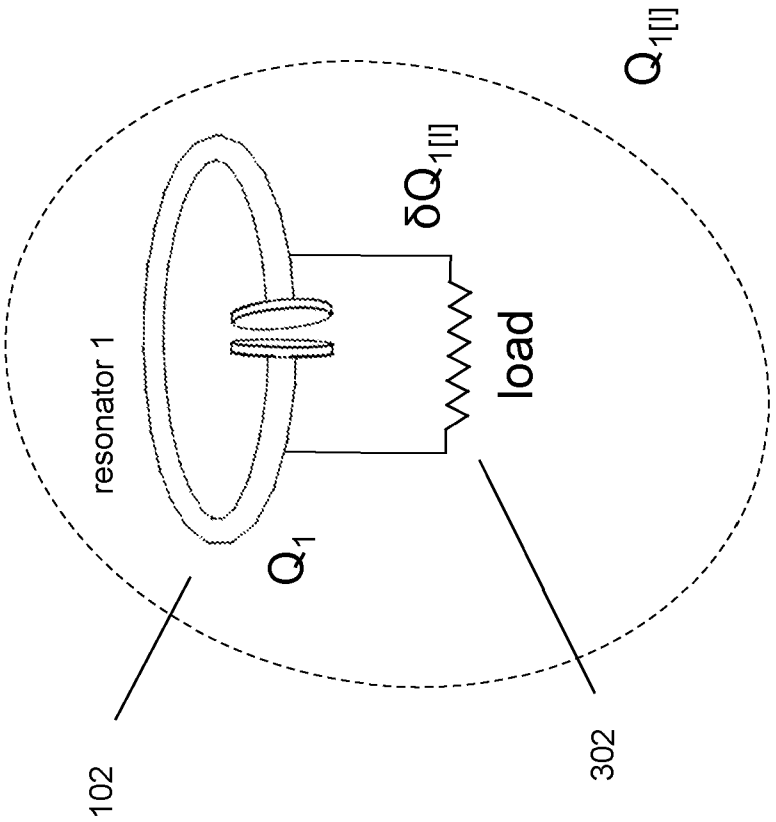


Fig. 4

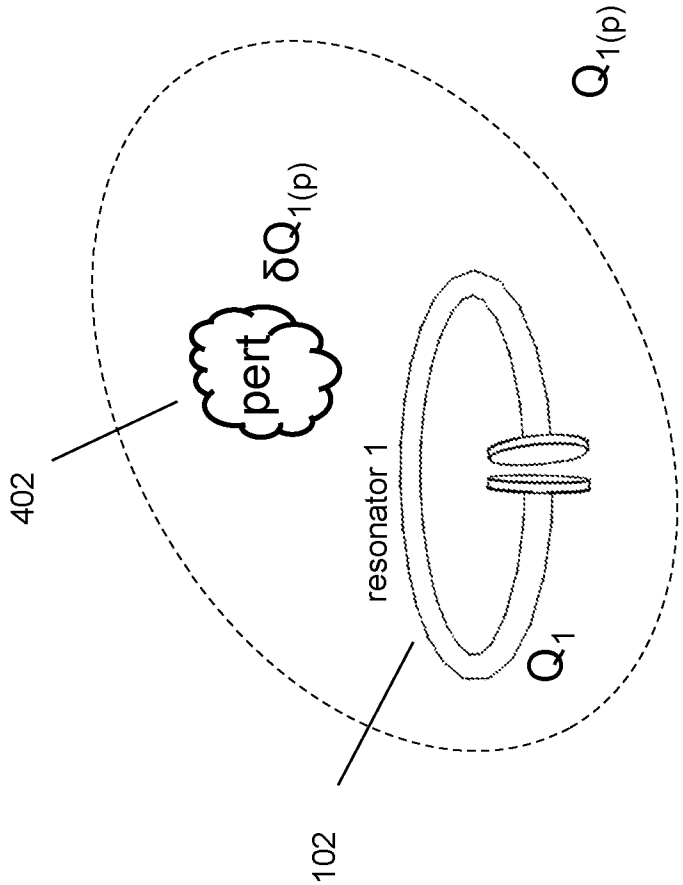
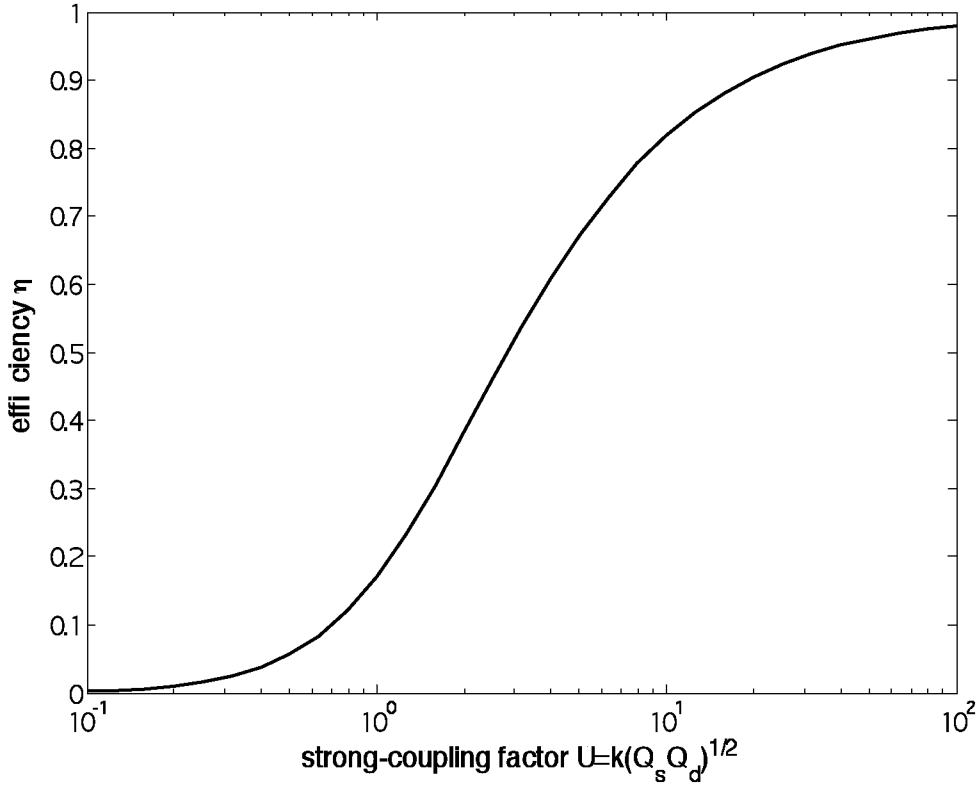


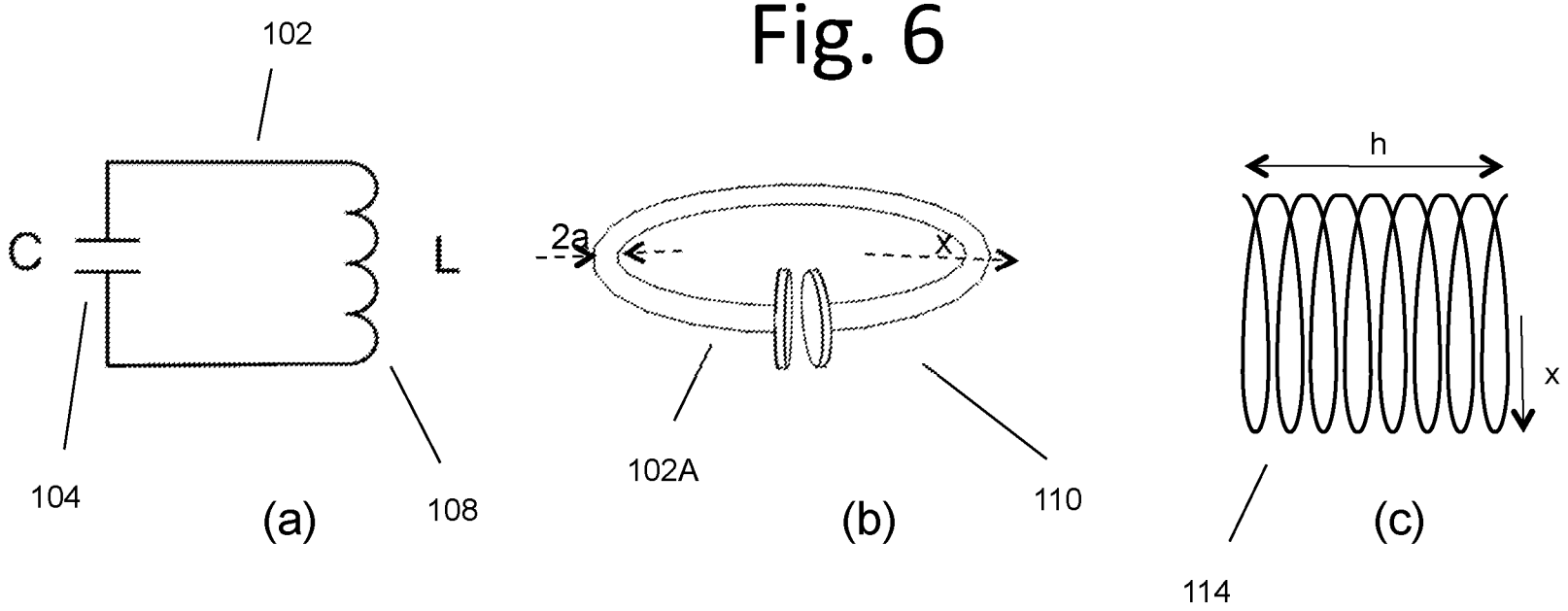
Fig. 5

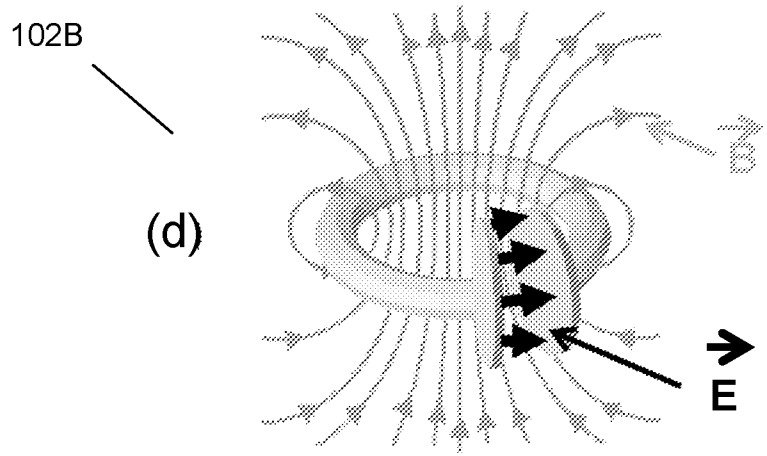


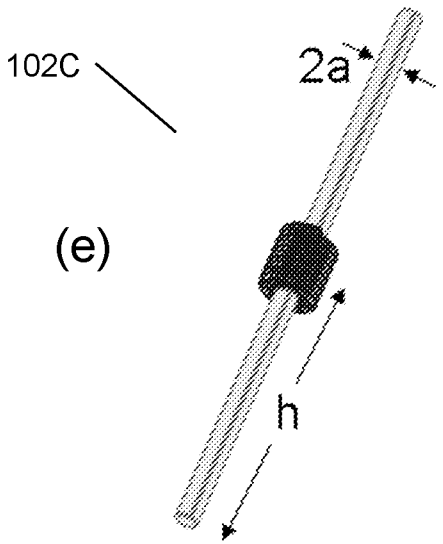
Replacement Sheet

InductEV, Inc.
Exhibit 1002
Page 246

Fig. 6







Replacement Sheet

InductEV, Inc.
Exhibit 1002
Page 247

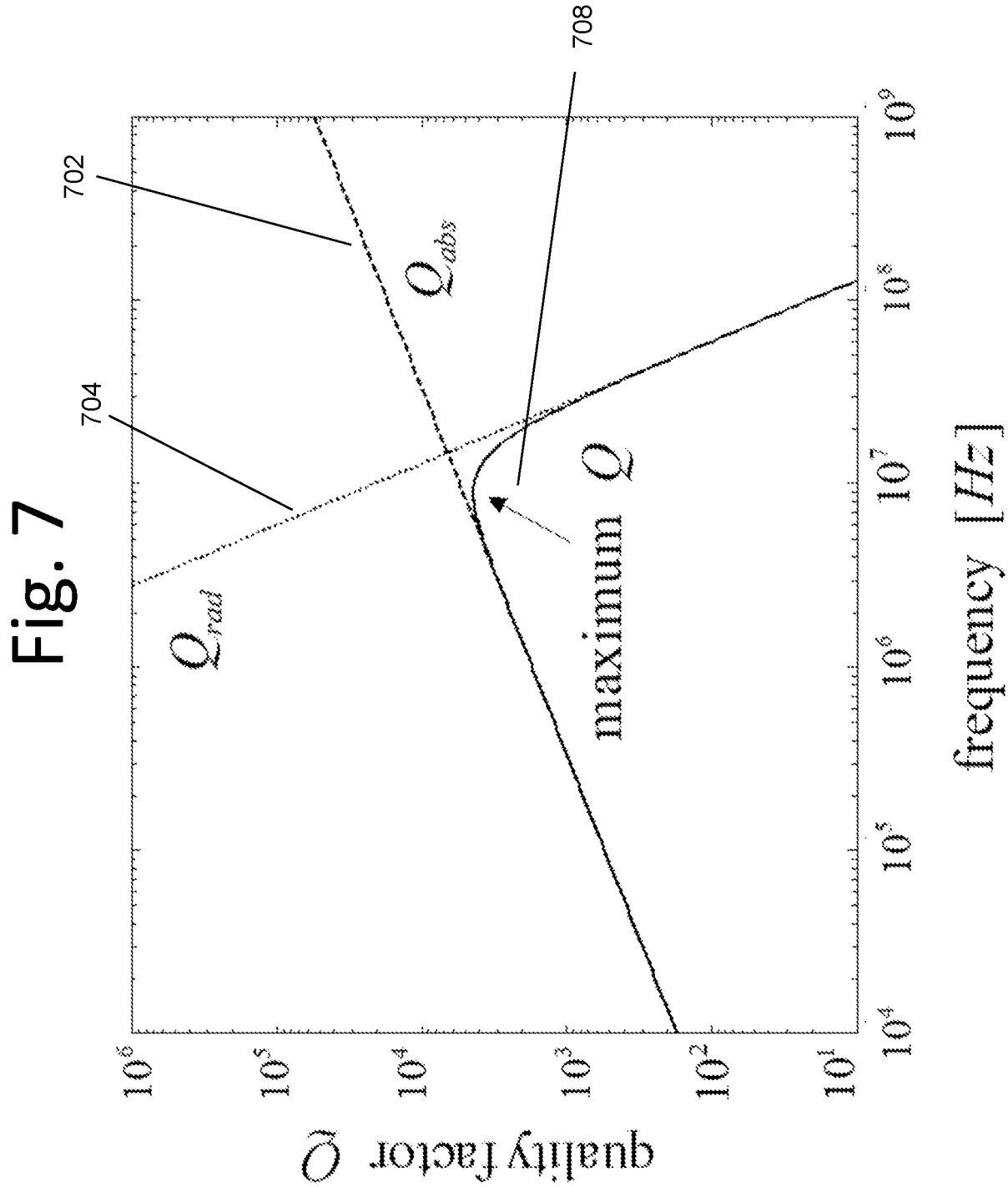
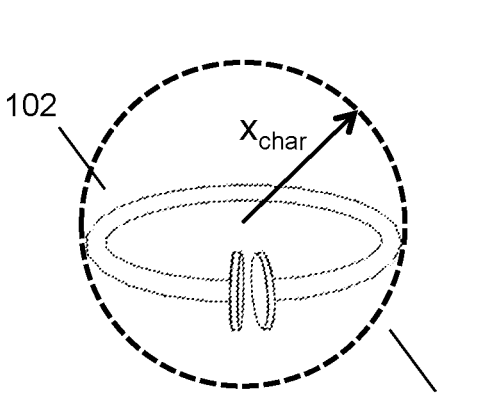
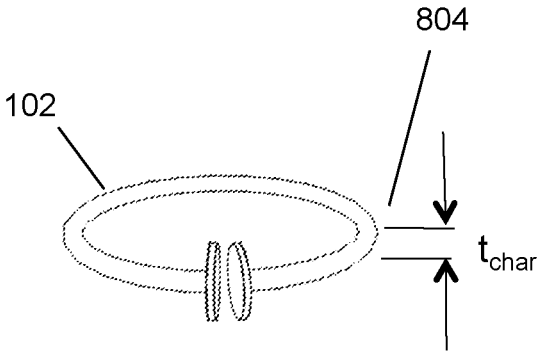

708
702
704
Q_{abs}
Q_{rad}
maximum Q
quality factor Q
frequency [Hz]
10^6
10^5
10^4
10^3
10^2
10^1
10^4
10^5
10^6
10^7
10^8
10^9

Fig. 7

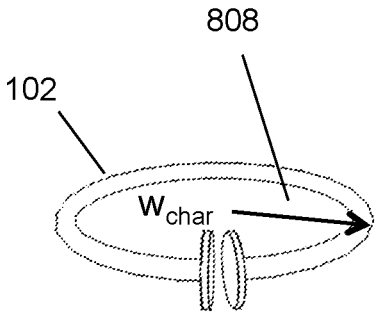
Fig. 8



characteristic size



characteristic thickness



characteristic width

Replacement Sheet

InductEV, Inc.
Exhibit 1002
Page 249

Fig. 9

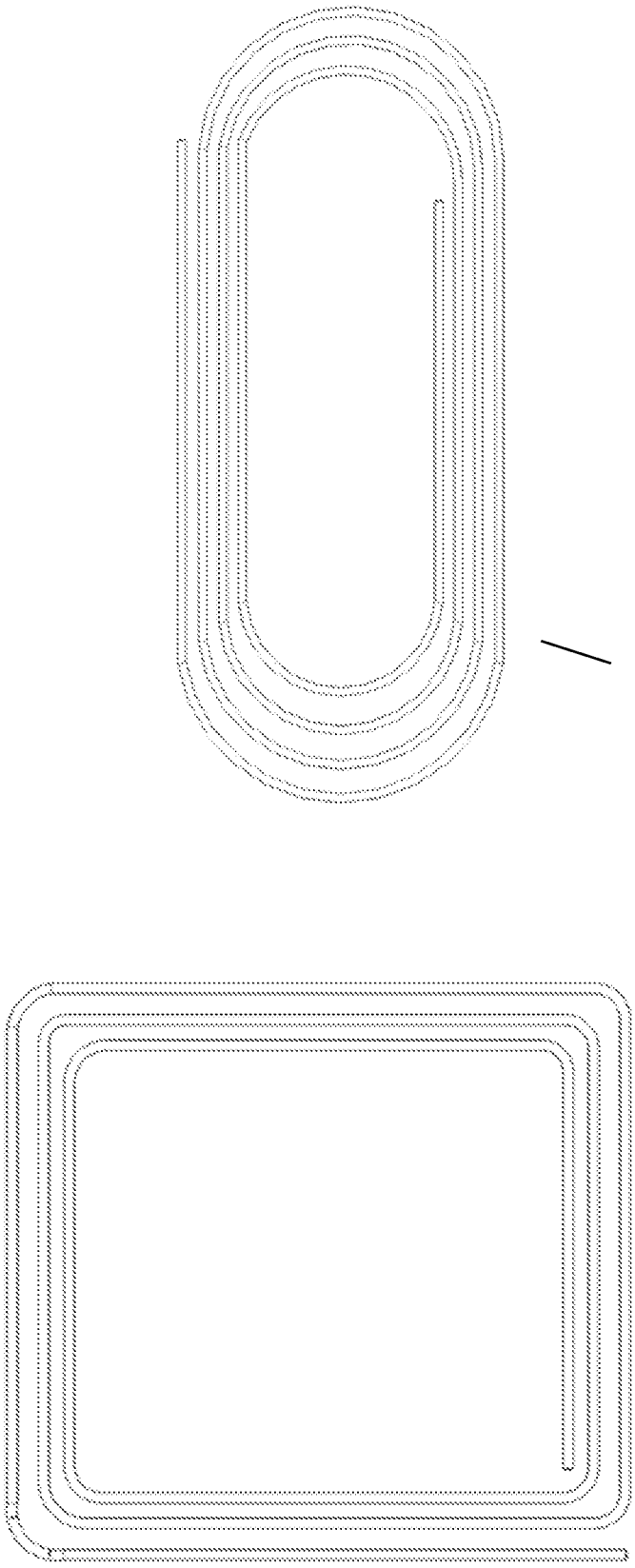


Fig. 10

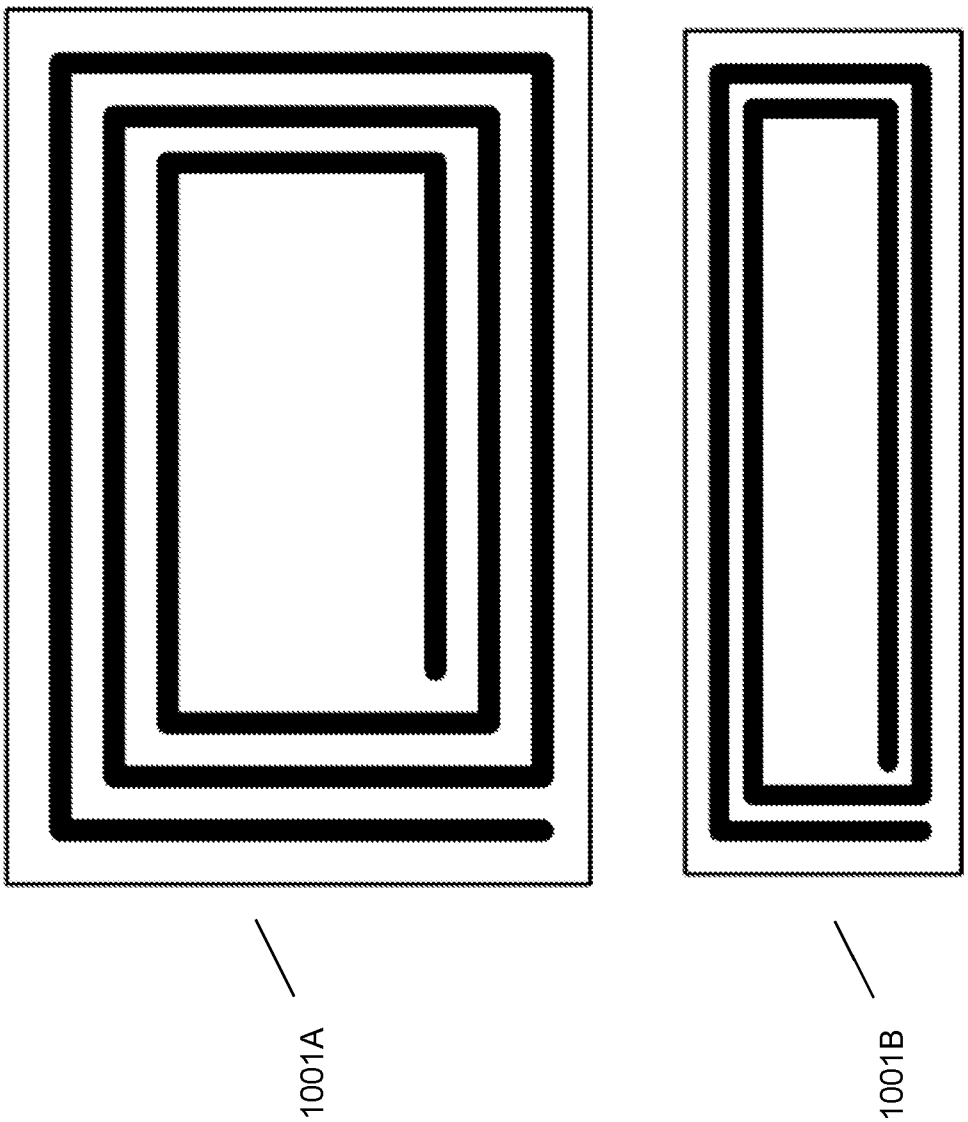
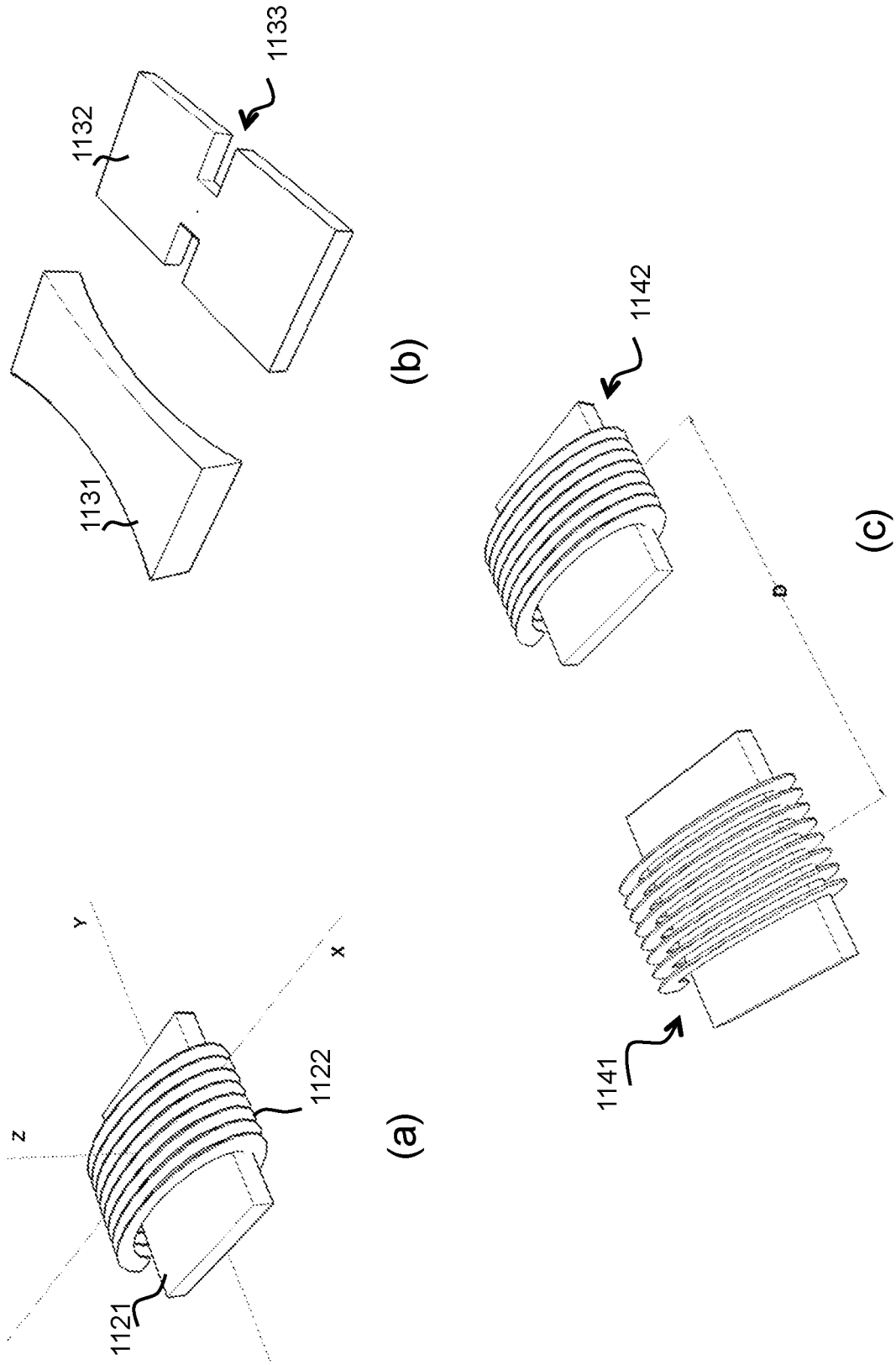


Fig. 11



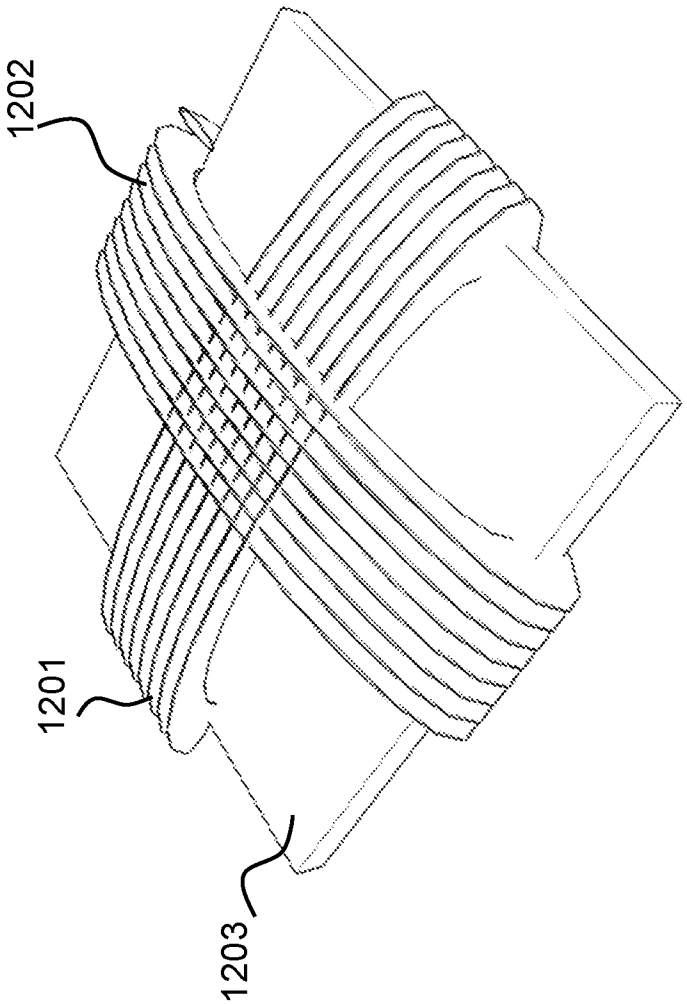


Fig. 12

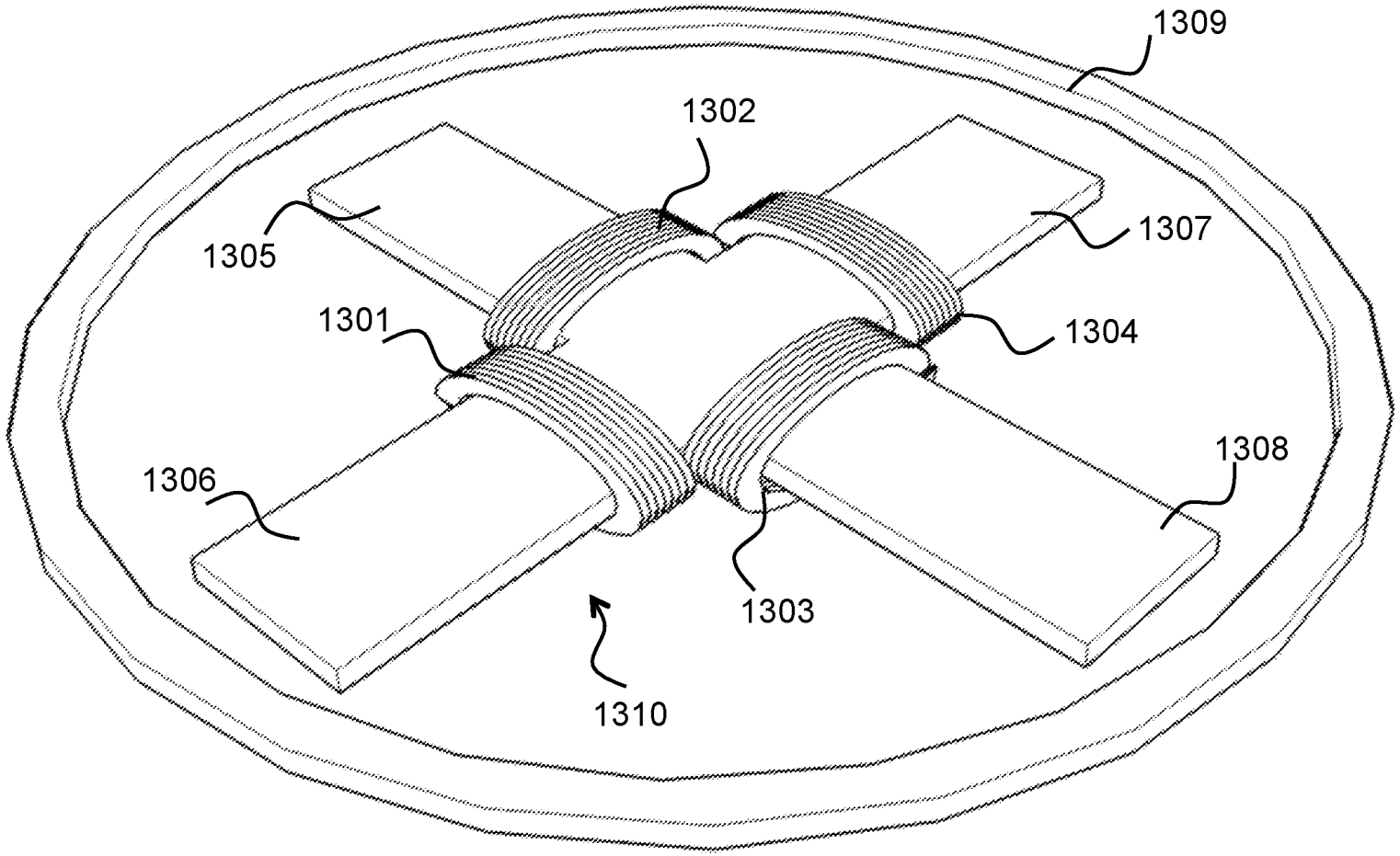


Fig. 13

Replacement Sheet

InductEV, Inc.
Exhibit 1002
Page 254

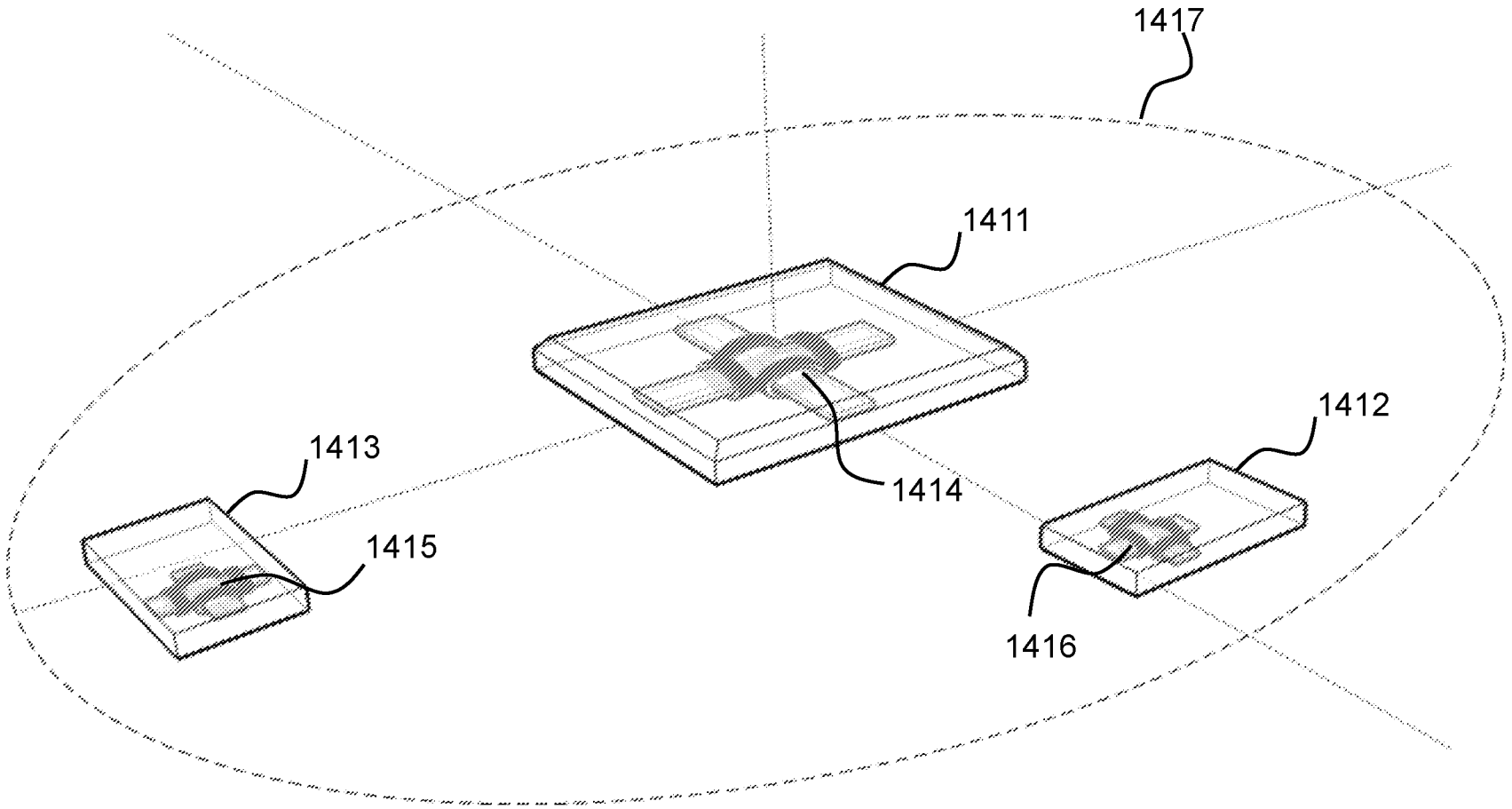


Fig. 14

Replacement Sheet

InductEV, Inc.
Exhibit 1002
Page 255

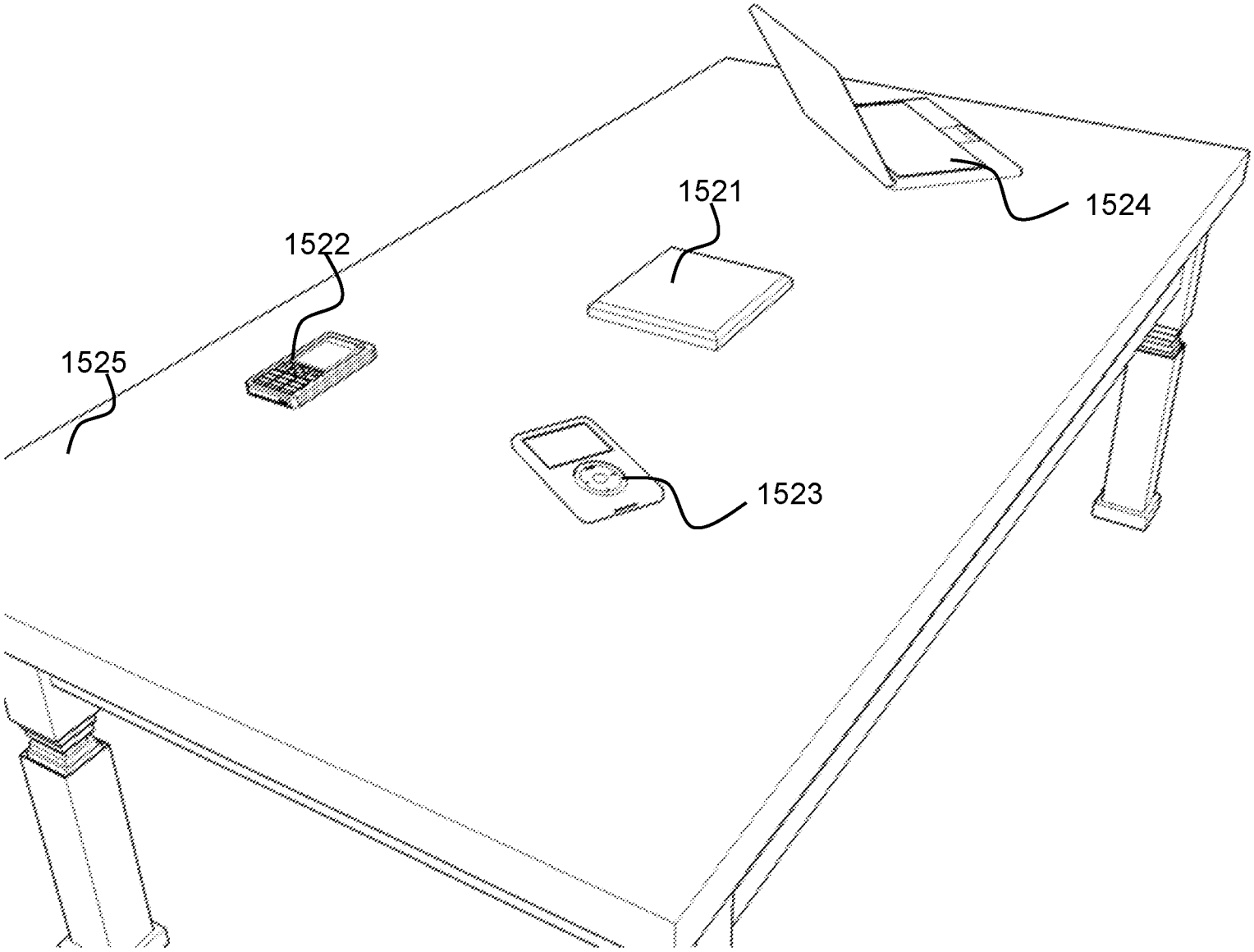


Fig. 15

Replacement Sheet

InductEV, Inc.
Exhibit 1002
Page 256

Fig. 16

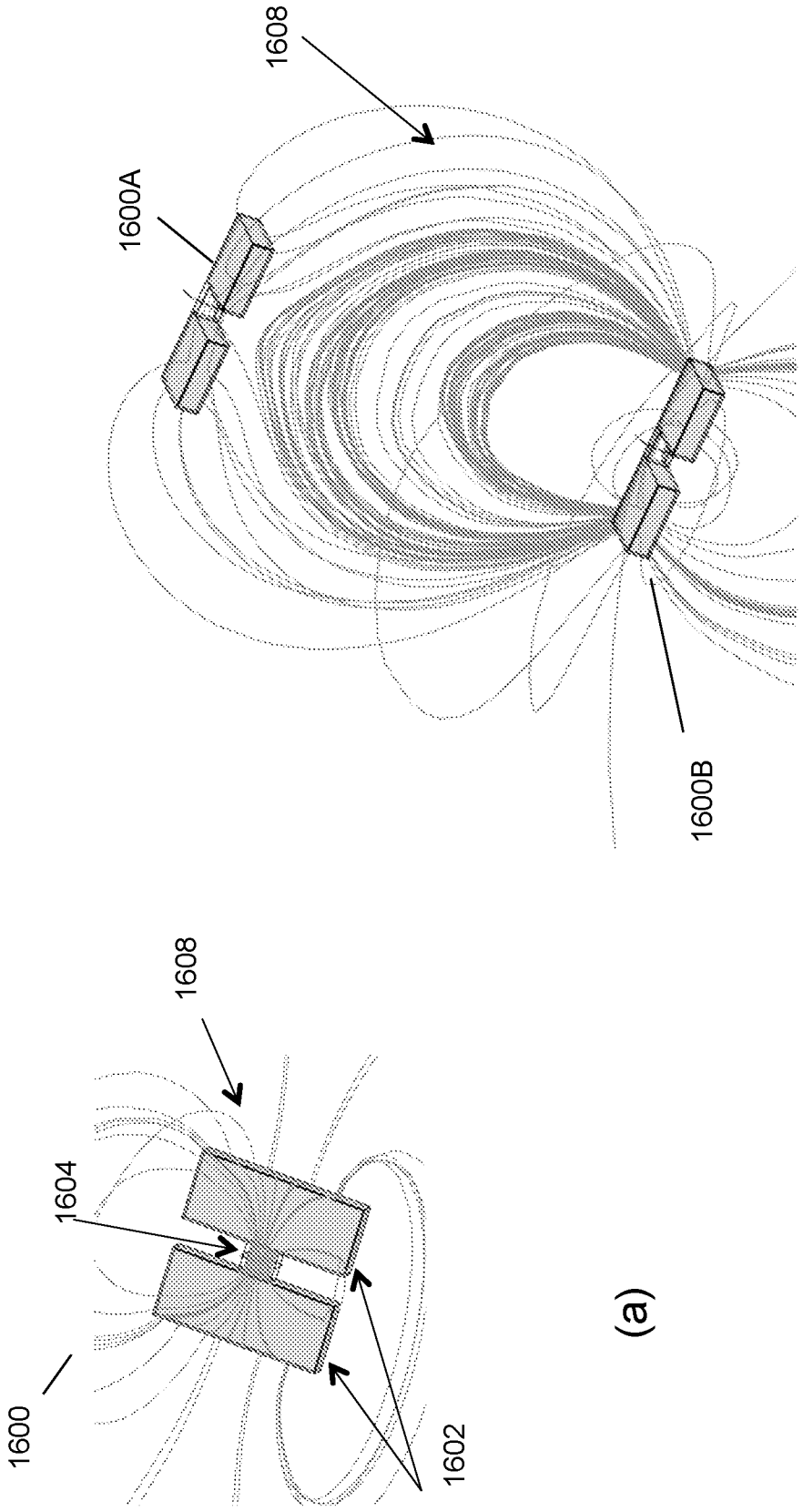
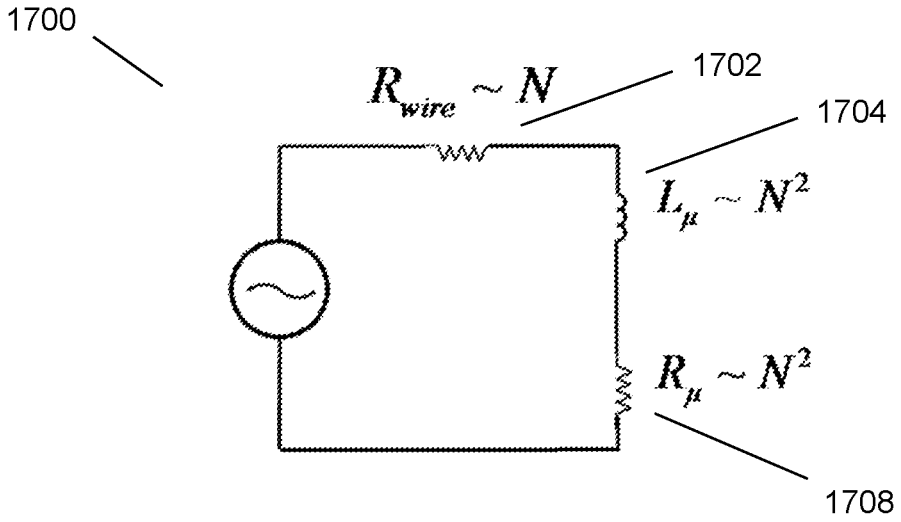


Fig. 17



Replacement Sheet

InductEV, Inc.
Exhibit 1002
Page 258

Fig. 18

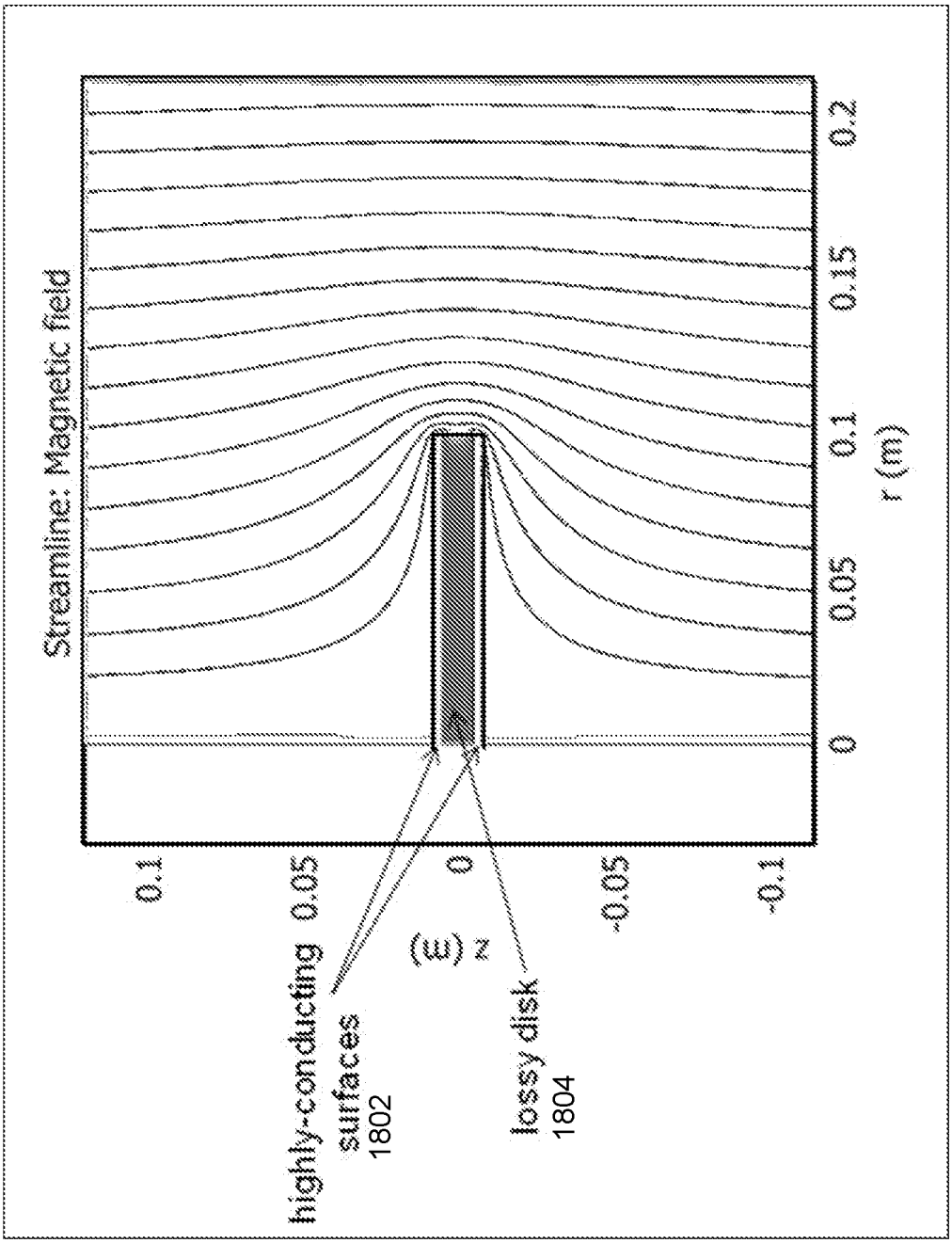

Streamline: Magnetic field
0.2
0.15
0.1
0.05
0
r (m)
0.1
0.05
0
-0.05
-0.1
z (m)
highly-conducting surfaces
1802
lossy disk
1804

Fig. 19

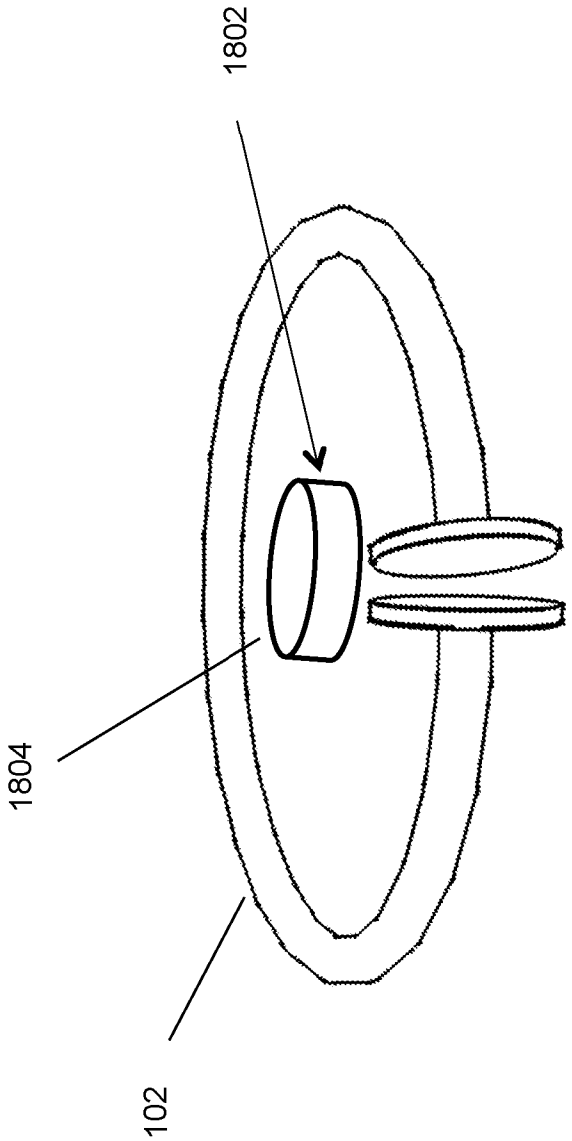


Fig. 20

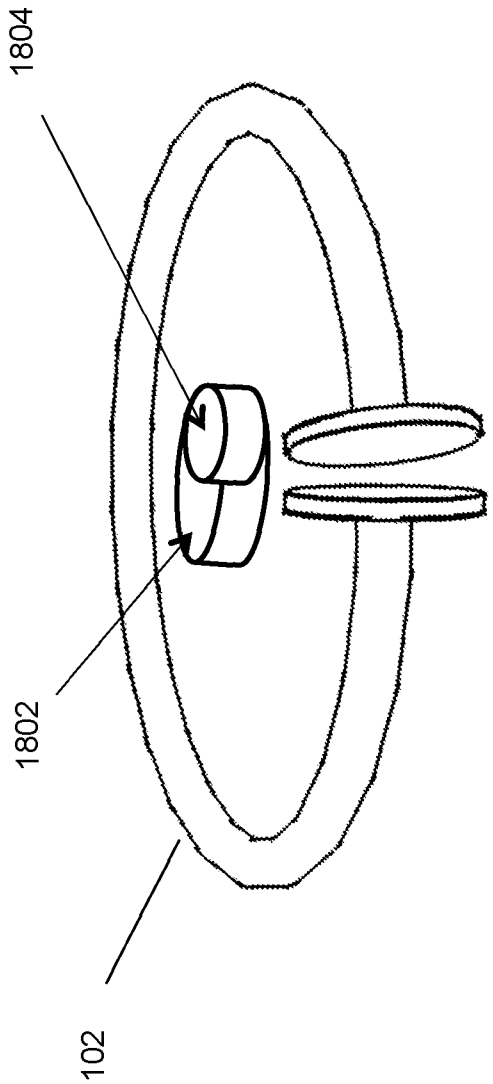


Fig. 21

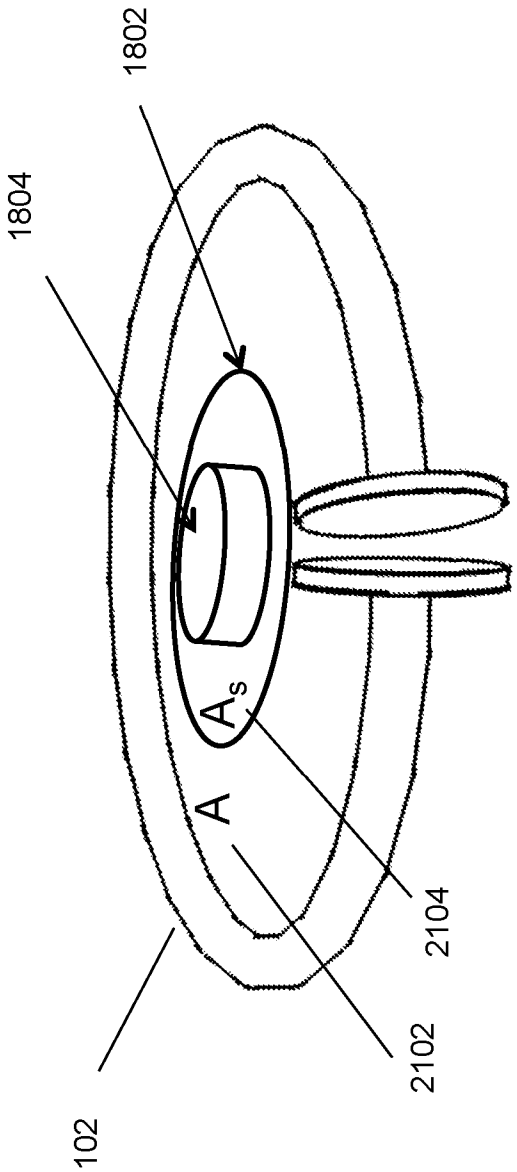
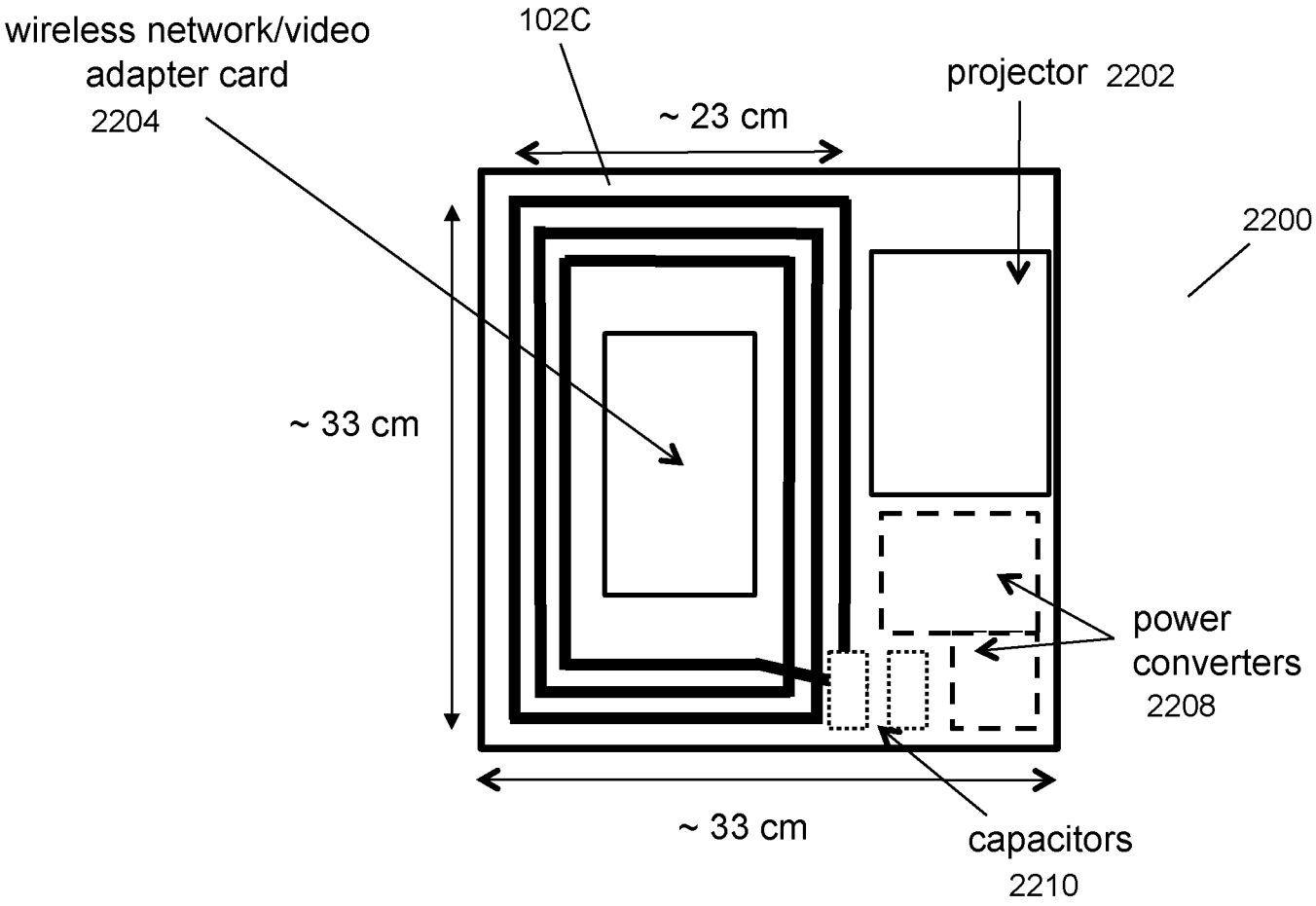


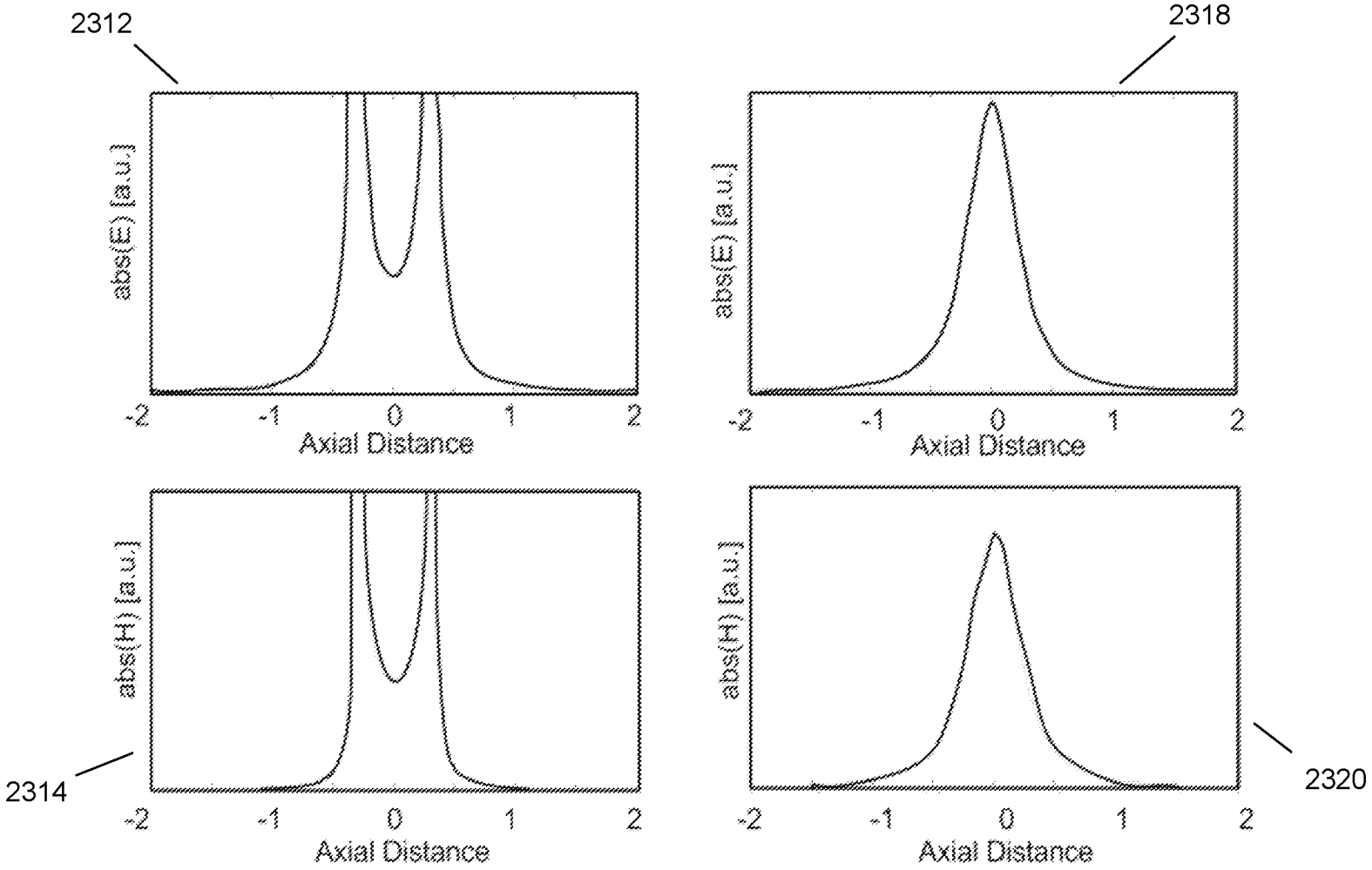
Fig. 22



Replacement Sheet

InductEV, Inc.
Exhibit 1002
Page 263

Fig. 23



Replacement Sheet

InductEV, Inc.
Exhibit 1002
Page 264

Fig. 24

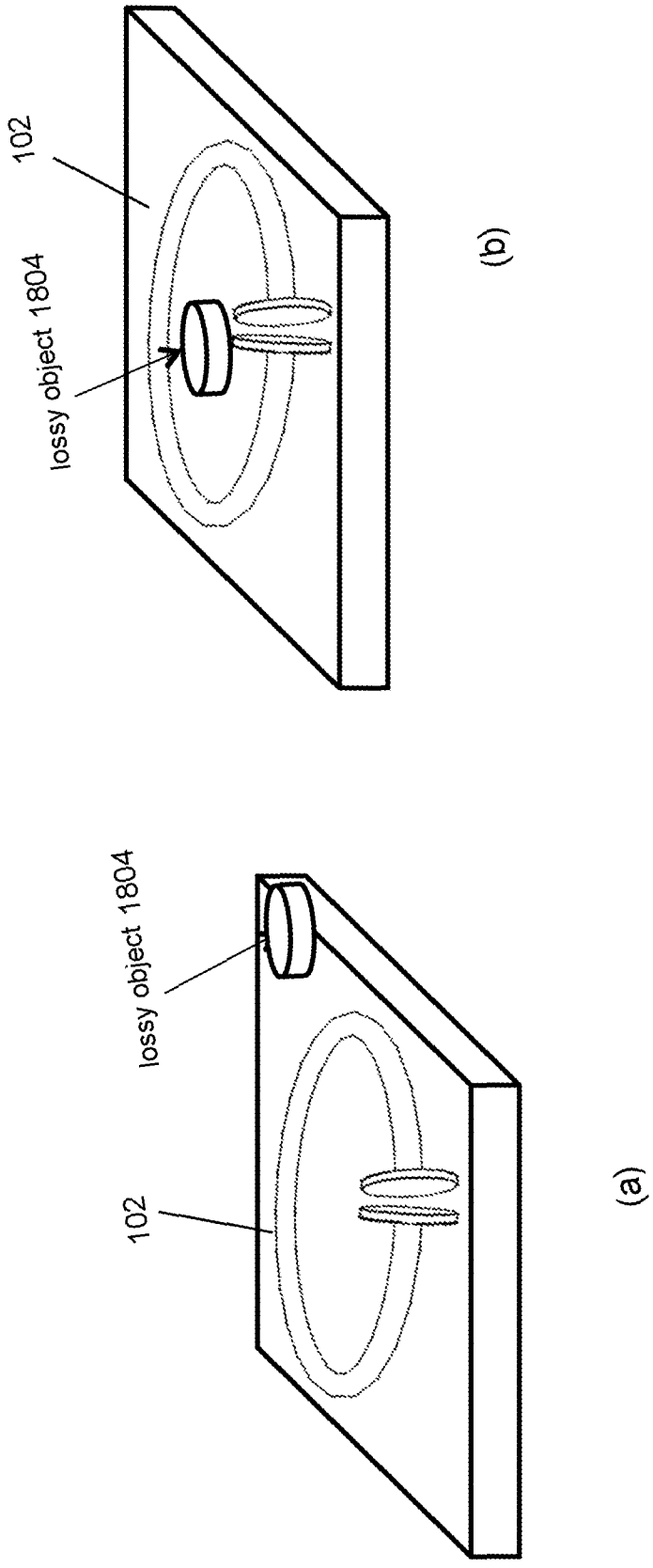


Fig. 25

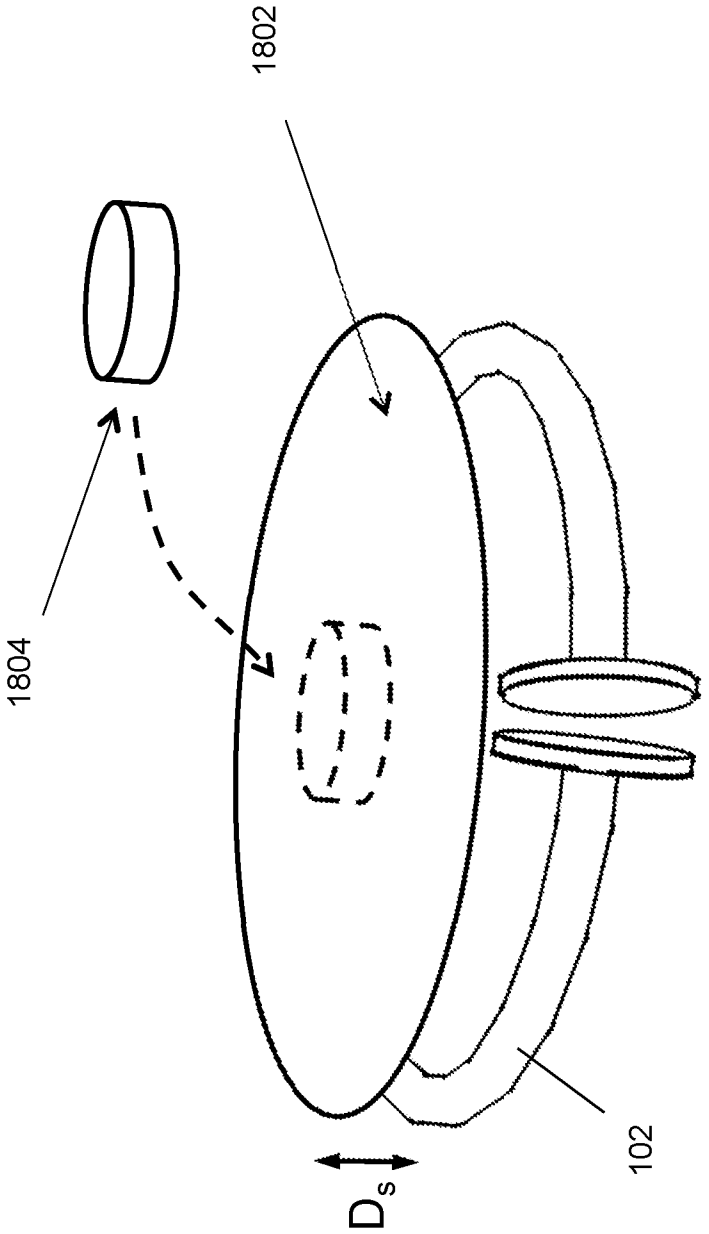
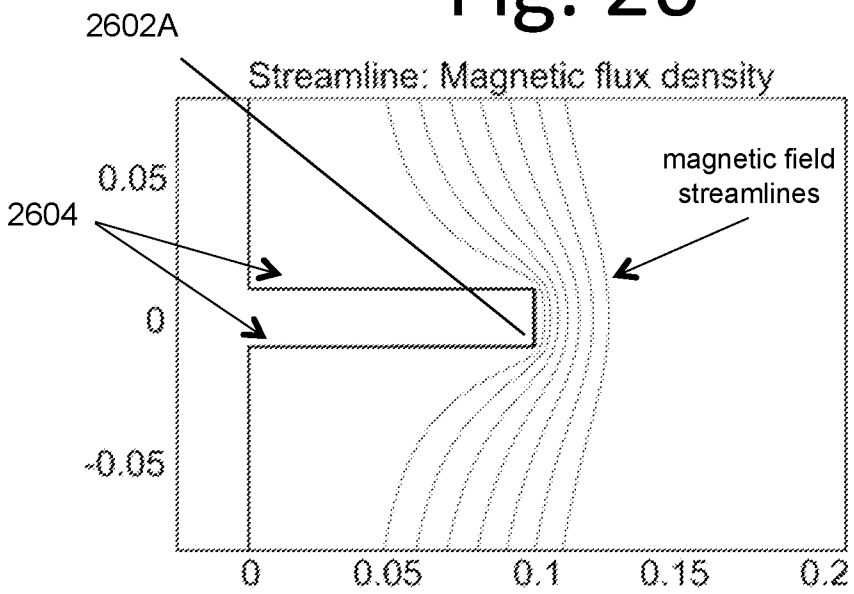
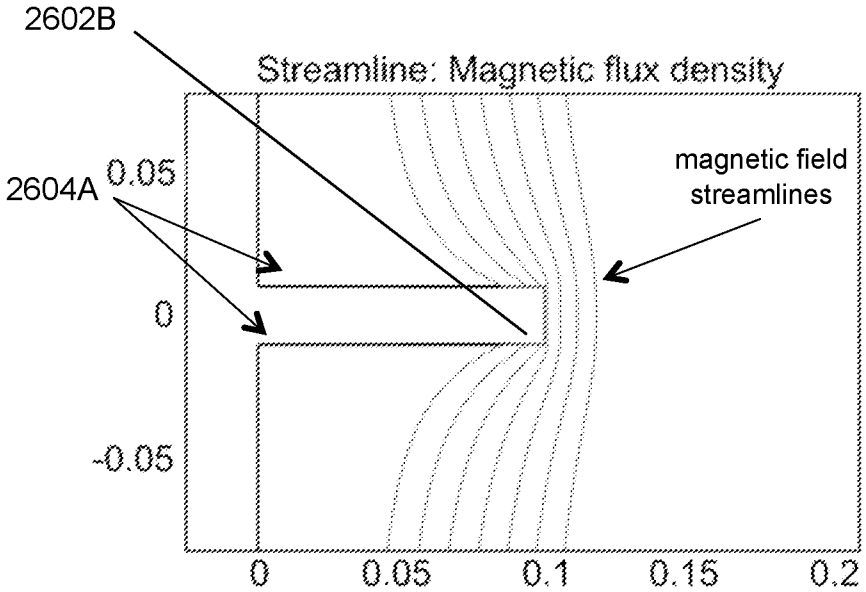


Fig. 26



(a)

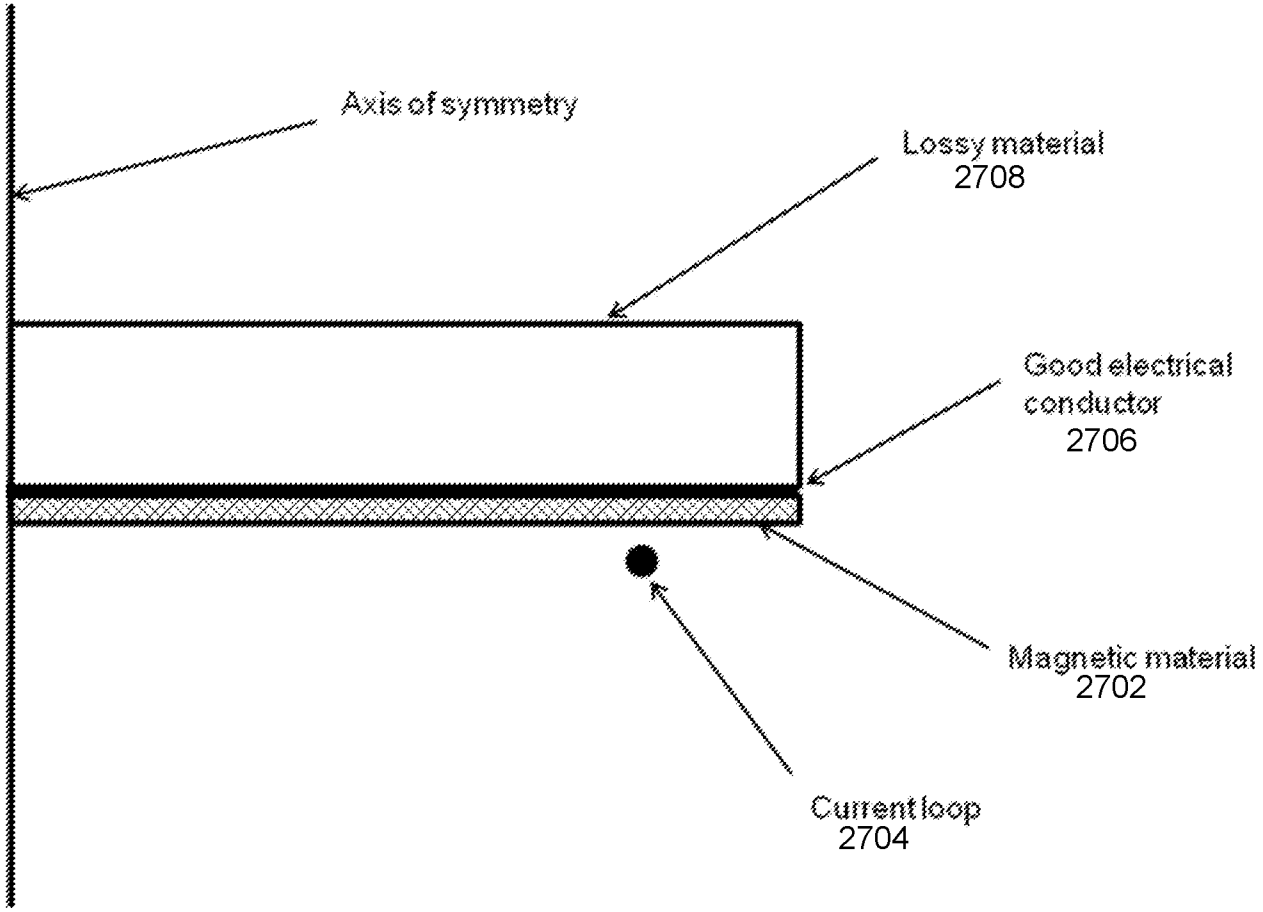


(b)

Replacement Sheet

InductEV, Inc.
Exhibit 1002
Page 267

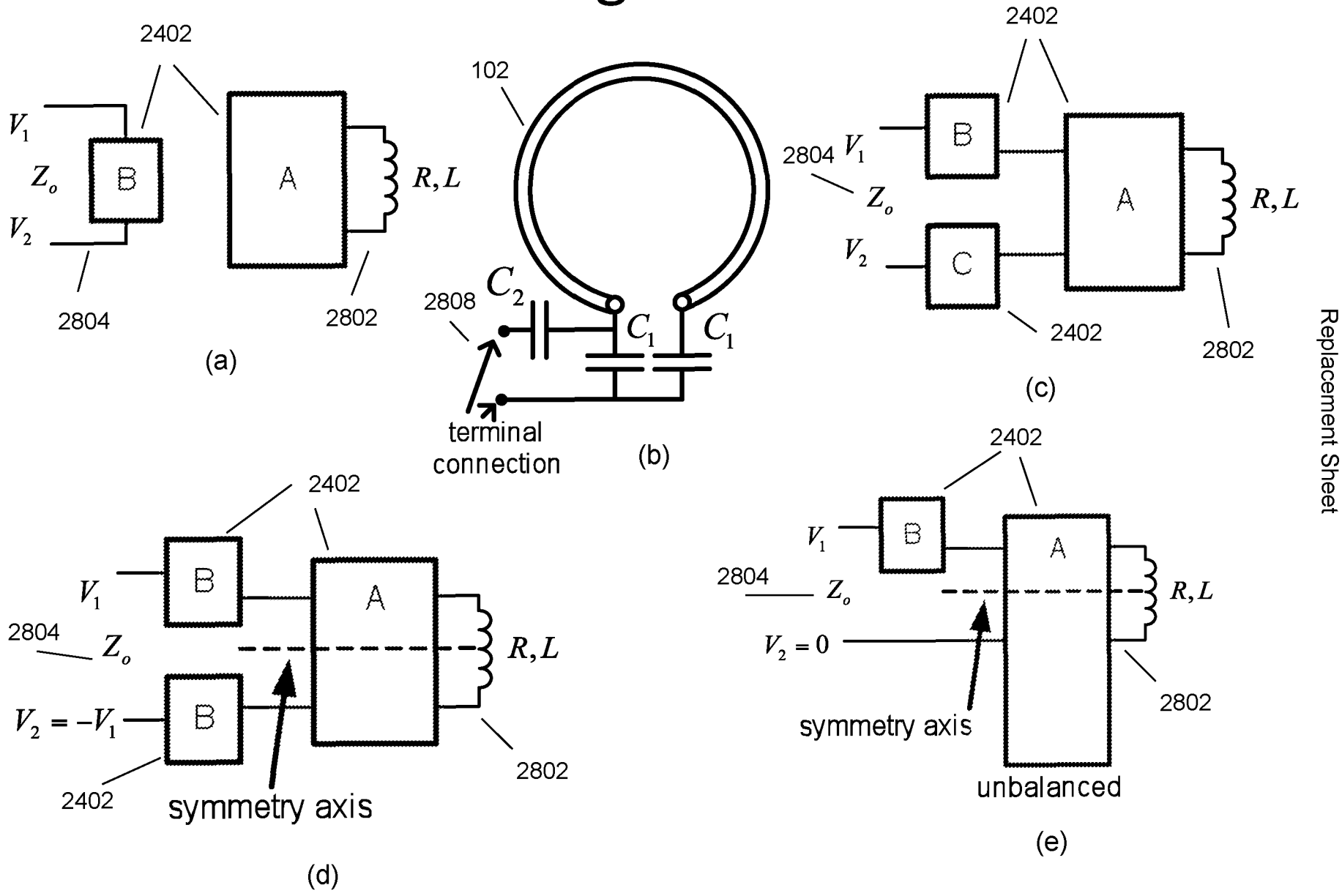
Fig. 27



Replacement Sheet

InductEV, Inc.
Exhibit 1002
Page 268

Fig. 28



Replacement Sheet

Fig. 29

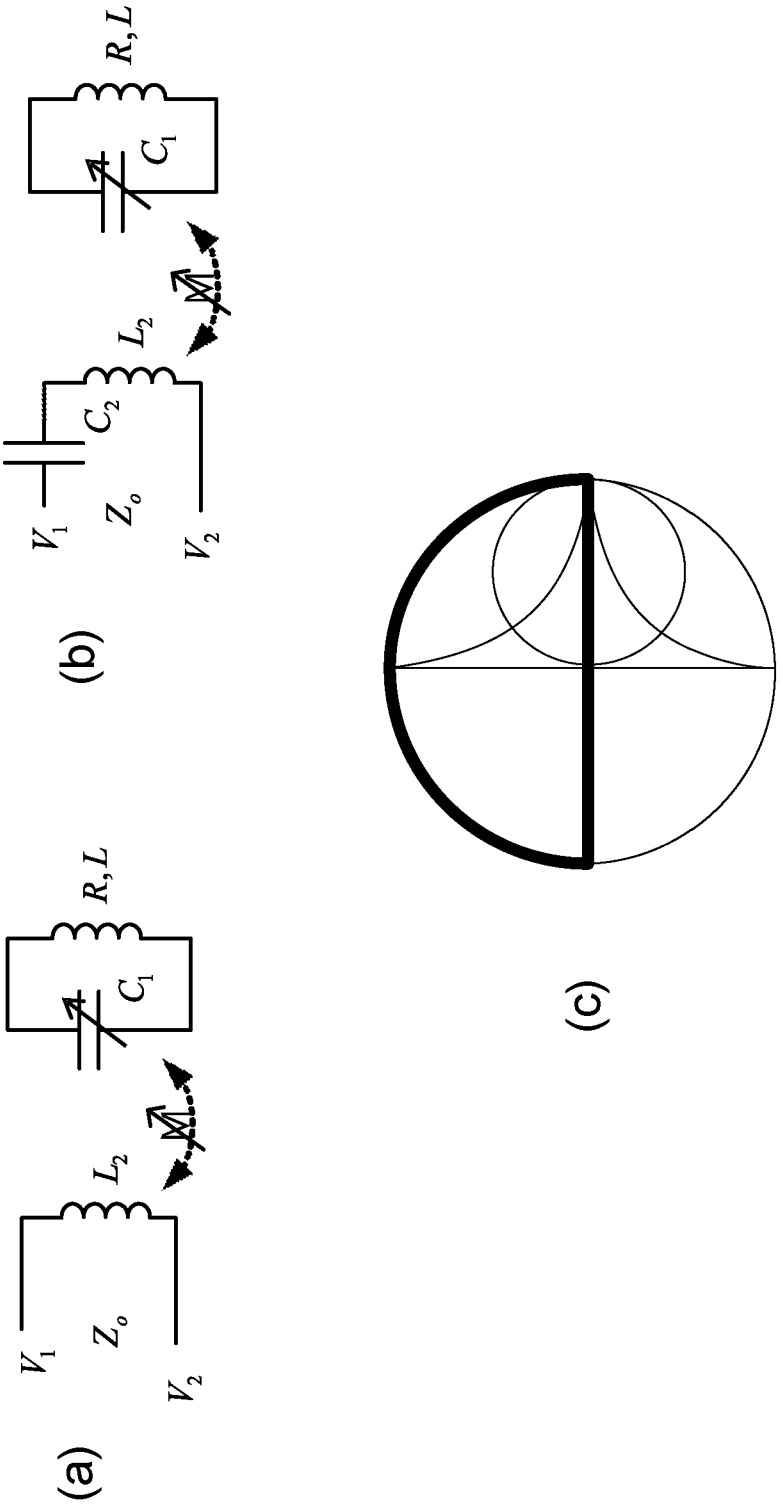
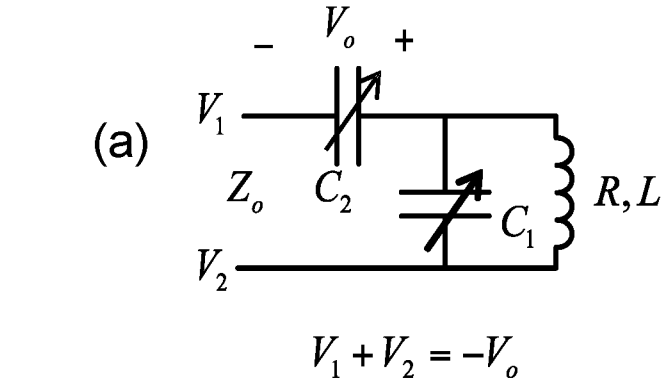
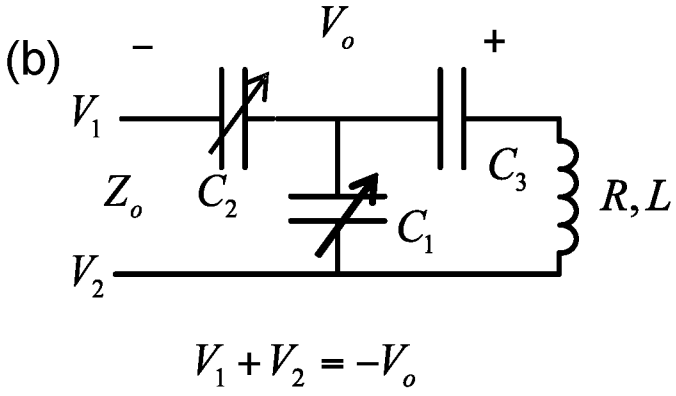
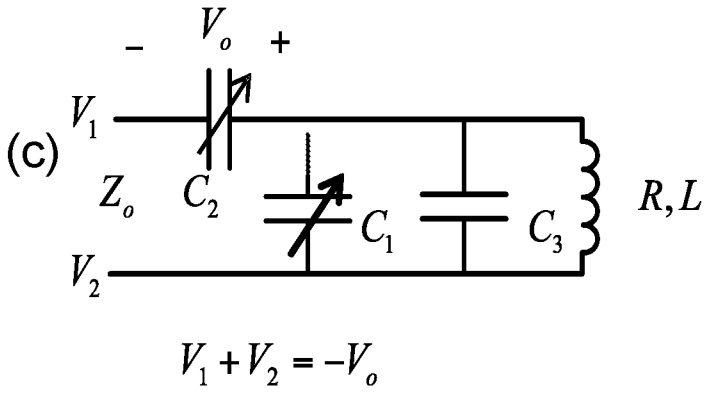
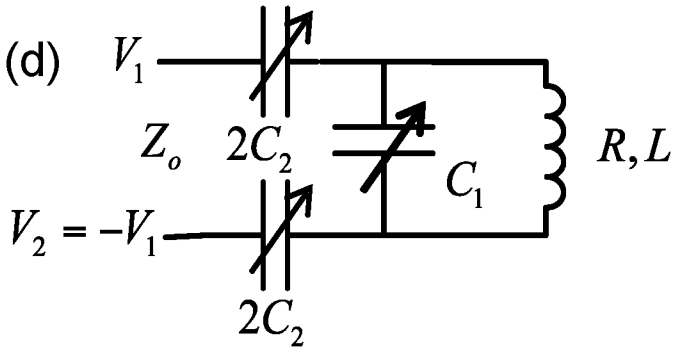


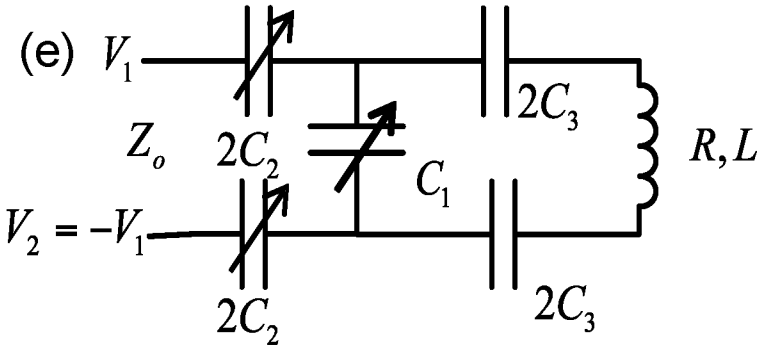
Fig. 30

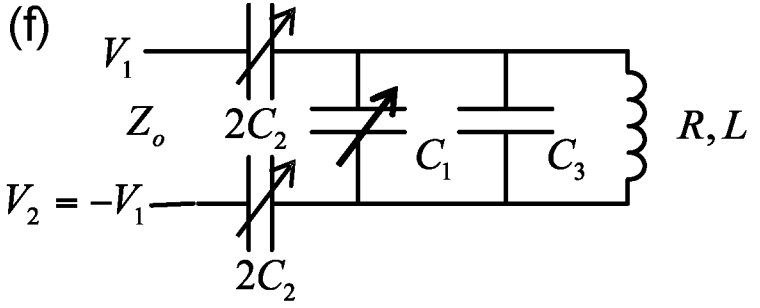


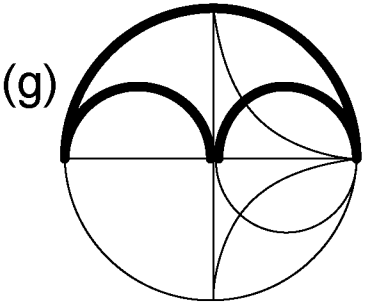












Replacement Sheet

InductEV, Inc.
Exhibit 1002
Page 271

Fig. 30

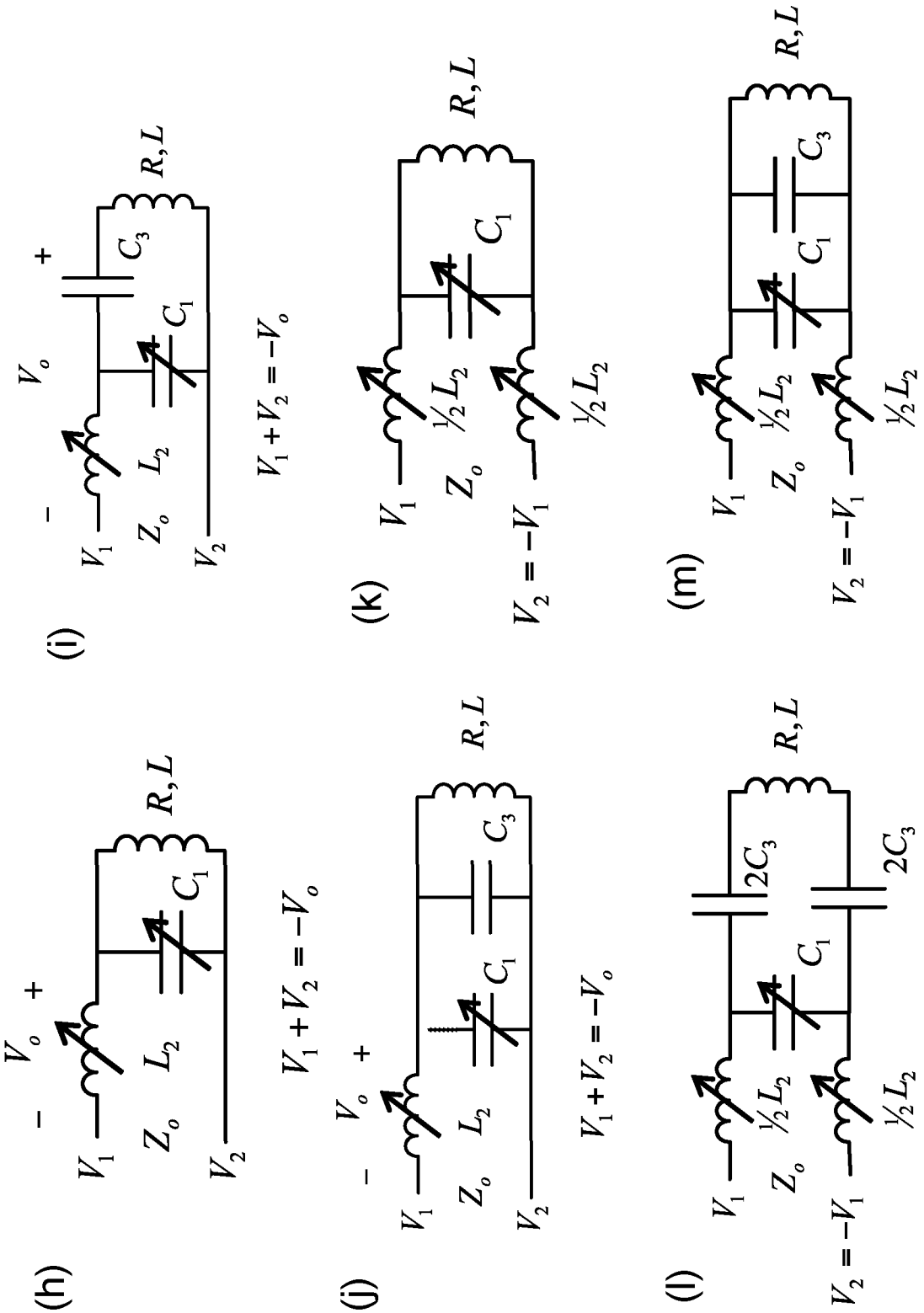
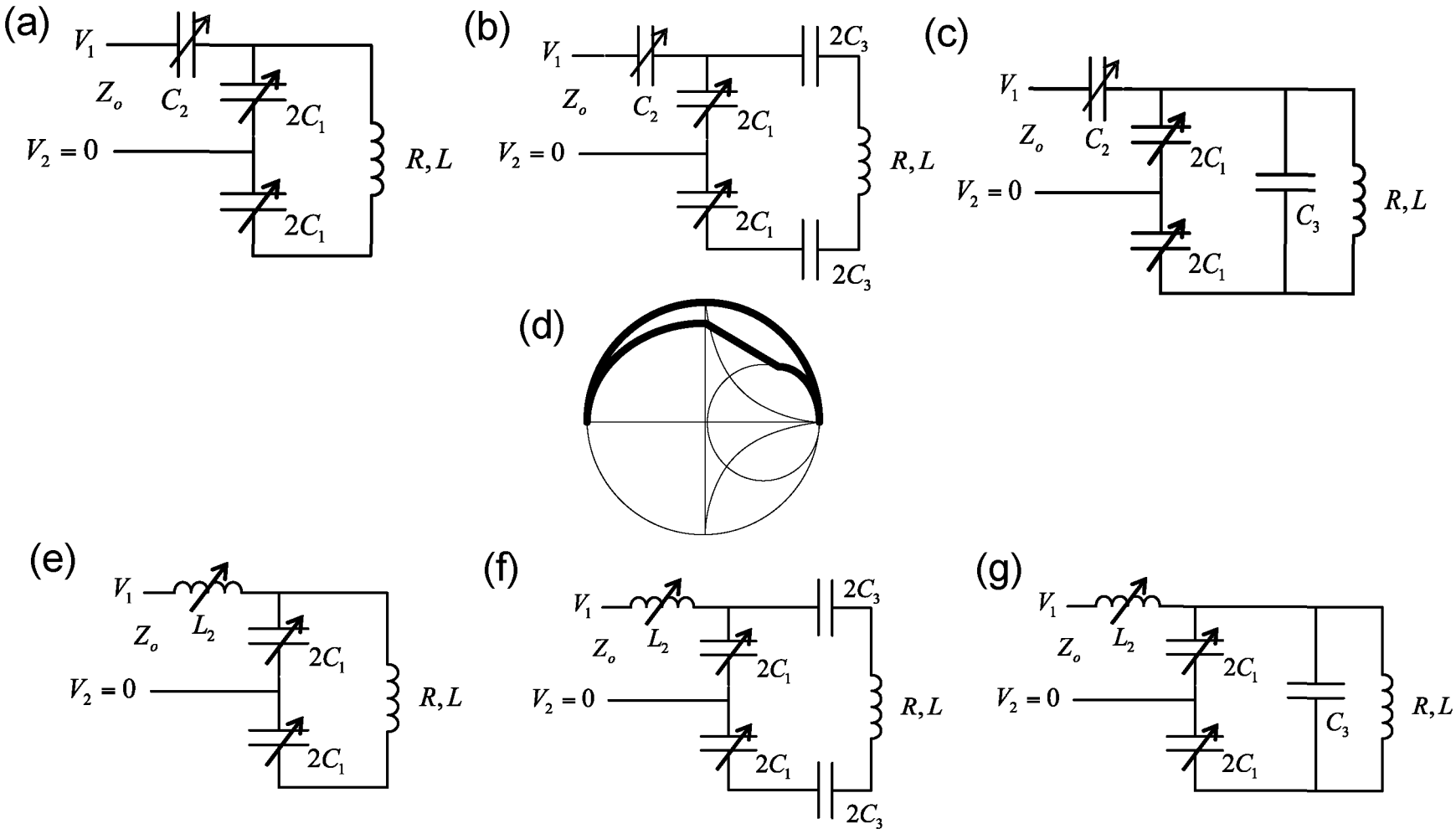

(h)
V_o
V_1
Z_o
L_2
C_1
R, L
V_2
$V_1 + V_2 = -V_o$
(i)
V_o
V_1
Z_o
L_2
C_1
C_3
R, L
V_2
$V_1 + V_2 = -V_o$
(j)
V_o
V_1
Z_o
L_2
C_1
C_3
R, L
V_2
$V_1 + V_2 = -V_o$
(k)
V_1
Z_o
$\frac{1}{2}L_2$
C_1
R, L
$\frac{1}{2}L_2$
$V_2 = -V_1$
(l)
V_1
Z_o
$\frac{1}{2}L_2$
$2C_3$
C_1
R, L
$2C_3$
$\frac{1}{2}L_2$
$V_2 = -V_1$
(m)
V_1
Z_o
$\frac{1}{2}L_2$
C_1
C_3
R, L
$\frac{1}{2}L_2$
$V_2 = -V_1$

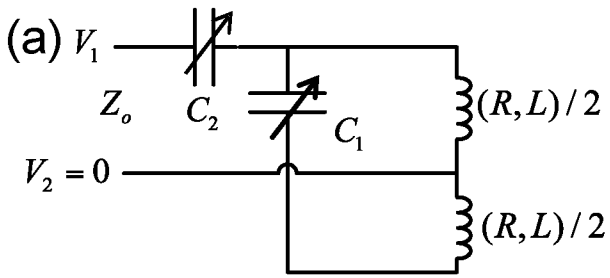
Fig. 31

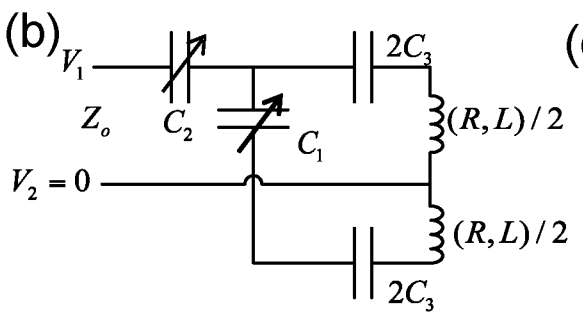


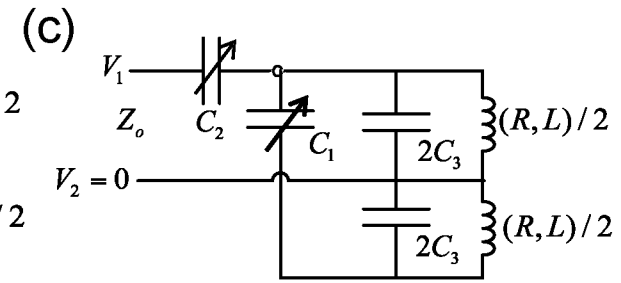
Replacement Sheet

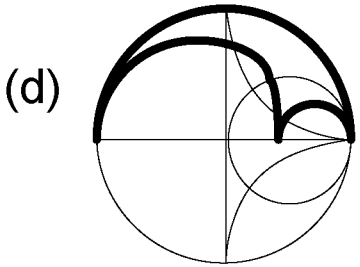
InductEV, Inc.
Exhibit 1002
Page 273

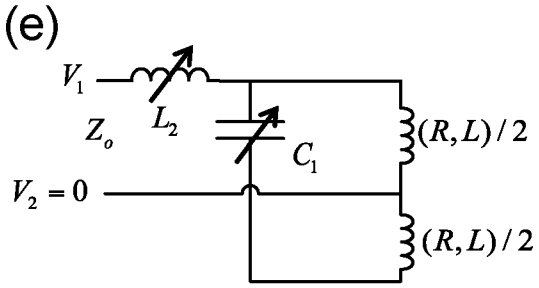
Fig. 32

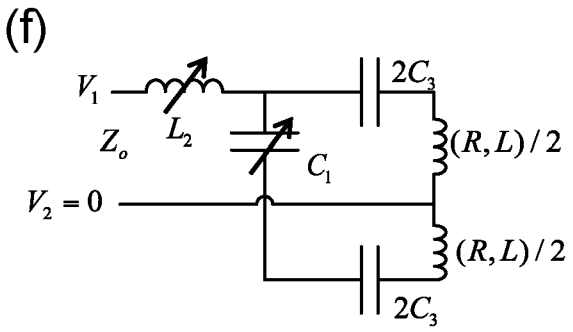


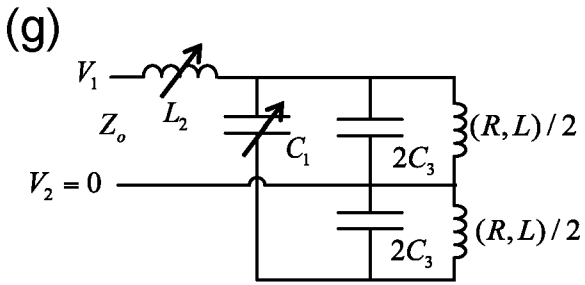










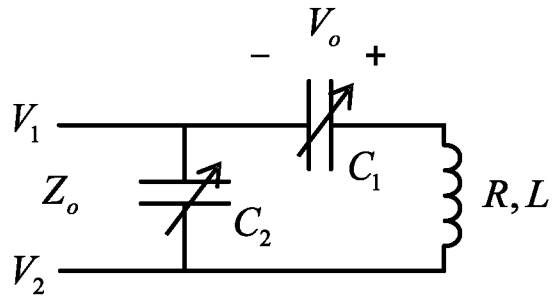


Replacement Sheet

InductEV, Inc.
Exhibit 1002
Page 274

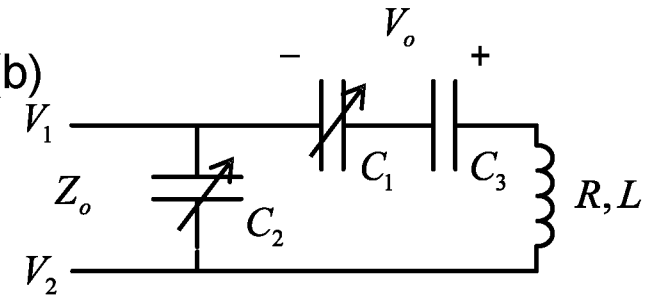
Fig. 33

(a)



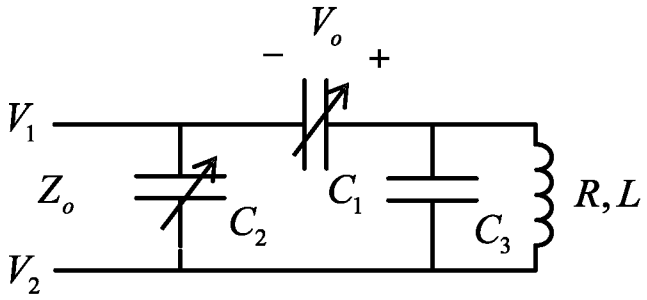
$$V_1 + V_2 = -V_o$$

(b)



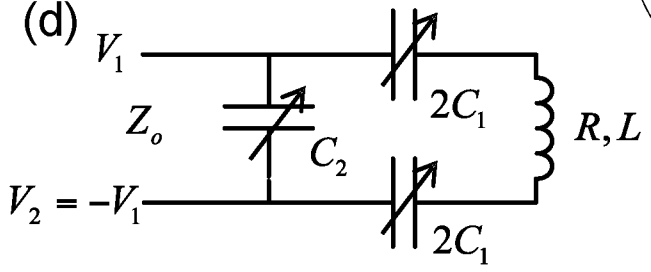
$$V_1 + V_2 = -V_o$$

(c)

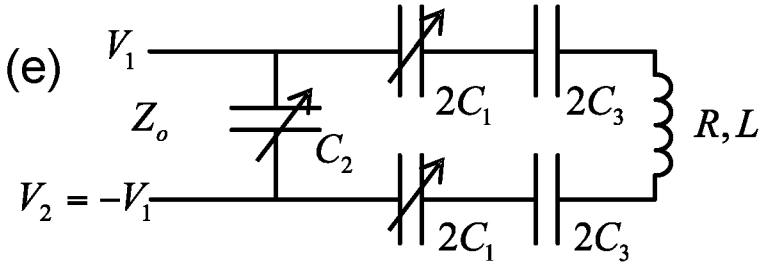


$$V_1 + V_2 = -V_o$$

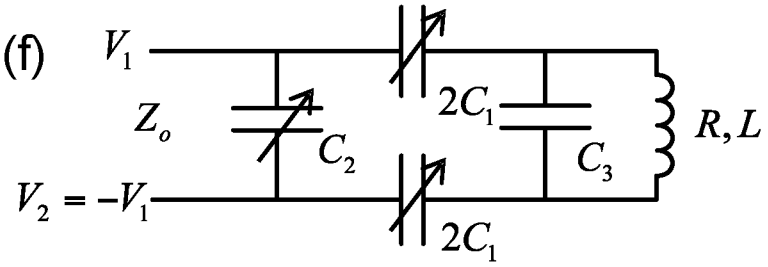
(d)



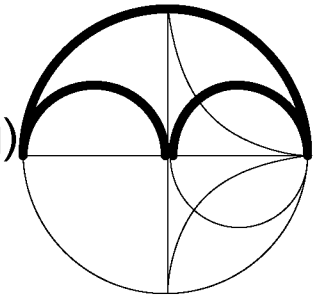
(e)



(f)



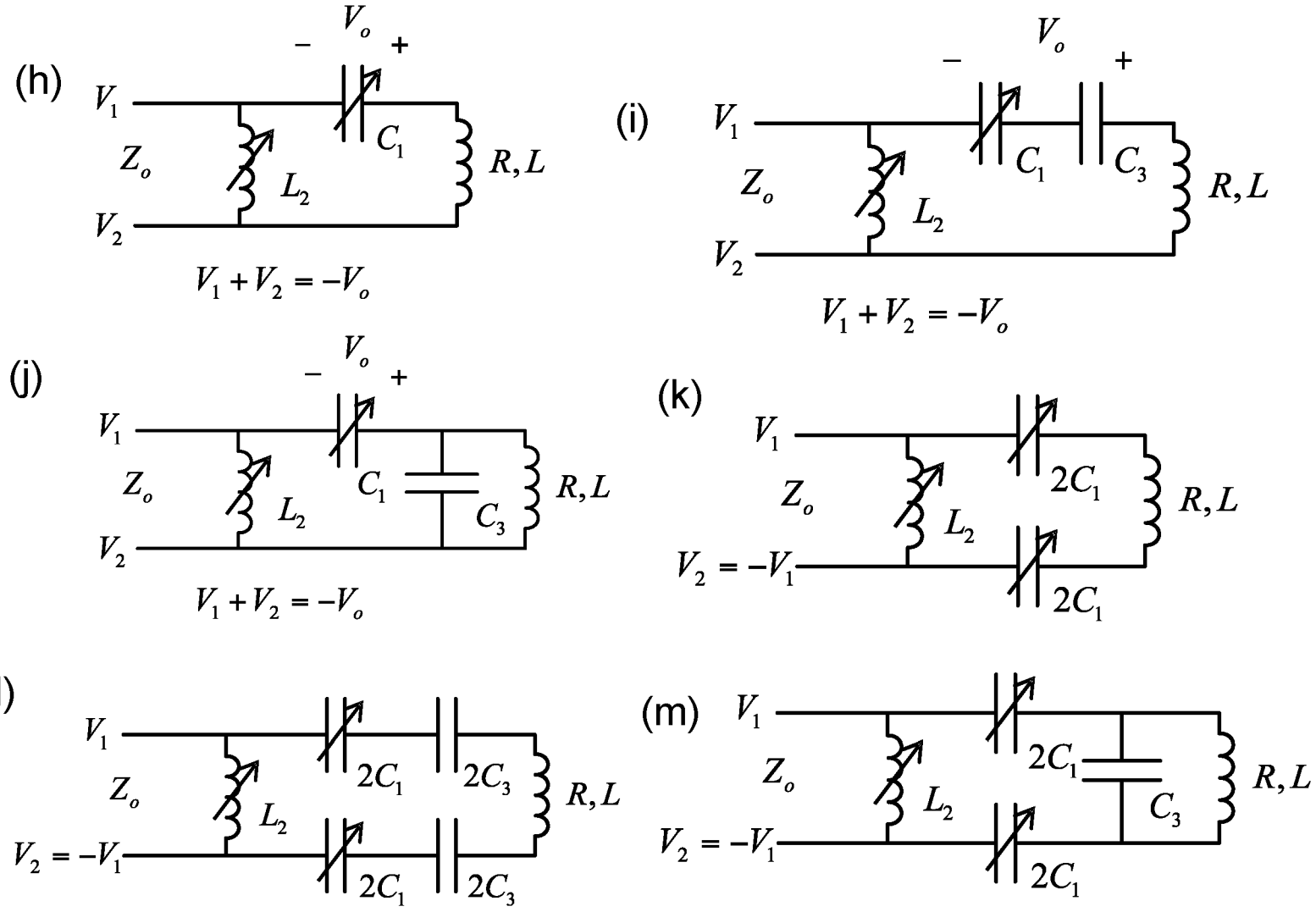
(g)



Replacement Sheet

InductEV, Inc.
Exhibit 1002
Page 275

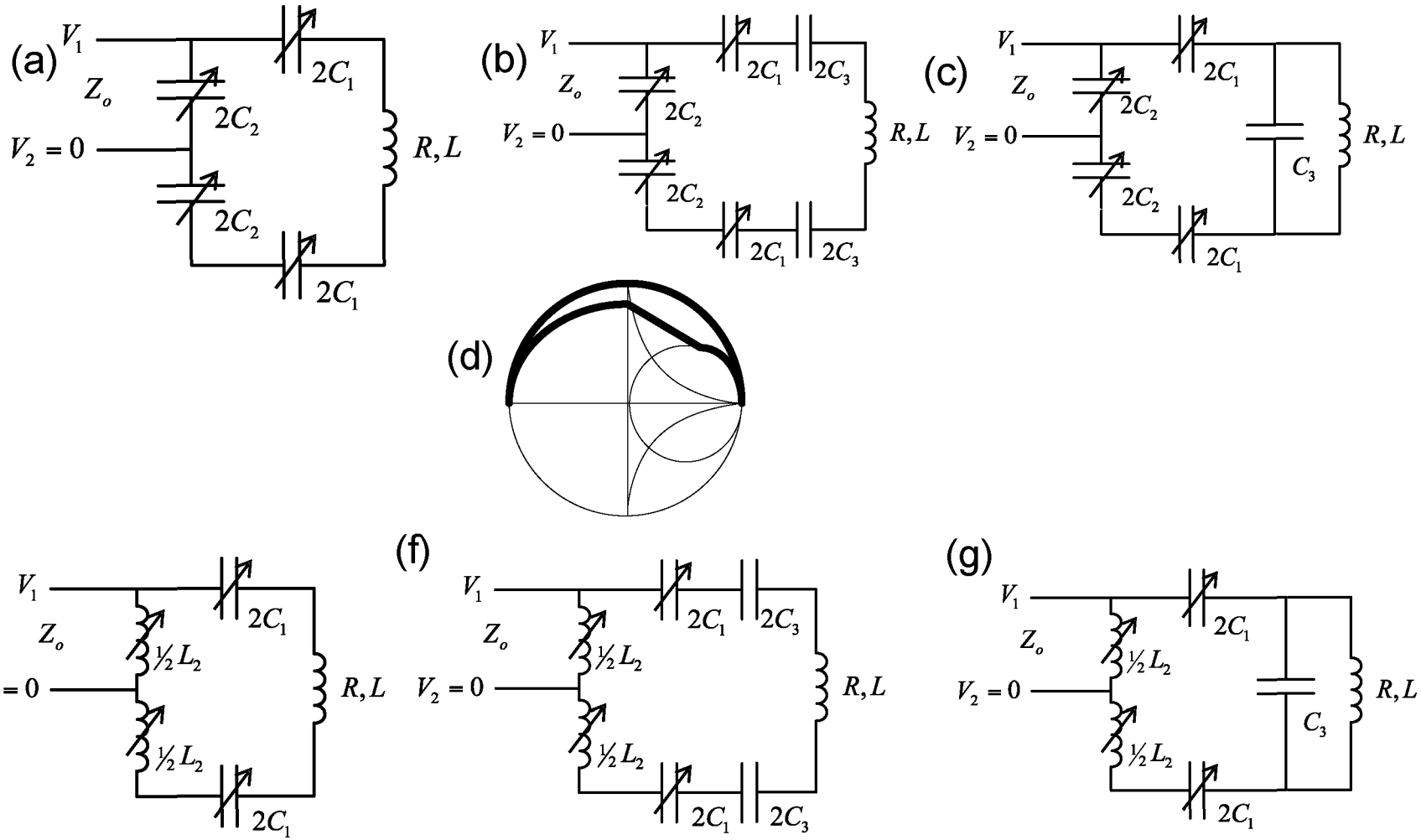
Fig. 33



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InductEV, Inc.
Exhibit 1002
Page 276

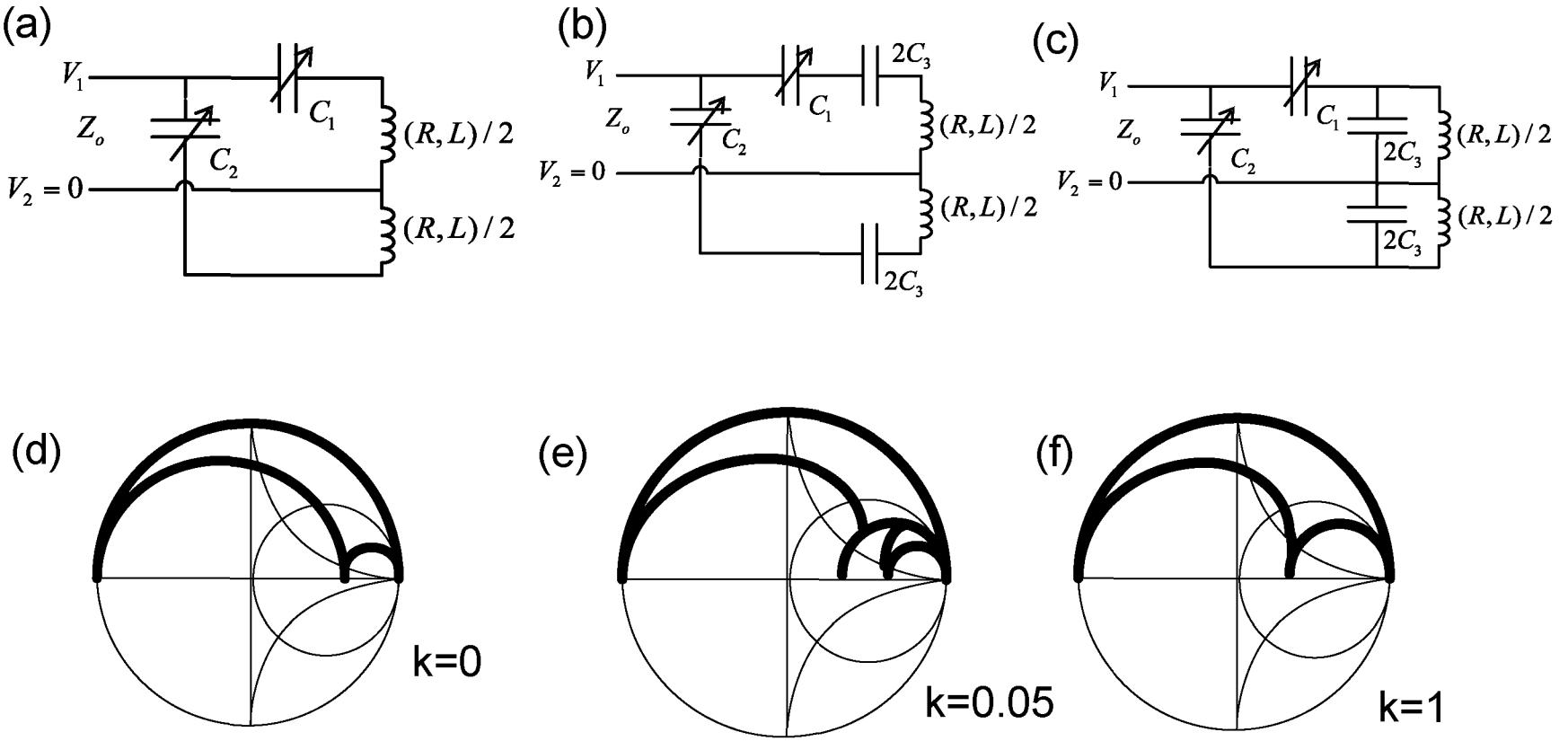
Fig. 34



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Exhibit 1002
Page 277

Fig. 35



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Exhibit 1002
Page 278

88

Fig. 36

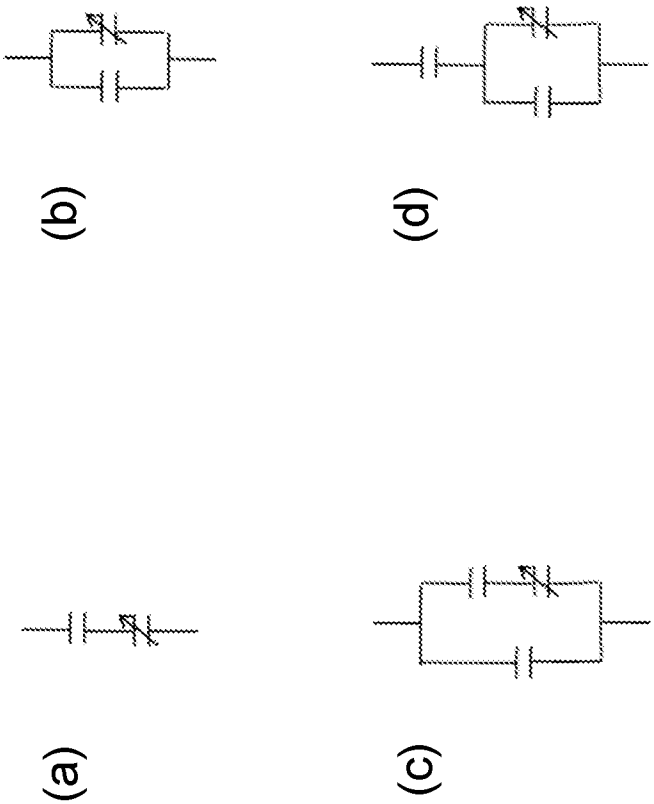


Fig. 37

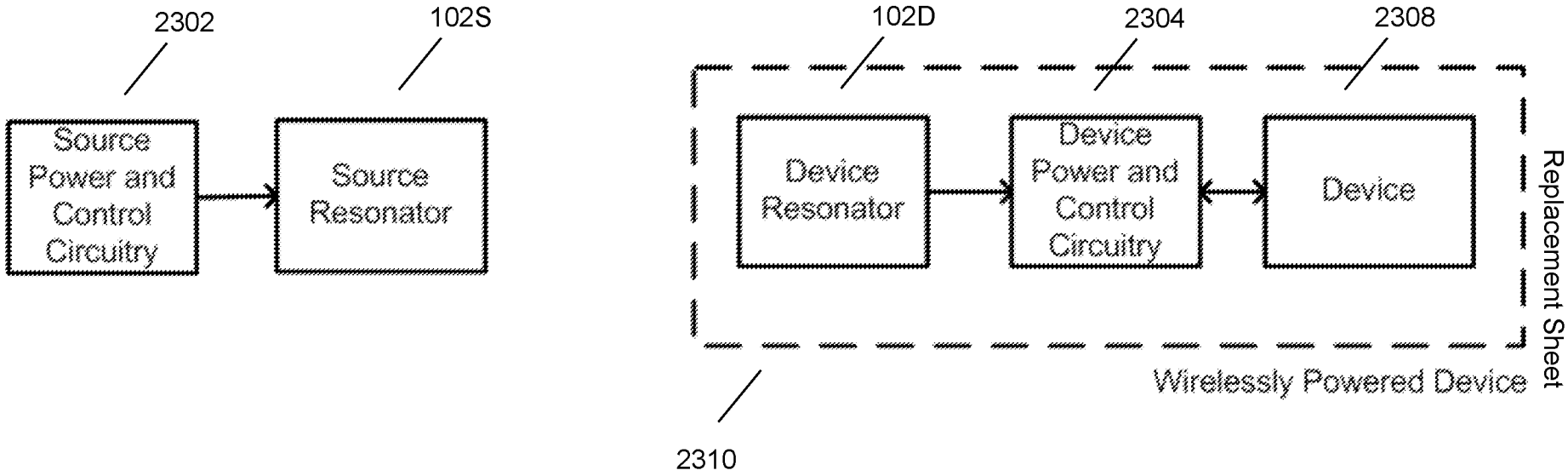


(b)



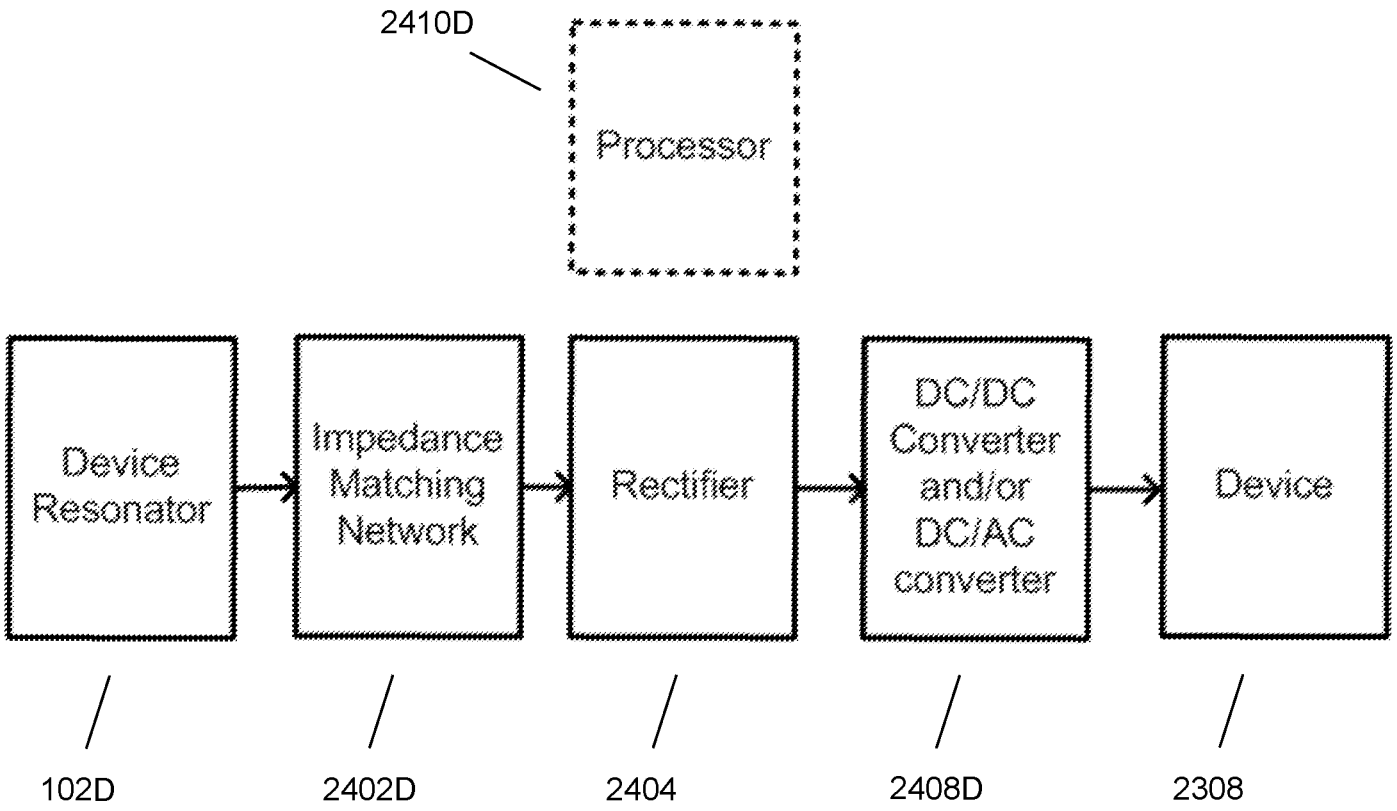
(a)

Fig. 38



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Exhibit 1002
Page 281

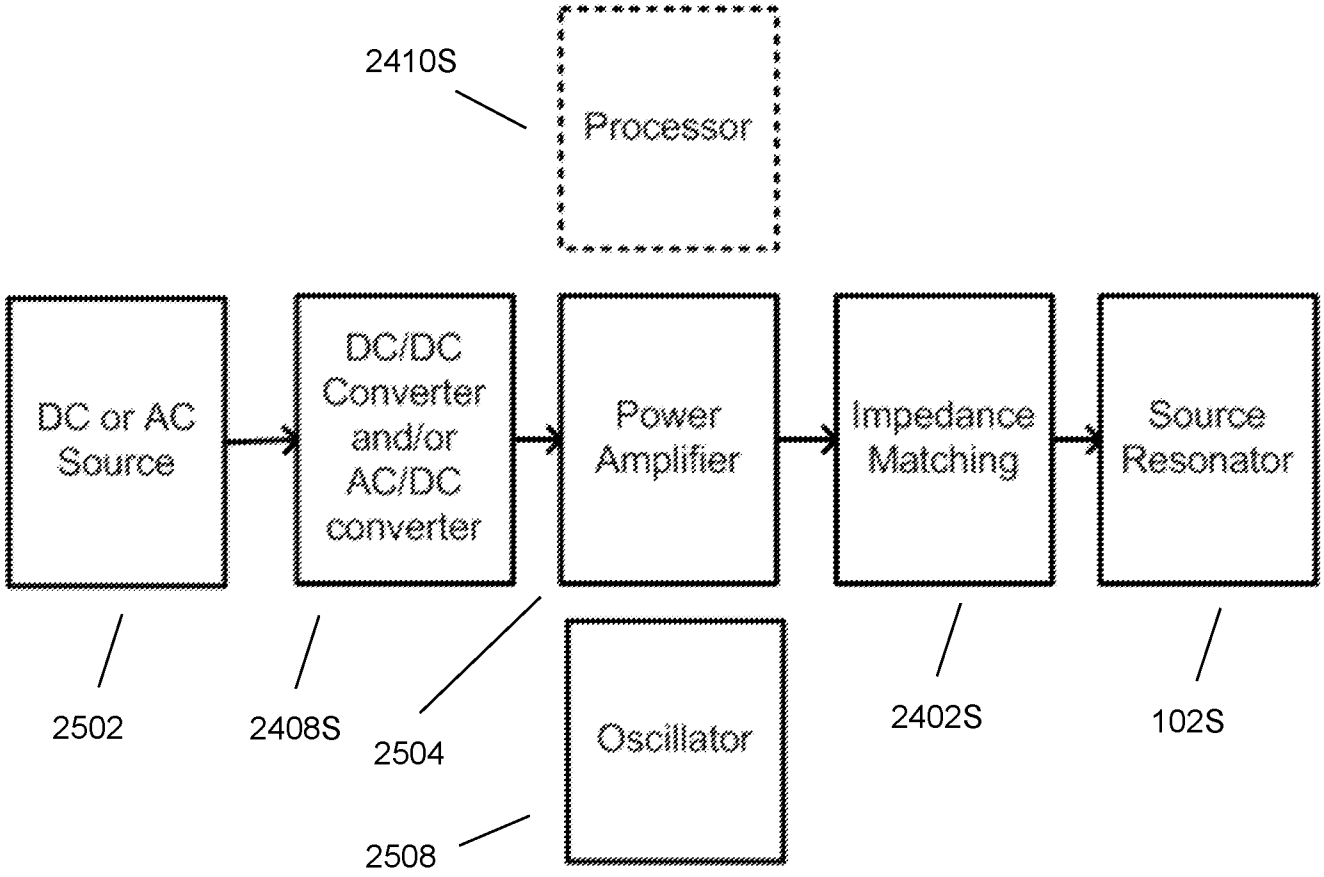
Fig. 39



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Page 282

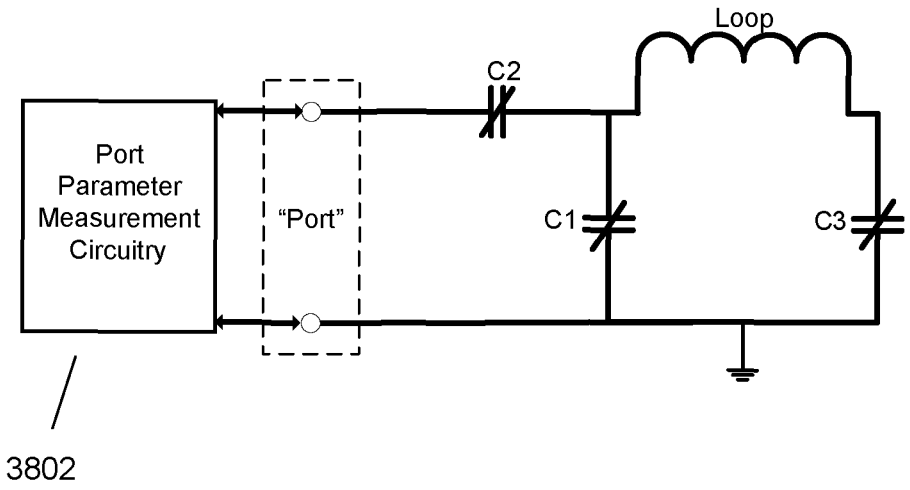
Fig. 40



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Exhibit 1002
Page 283

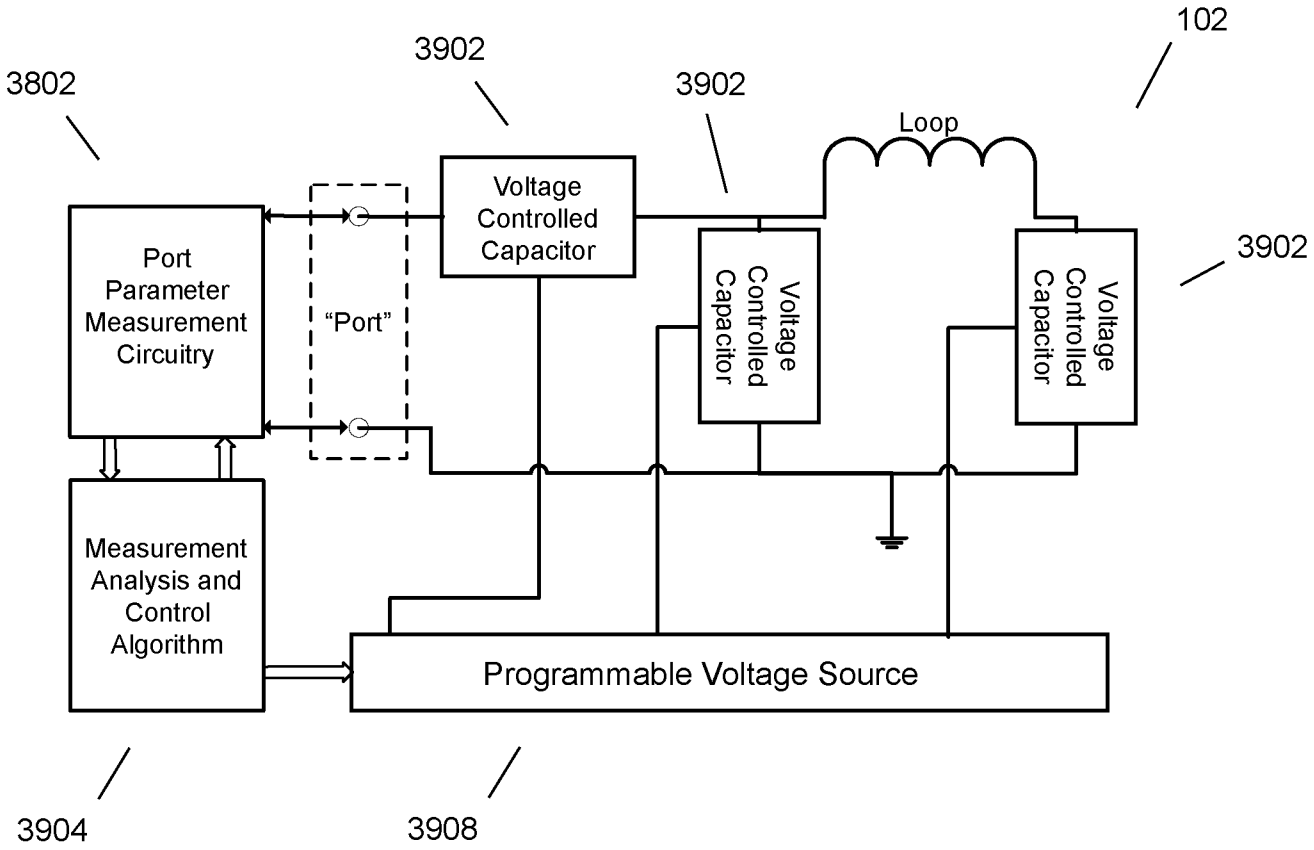
Fig. 41



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Page 284

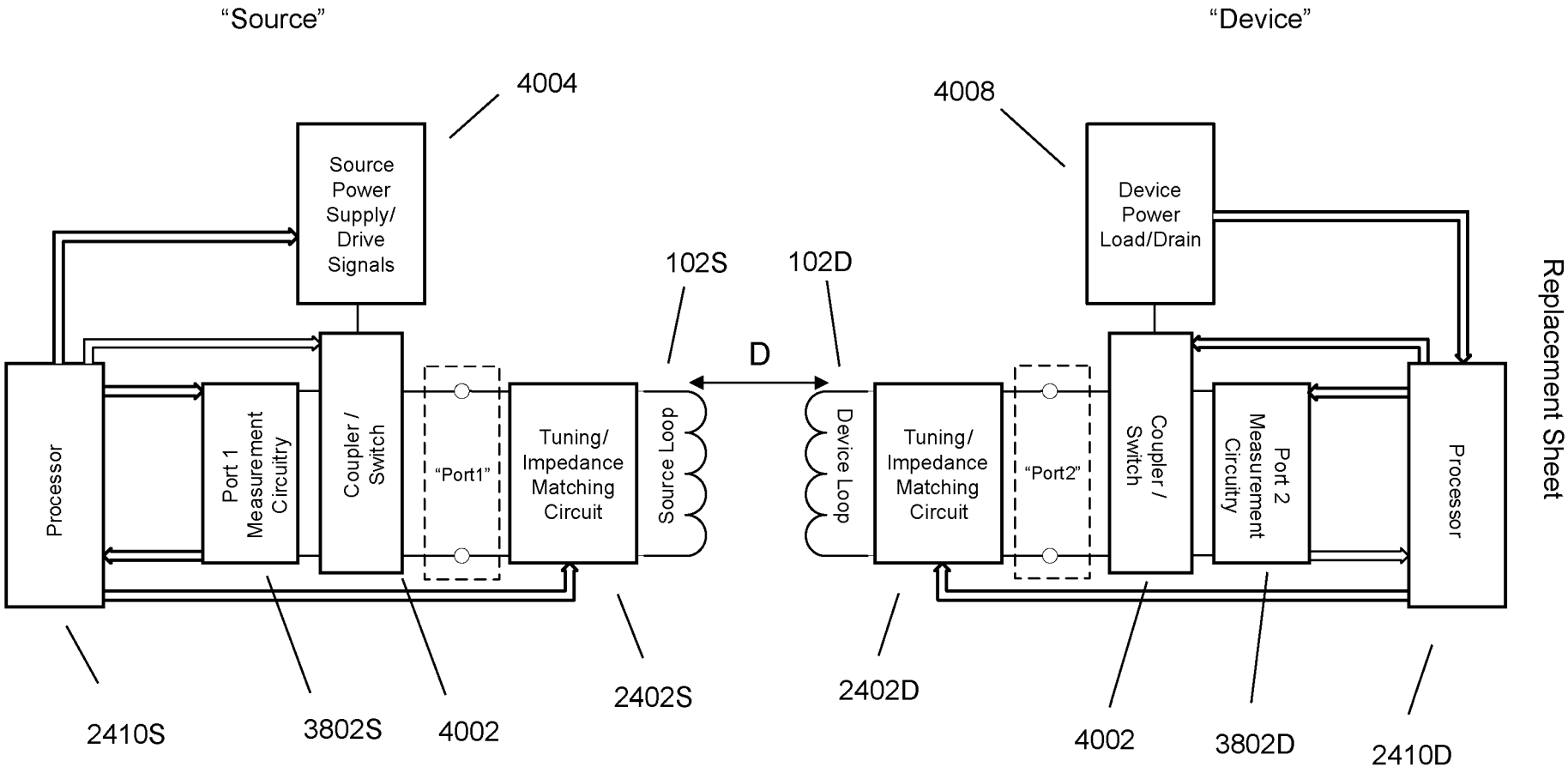
Fig. 42



Replacement Sheet

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Exhibit 1002
Page 285

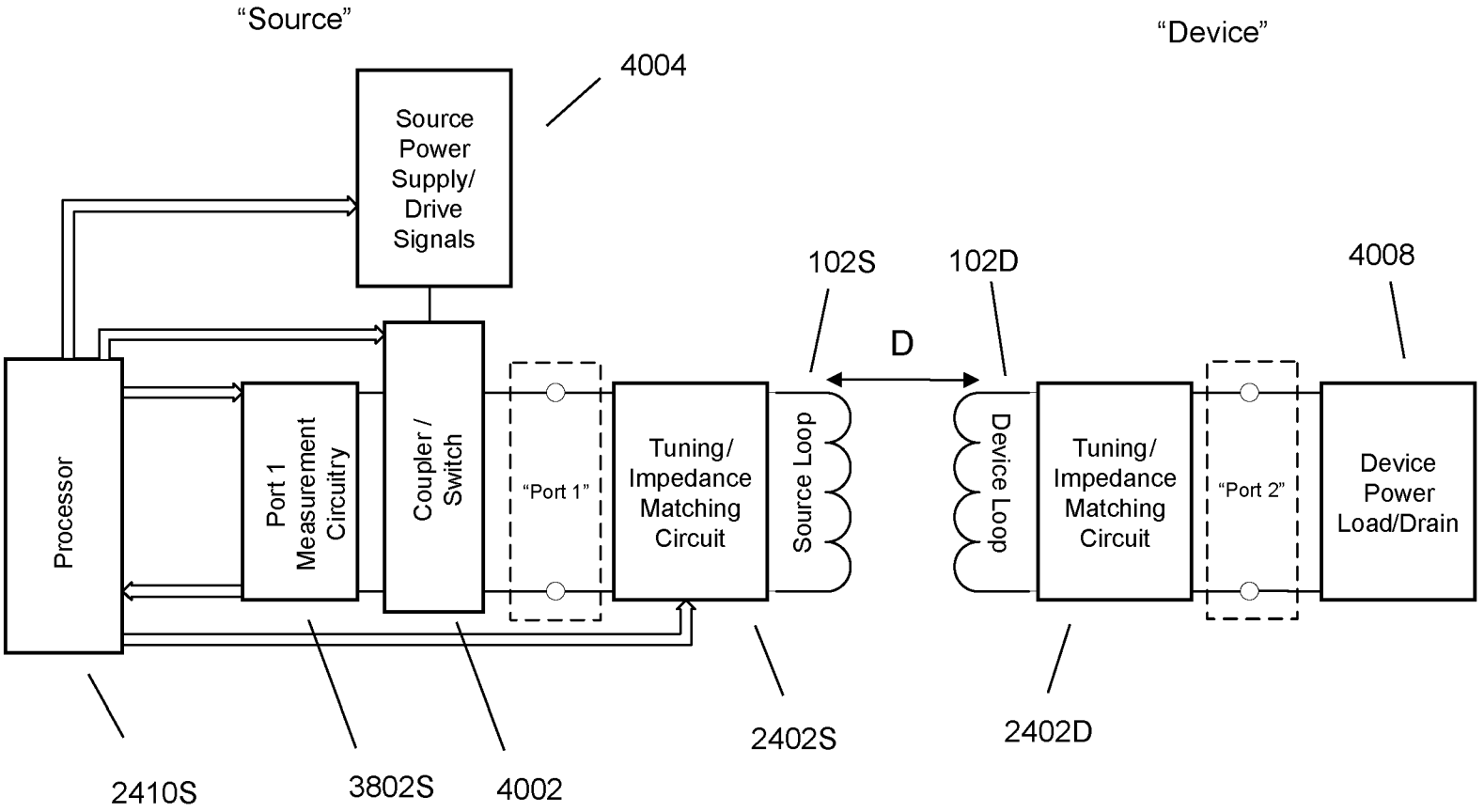
Fig. 43



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Page 286

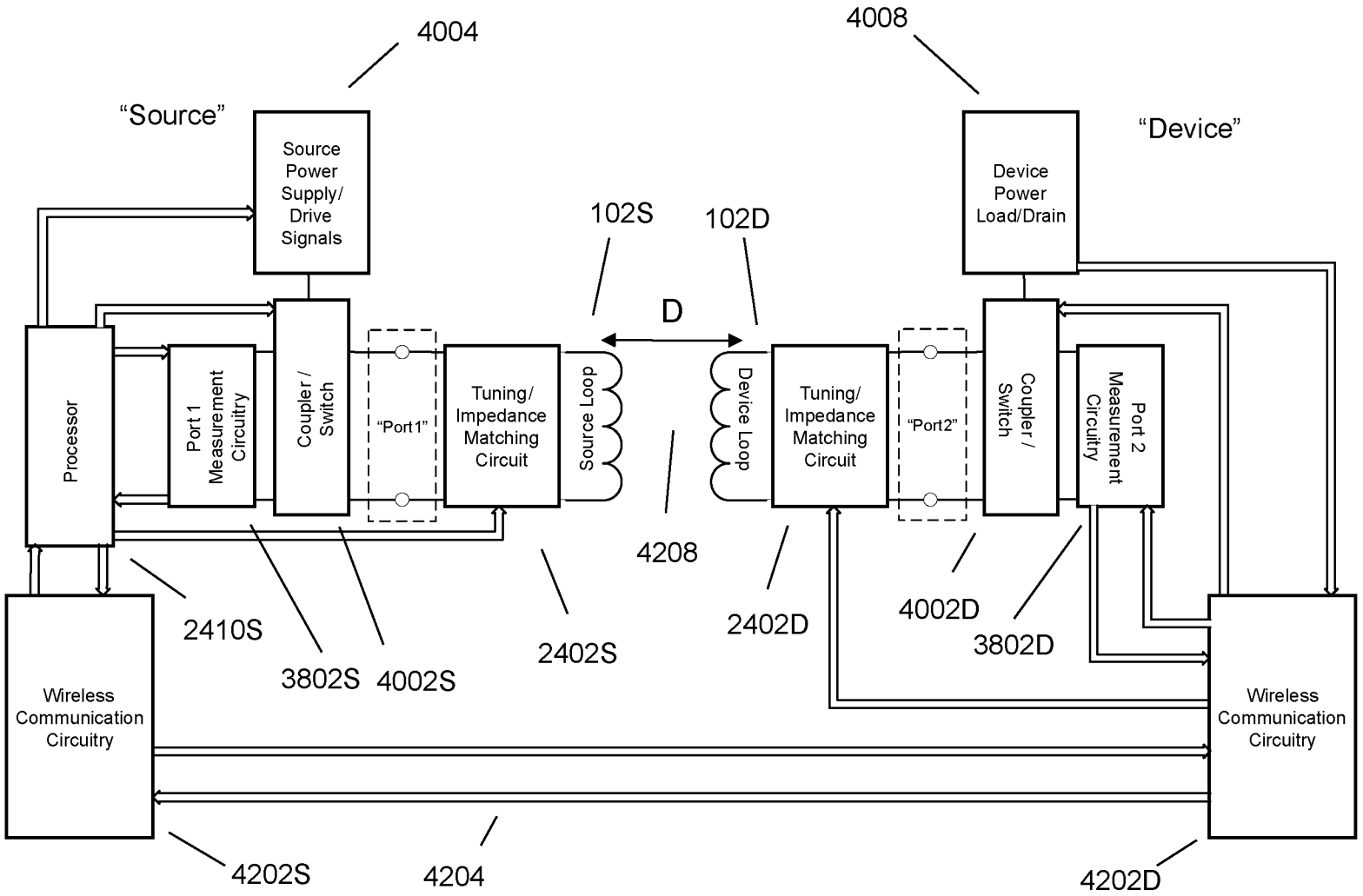
Fig. 44



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Page 287

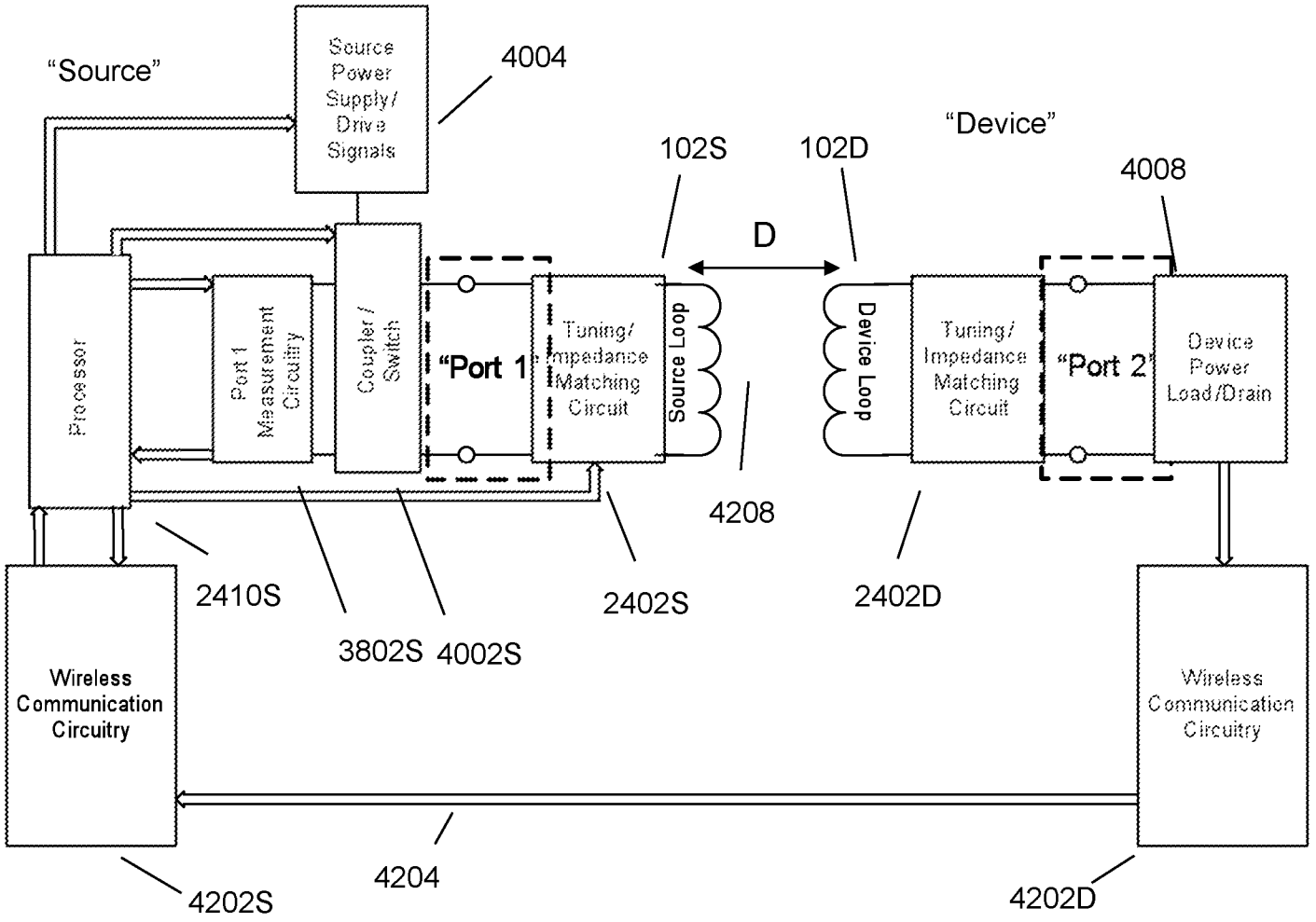
Fig. 45



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Exhibit 1002
Page 288

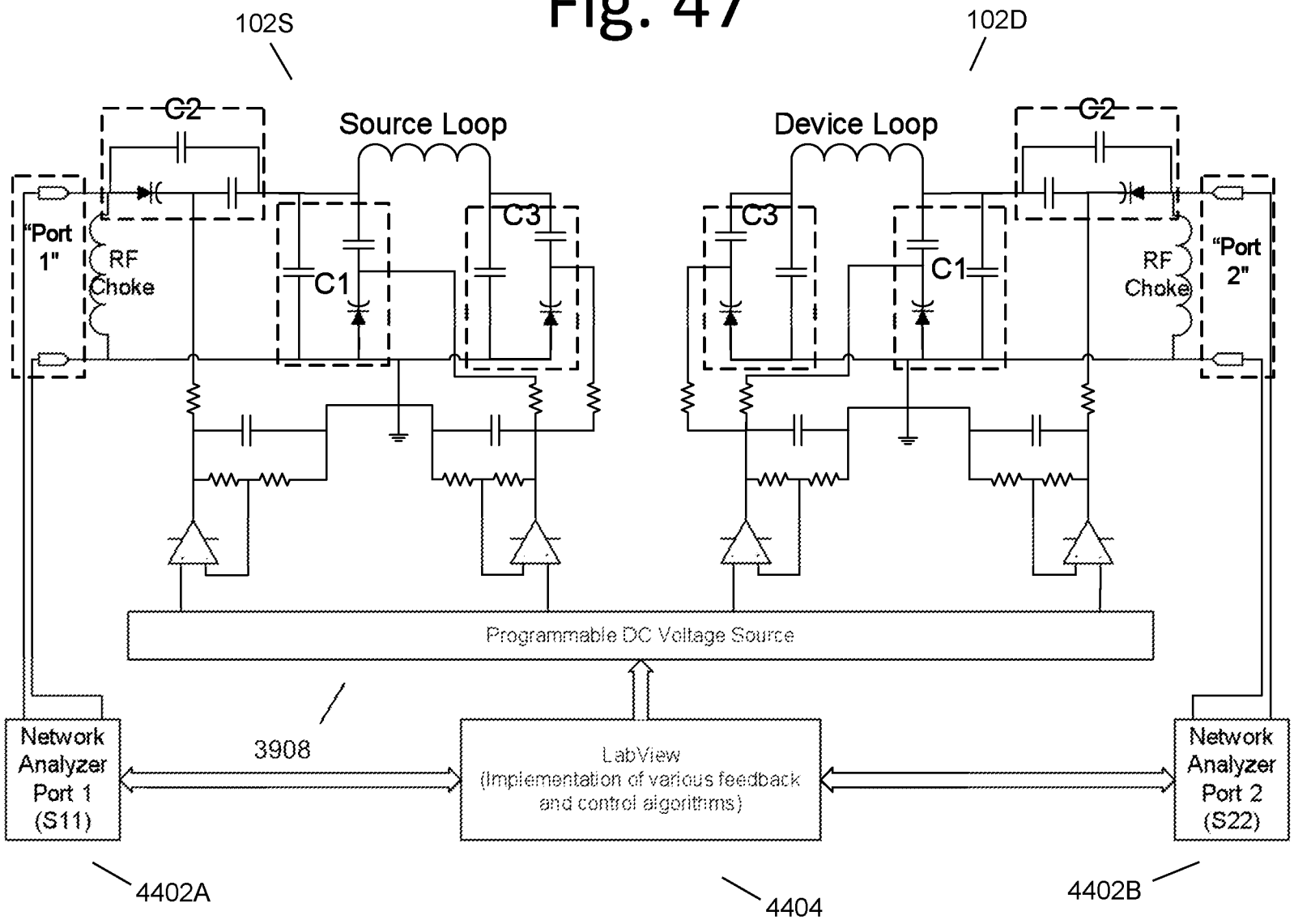
Fig. 46



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InductEV, Inc.
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Page 289

Fig. 47



Replacement Sheet

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Exhibit 1002
Page 290

Fig. 48

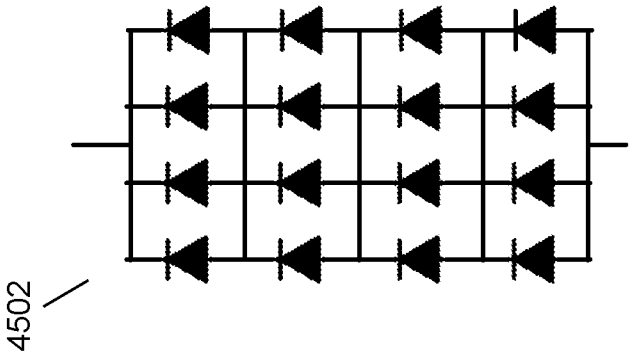


Fig. 49

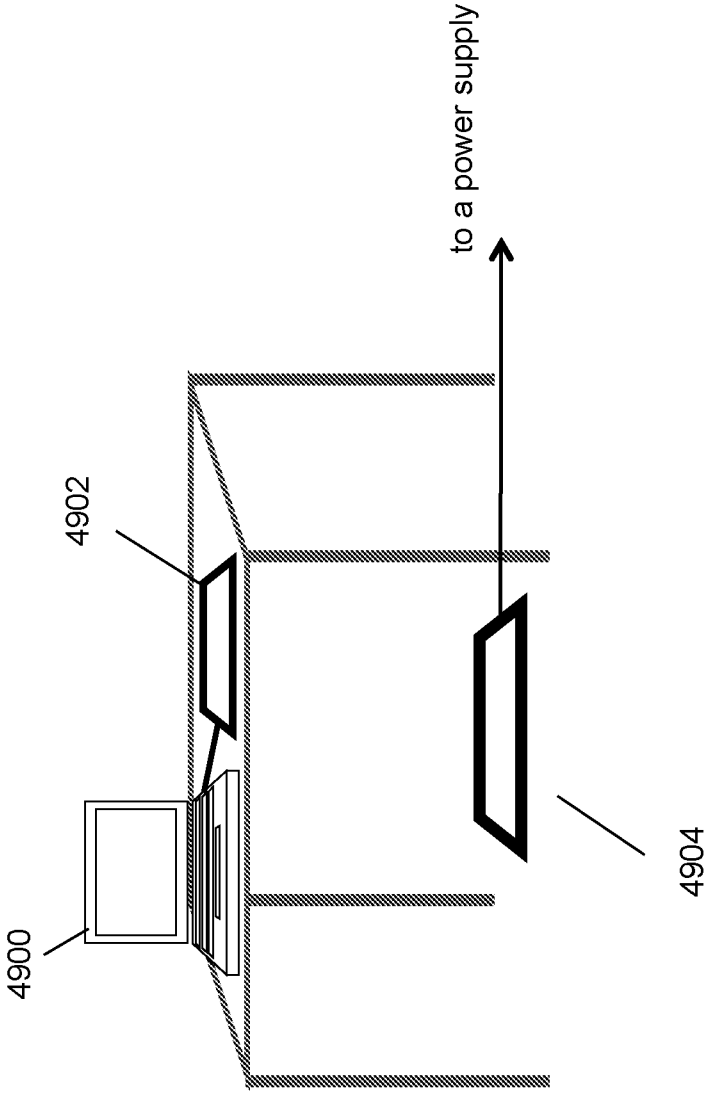
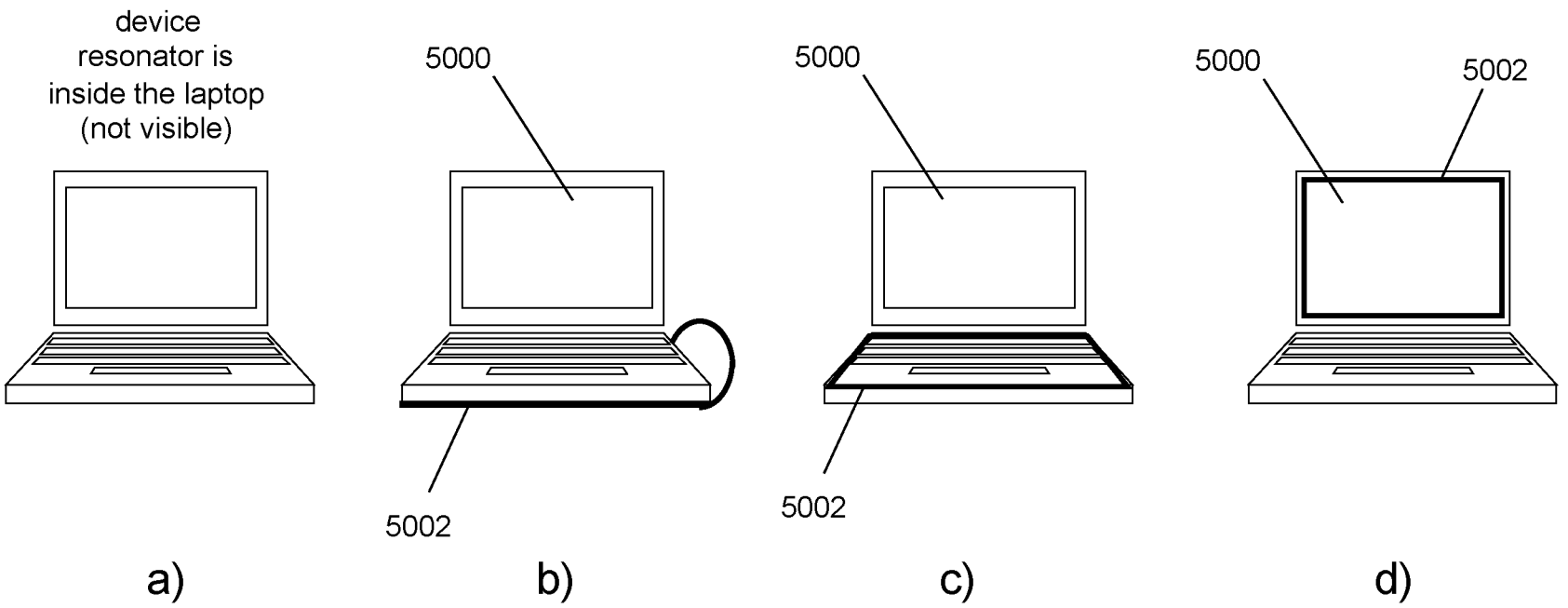


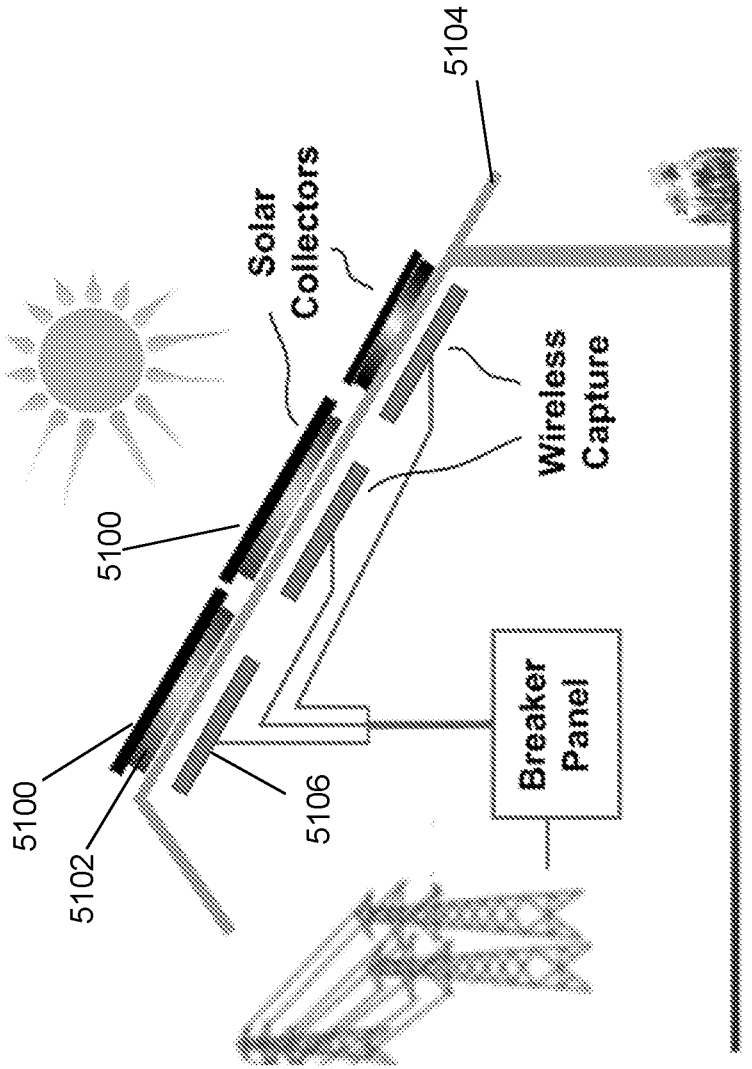
Fig. 50



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InductEV, Inc.
Exhibit 1002
Page 293

Fig. 51


5104
Solar Collectors
Wireless Capture
5100
5100
5102
5106
Breaker Panel

Remarks

As requested in the Notice to File Missing Parts, the applicant has provided formal draws for the originally filed figures 1-51, all the replacement drawing sheets include "Replacement Sheet" to the top margin. The applicant believes that an amended Brief Description of Figures is not required because in paragraph [0033] Figure 9 is currently described as "Fig. 9(a) and (b)".

Additionally, please correct the applicant names Morris P. Kesler and Eric R. Giler as shown on the marked Filing Receipt provided herewith. A supplemental application data sheet is provided herewith that includes the correct applicant information. The applicant respectfully request an updated Filing Receipt the reflects the correct applicant name information.

No new matter is added by these amendments.

The Commissioner is hereby authorized to charge any additional required fees to Deposit Account No. 50-5087 in order to have this amendment considered.

Respectfully submitted
STRATEGIC PATENTS, P.C.

/John Nortrup/

John H. Nortrup
Reg. No. 59,063
Tel.: (207) 985-2126

December 14, 2009

InductEV, Inc.
Exhibit 1002
Page 295

SCORE Placeholder Sheet for IFW Content

Application Number: 12567716 Document Date: 12/14/2009

The presence of this form in the IFW record indicates that the following document type was received in electronic format on the date identified above. This content is stored in the SCORE database.

- Drawings – Other than Black and White Line Drawings

Since this was an electronic submission, there is no physical artifact folder, no artifact folder is recorded in PALM, and no paper documents or physical media exist. The TIFF images in the IFW record were created from the original documents that are stored in SCORE.

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Form Revision Date: February 8, 2006

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Alexandria, Virginia 22313-1450
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APPLICATION NUMBER	FILING or 371(c) DATE	GRP ART UNIT	FIL FEE REC'D	ATTY.DOCKET.NO	TOT CLAIMS	IND CLAIMS
12/567,716	09/25/2009	2828	1646	WTCY-0026-P01	23	3

CONFIRMATION NO. 4901

UPDATED FILING RECEIPT

43520
STRATEGIC PATENTS P.C..
C/O PORTFOLIOIP
P.O. BOX 52050
MINNEAPOLIS, MN 55402

OC000000039393864

Date Mailed: 01/04/2010

Receipt is acknowledged of this non-provisional patent application. The application will be taken up for examination in due course. Applicant will be notified as to the results of the examination. Any correspondence concerning the application must include the following identification information: the U.S. APPLICATION NUMBER, FILING DATE, NAME OF APPLICANT, and TITLE OF INVENTION. Fees transmitted by check or draft are subject to collection. Please verify the accuracy of the data presented on this receipt. **If an error is noted on this Filing Receipt, please submit a written request for a Filing Receipt Correction. Please provide a copy of this Filing Receipt with the changes noted thereon. If you received a "Notice to File Missing Parts" for this application, please submit any corrections to this Filing Receipt with your reply to the Notice. When the USPTO processes the reply to the Notice, the USPTO will generate another Filing Receipt incorporating the requested corrections**

Applicant(s)

Morris P. Kesler, Bedford, MA;
Aristeidis Karalis, Boston, MA;
Andre B. Kurs, Chestnut Hill, MA;
Andrew J. Campanella, Waltham, MA;
Ron Fiorello, Tewksbury, MA;
Qiang Li, Malden, MA;
Konrad J. Kulikowski, Somerville, MA;
Eric R. Giler, Wellesley, MA;
Frank J. Pergal, Gloucester, MA;
David A. Schatz, Needham, MA;
Katherine L. Hall, Westford, MA;
Marin Soljacic, Belmont, MA;

Power of Attorney: The patent practitioners associated with Customer Number 43520

Domestic Priority data as claimed by applicant

This appln claims benefit of 61/100,721 09/27/2008
and claims benefit of 61/108,743 10/27/2008
and claims benefit of 61/147,386 01/26/2009
and claims benefit of 61/152,086 02/12/2009
and claims benefit of 61/178,508 05/15/2009
and claims benefit of 61/182,768 06/01/2009
and claims benefit of 61/121,159 12/09/2008
and claims benefit of 61/142,977 01/07/2009
and claims benefit of 61/142,885 01/06/2009
and claims benefit of 61/142,796 01/06/2009

and claims benefit of 61/142,889 01/06/2009
and claims benefit of 61/142,880 01/06/2009
and claims benefit of 61/142,818 01/06/2009
and claims benefit of 61/142,887 01/06/2009
and claims benefit of 61/156,764 03/02/2009
and claims benefit of 61/143,058 01/07/2009
and claims benefit of 61/152,390 02/13/2009
and claims benefit of 61/163,695 03/26/2009
and claims benefit of 61/172,633 04/24/2009
and claims benefit of 61/169,240 04/14/2009
and claims benefit of 61/173,747 04/29/2009

Foreign Applications

Projected Publication Date: To Be Determined - pending completion of Security Review

Non-Publication Request: No

Early Publication Request: No

Title

WIRELESS ENERGY TRANSFER SYSTEMS

Preliminary Class

372

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Since the rights granted by a U.S. patent extend only throughout the territory of the United States and have no effect in a foreign country, an inventor who wishes patent protection in another country must apply for a patent in a specific country or in regional patent offices. Applicants may wish to consider the filing of an international application under the Patent Cooperation Treaty (PCT). An international (PCT) application generally has the same effect as a regular national patent application in each PCT-member country. The PCT process **simplifies** the filing of patent applications on the same invention in member countries, but **does not result** in a grant of "an international patent" and does not eliminate the need of applicants to file additional documents and fees in countries where patent protection is desired.

Almost every country has its own patent law, and a person desiring a patent in a particular country must make an application for patent in that country in accordance with its particular laws. Since the laws of many countries differ in various respects from the patent law of the United States, applicants are advised to seek guidance from specific foreign countries to ensure that patent rights are not lost prematurely.

Applicants also are advised that in the case of inventions made in the United States, the Director of the USPTO must issue a license before applicants can apply for a patent in a foreign country. The filing of a U.S. patent application serves as a request for a foreign filing license. The application's filing receipt contains further information and guidance as to the status of applicant's license for foreign filing.

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patent applications. The guide is available either by contacting the USPTO Contact Center at 800-786-9199, or it can be viewed on the USPTO website at http://www.uspto.gov/web/offices/pac/doc/general/index.html.

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APPLICATION NUMBER	FILING OR 371(C) DATE	FIRST NAMED APPLICANT	ATTY. DOCKET NO./TITLE
12/567,716	09/25/2009	Morris P. Kesler	WTCY-0026-P01

CONFIRMATION NO. 4901

NEW OR REVISED PPD NOTICE

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P.O. BOX 52050
MINNEAPOLIS, MN 55402

OC000000040420668

NOTICE OF NEW OR REVISED PROJECTED PUBLICATION DATE

The above-identified application has a new or revised projected publication date. The current projected publication date for this application is 06/10/2010. If this is a new projected publication date (there was no previous projected publication date), the application has been cleared by Licensing & Review or a secrecy order has been rescinded and the application is now in the publication queue.

If this is a revised projected publication date (one that is different from a previously communicated projected publication date), the publication date has been revised due to processing delays in the USPTO or the abandonment and subsequent revival of an application. The application is anticipated to be published on a date that is more than six weeks different from the originally-projected publication date.

More detailed publication information is available through the private side of Patent Application Information Retrieval (PAIR) System. The direct link to access PAIR is currently http://pair.uspto.gov. Further assistance in electronically accessing the publication, or about PAIR, is available by calling the Patent Electronic Business Center at 1-866-217-9197.

Questions relating to this Notice should be directed to the Office of Data Management, Application Assistance Unit at (571) 272-4000, or (571) 272-4200, or 1-888-786-0101.

ATTORNEY'S DOCKET NO. WTCY-0026-P01

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

Serial No.:	12/567,716
Filing Date:	September 25, 2009
Applicant:	Morris P. Kesler et al.
Title:	WIRELESS ENERGY TRANSFER SYSTEMS
Group Art Unit:	2828
Examiner:	Not Yet Known
Conf. No.:	4901

INFORMATION DISCLOSURE STATEMENT

Commissioner for Patents
P.O. Box 1450
Alexandria, VA 22313-1450

In compliance with the duty imposed by 37 C.F.R. § 1.56, and in accordance with 37 C.F.R. §§ 1.97 *et seq.*, the referenced materials are brought to the attention of the Examiner for consideration in connection with the above-identified patent application. Applicants respectfully request that this Information Disclosure Statement be entered and the documents listed on the attached Form 1449 be considered by the Examiner and made of record. Pursuant to the provisions of MPEP 609, Applicants request that a copy of the 1449 form, initialed as being considered by the Examiner, be returned to the Applicants with the next official communication.

Pursuant to 37 C.F.R. §1.97(b), it is believed that no fee or statement is required with the Information Disclosure Statement. However, if an Office Action on the merits has been mailed, the Commissioner is hereby authorized to charge the required fees to Deposit Account No. 50-4262 in order to have this Information Disclosure Statement considered.

Pursuant to 37 C.F.R. 1.98(a)(2), Applicant believes that copies of cited U.S. Patents and Published and Non-Published Applications identifiable by USPTO Serial Number are no longer required to be provided to the Office. Notification of this change to this effect was provided in the United States Patent and Trademark Office OG Notices dated October 12, 2004 and October 19, 2004. Thus, Applicant has not included copies of any US Patents or US Patent Applications

identifiable by serial number that may be cited with this submission. Should the Office require copies to be provided, Applicant respectfully requests that notice of such requirement be directed to Applicant's below-signed representative. Applicant acknowledges the requirement to submit copies of foreign patent documents and non-patent literature in accordance with 37 C.F.R. 1.98(a)(2).

The Examiner is invited to contact the Applicants' Representative at the below-listed telephone number if there are any questions regarding this communication.

Respectfully submitted on March 15, 2010,

STRATEGIC PATENTS, P.C.

/John Nortrup, Reg. No. 59,063/
John H. Nortrup
Telephone: 207-985-2126

Customer Number 43520

PTO/SB/08a (01-08)
Approved for use through 05/31/2008. OMB 0651-0031
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Substitute for form 1449A/PTO

INFORMATION DISCLOSURE STATEMENT BY APPLICANT

(Use as many sheets as necessary)

Complete if Known	
Application Number	12/567,716
Filing Date	Sep 25, 2009
First Named Inventor	Morris P. Kesler
Art Unit	2828
Examiner Name	Not Yet Known

Sheet	1	of	1	Attorney Docket No: WTCY-0026-P01

US PATENT DOCUMENTS

Examiner Initial *	Cite No	Document Number	Publication Date	Name of Patentee or Applicant of Cited Document	Pages, Columns, Lines, Where Relevant Passages or RelevantFigures Appear
		20070222542A1	Sep 27, 2007	Joannopoulos, J. D., et al.	
		20090085706	Apr 2, 2009	Baarman, David W., et al.	
		20090230777	Sep 17, 2009	Baarman, David W., et al.	
		6452465B1	Sep 17, 2002	Brown, B. et al.	
		7492247	Feb 17, 2009	Schmidt, Josef et al.	

FOREIGN PATENT DOCUMENTS

Examiner Initials*	Cite No	Foreign Patent Document	Publication Date	Name of Patentee or Applicant of cited Document	Pages, Columns, Lines, Where Relevant Passages or RelevantFigures Appear	T[2]

OTHER DOCUMENTS -- NON PATENT LITERATURE DOCUMENTS

Examiner Initials*	Cite No [1]	Include name of the author (in CAPITAL LETTERS), title of the article (when appropriate), title of the item (book, magazine, journal, serial, symposium, catalog, etc.), date, page(s), volume-issue number(s), publisher, city and/or country where published.	T[2]
	NPL-1	, "International Application Serial No. PCT/US09/58499, Search Report and Written Opinion mailed 12-10-2009",	

EXAMINER **DATE CONSIDERED**

Substitute Disclosure Statement Form (PTO-1449)
* EXAMINER: Initial if reference considered, whether or not citation is in conformance with MPEP 609. Draw line through citation if not in conformance and not considered. Include copy of this form with next communication to applicant. 1 Applicant's unique citation designation number (optional) 2 Applicant is to place a check mark here if English language Translation is attached

Electronic Acknowledgement Receipt

EFS ID:	7207634
Application Number:	12567716
International Application Number:	
Confirmation Number:	4901
Title of Invention:	WIRELESS ENERGY TRANSFER SYSTEMS
First Named Inventor/Applicant Name:	Morris P. Kesler
Customer Number:	43520
Filer:	John H. Nortrop/Elizabeth Nortrup
Filer Authorized By:	John H. Nortrop
Attorney Docket Number:	WTCY-0026-P01
Receipt Date:	15-MAR-2010
Filing Date:	25-SEP-2009
Time Stamp:	14:42:52
Application Type:	Utility under 35 USC 111(a)

Payment information:

Submitted with Payment	no

File Listing:

Document Number	Document Description	File Name	File Size(Bytes)/ Message Digest	Multi Part /.zip	Pages (if appl.)
1	Transmittal Letter	WTCY-0026-P01_031510_IDSCommunication.pdf	89655 8213bf32fc709625106a8f647c38b9f2f4b2f038	no	2

Warnings:	
Information:	

2	Information Disclosure Statement (IDS) Filed (SB/08)	WTCY-0026-P01_031510_Form1449.pdf	128301 5adadc77f1fb84ba3e4cc85f9924674cbe28a8b6	no	1
Warnings:					
Information:					
This is not an USPTO supplied IDS fillable form					
3	NPL Documents	NPL-1_PCTUS0958499_ISR-121009.pdf	1734426 7b273cea5fbcd6d360a04814 3213c8c0fe1238f9	no	11
Warnings:					
Information:					
		Total Files Size (in bytes):	1952382		

This Acknowledgement Receipt evidences receipt on the noted date by the USPTO of the indicated documents, characterized by the applicant, and including page counts, where applicable. It serves as evidence of receipt similar to a Post Card, as described in MPEP 503.

New Applications Under 35 U.S.C. 111

If a new application is being filed and the application includes the necessary components for a filing date (see 37 CFR 1.53(b)-(d) and MPEP 506), a Filing Receipt (37 CFR 1.54) will be issued in due course and the date shown on this Acknowledgement Receipt will establish the filing date of the application.

National Stage of an International Application under 35 U.S.C. 371

If a timely submission to enter the national stage of an international application is compliant with the conditions of 35 U.S.C. 371 and other applicable requirements a Form PCT/DO/EO/903 indicating acceptance of the application as a national stage submission under 35 U.S.C. 371 will be issued in addition to the Filing Receipt, in due course.

New International Application Filed with the USPTO as a Receiving Office

If a new international application is being filed and the international application includes the necessary components for an international filing date (see PCT Article 11 and MPEP 1810), a Notification of the International Application Number and of the International Filing Date (Form PCT/RO/105) will be issued in due course, subject to prescriptions concerning national security, and the date shown on this Acknowledgement Receipt will establish the international filing date of the application.

PATENT COOPERATION TREATY

From the INTERNATIONAL SEARCHING AUTHORITY

To:
ROBERT A. MAZZARESE
STRATEGIC PATENTS, P.C.
C/O INTELLEVATE
P.O. BOX 52050
MINNEAPOLIS, MN 55402

PCT

NOTIFICATION OF TRANSMITTAL OF THE INTERNATIONAL SEARCH REPORT AND THE WRITTEN OPINION OF THE INTERNATIONAL SEARCHING AUTHORITY, OR THE DECLARATION

(PCT Rule 44.1)

	Date of mailing *(day/month/year)*
Applicant's or agent's file reference WTCY0026PWO	**FOR FURTHER ACTION** See paragraphs 1 and 4 below
International application No. PCT/US 09/58499	International filing date *(day/month/year)* 25 September 2009 (25.09.2009)
Applicant WITRICITY CORPORATION	

80157.E92WO1

1. ☒ The applicant is hereby notified that the international search report and the written opinion of the International Searching Authority have been established and are transmitted herewith.

   Filing of amendments and statement under Article 19:
   The applicant is entitled, if he so wishes, to amend the claims of the international application (see Rule 46):

   When? The time limit for filing such amendments is normally two months from the date of transmittal of the international search report.

   Where? Directly to the International Bureau of WIPO, 34 chemin des Colombettes 1211 Geneva 20, Switzerland, Facsimile No.: +41 22 338 8270

   For more detailed instructions, see the notes on the accompanying sheet.

2. ☐ The applicant is hereby notified that no international search report will be established and that the declaration under Article 17(2)(a) to that effect and the written opinion of the International Searching Authority are transmitted herewith.

3. ☐ **With regard to the protest** against payment of (an) additional fee(s) under Rule 40.2, the applicant is notified that:

   ☐ the protest together with the decision thereon has been transmitted to the International Bureau together with the applicant's request to forward the texts of both the protest and the decision thereon to the designated Offices.

   ☐ no decision has been made yet on the protest; the applicant will be notified as soon as a decision is made.

4. **Reminders**

   Shortly after the expiration of **18 months** from the priority date, the international application will be published by the International Bureau. If the applicant wishes to avoid or postpone publication, a notice of withdrawal of the international application, or of the priority claim, must reach the International Bureau as provided in Rules 90*bis*.1 and 90*bis*.3, respectively, before the completion of the technical preparations for international publication.

   The applicant may submit comments on an informal basis on the written opinion of the International Searching Authority to the International Bureau. The International Bureau will send a copy of such comments to all designated Offices unless an international preliminary examination report has been or is to be established. These comments would also be made available to the public but not before the expiration of 30 months from the priority date.

   Within **19 months** from the priority date, but only in respect of some designated Offices, a demand for international preliminary examination must be filed if the applicant wishes to postpone the entry into the national phase **until 30 months** from the priority date (in some Offices even later); otherwise, the applicant must, **within 20 months** from the priority date, perform the prescribed acts for entry into the national phase before those designated Offices.

   In respect of other designated Offices, the time limit of **30 months** (or later) will apply even if no demand is filed within 19 months.

   See the Annex to Form PCT/IB/301 and, for details about the applicable time limits, Office by Office, see the *PCT Applicant's Guide*, Volume II, National Chapters and the WIPO Internet site.

Name and mailing address of the ISA/US Mail Stop PCT, Attn: ISA/US Commissioner for Patents P.O. Box 1450, Alexandria, Virginia 22313-1450 Facsimile No. 571-273-3201	Authorized officer: Lee W. Young PCT Helpdesk: 571-272-4300 PCT OSP: 571-272-7774

Form PCT/ISA/220 (January 2004) *(See notes on accompanying sheet)*

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PATENT COOPERATION TREATY

From the INTERNATIONAL SEARCHING AUTHORITY

To:
ROBERT A. MAZZARESE
STRATEGIC PATENTS, P.C.
C/O INTELLEVATE
P.O. BOX 52050
MINNEAPOLIS, MN 55402

PCT

NOTIFICATION OF TRANSMITTAL OF THE INTERNATIONAL SEARCH REPORT AND THE WRITTEN OPINION OF THE INTERNATIONAL SEARCHING AUTHORITY, OR THE DECLARATION

(PCT Rule 44.1)

	Date of mailing *(day/month/year)* 10 DEC 2009
Applicant's or agent's file reference WTCY0026PWO	**FOR FURTHER ACTION** See paragraphs 1 and 4 below
International application No. PCT/US 09/58499	International filing date *(day/month/year)* 25 September 2009 (25.09.2009)
Applicant WITRICITY CORPORATION	

1. ☒ The applicant is hereby notified that the international search report and the written opinion of the International Searching Authority have been established and are transmitted herewith.

   Filing of amendments and statement under Article 19:
   The applicant is entitled, if he so wishes, to amend the claims of the international application (see Rule 46):

   When? The time limit for filing such amendments is normally two months from the date of transmittal of the international search report.

   Where? Directly to the International Bureau of WIPO, 34 chemin des Colombettes 1211 Geneva 20, Switzerland, Facsimile No.: +41 22 338 8270

   For more detailed instructions, see the notes on the accompanying sheet.

2. ☐ The applicant is hereby notified that no international search report will be established and that the declaration under Article 17(2)(a) to that effect and the written opinion of the International Searching Authority are transmitted herewith.

3. ☐ **With regard to the protest** against payment of (an) additional fee(s) under Rule 40.2, the applicant is notified that:

   ☐ the protest together with the decision thereon has been transmitted to the International Bureau together with the applicant's request to forward the texts of both the protest and the decision thereon to the designated Offices.

   ☐ no decision has been made yet on the protest; the applicant will be notified as soon as a decision is made.

4. **Reminders**

   Shortly after the expiration of **18 months** from the priority date, the international application will be published by the International Bureau. If the applicant wishes to avoid or postpone publication, a notice of withdrawal of the international application, or of the priority claim, must reach the International Bureau as provided in Rules 90*bis*.1 and 90*bis*.3, respectively, before the completion of the technical preparations for international publication.

   The applicant may submit comments on an informal basis on the written opinion of the International Searching Authority to the International Bureau. The International Bureau will send a copy of such comments to all designated Offices unless an international preliminary examination report has been or is to be established. These comments would also be made available to the public but not before the expiration of 30 months from the priority date.

   Within **19 months** from the priority date, but only in respect of some designated Offices, a demand for international preliminary examination must be filed if the applicant wishes to postpone the entry into the national phase **until 30 months** from the priority date (in some Offices even later); otherwise, the applicant must, **within 20 months** from the priority date, perform the prescribed acts for entry into the national phase before those designated Offices.

   In respect of other designated Offices, the time limit of **30 months** (or later) will apply even if no demand is filed within 19 months.

   See the Annex to Form PCT/IB/301 and, for details about the applicable time limits, Office by Office, see the *PCT Applicant's Guide*, Volume II, National Chapters and the WIPO Internet site.

Name and mailing address of the ISA/US Mail Stop PCT, Attn: ISA/US Commissioner for Patents P.O. Box 1450, Alexandria, Virginia 22313-1450 Facsimile No. 571-273-3201	Authorized officer: Lee W. Young PCT Helpdesk: 571-272-4300 PCT OSP: 571-272-7774

Form PCT/ISA/220 (January 2004) *(See notes on accompanying sheet)*

PATENT COOPERATION TREATY

PCT

INTERNATIONAL SEARCH REPORT

(PCT Article 18 and Rules 43 and 44)

Applicant's or agent's file reference WTCY0026PWO	**FOR FURTHER ACTION**	see Form PCT/ISA/220 as well as, where applicable, item 5 below.
International application No. PCT/US 09/58499	International filing date *(day/month/year)* 25 September 2009 (25.09.2009)	(Earliest) Priority Date *(day/month/year)* 27 September 2008 (27.09.2008)
Applicant WITRICITY CORPORATION		

This international search report has been prepared by this International Searching Authority and is transmitted to the applicant according to Article 18. A copy is being transmitted to the International Bureau.

This international search report consists of a total of 2 sheets.

☐ It is also accompanied by a copy of each prior art document cited in this report.

1. **Basis of the report**

   a. With regard to the **language**, the international search was carried out on the basis of:

   ☒ the international application in the language in which it was filed.

   ☐ a translation of the international application into _____ which is the language of a translation furnished for the purposes of international search (Rules 12.3(a) and 23.1(b)).

   b. ☐ This international search report has been established taking into account the **rectification of an obvious mistake** authorized by or notified to this Authority under Rule 91 (Rule 43.6*bis*(a)).

   c. ☐ With regard to any **nucleotide and/or amino acid sequence** disclosed in the international application, see Box No. I.

2. ☐ **Certain claims were found unsearchable** (see Box No. II).

3. ☐ **Unity of invention is lacking** (see Box No. III).

4. With regard to the **title**,

   ☒ the text is approved as submitted by the applicant.

   ☐ the text has been established by this Authority to read as follows:

5. With regard to the **abstract**,

   ☒ the text is approved as submitted by the applicant.

   ☐ the text has been established, according to Rule 38.2, by this Authority as it appears in Box No. IV. The applicant may, within one month from the date of mailing of this international search report, submit comments to this Authority.

6. With regard to the **drawings**,

   a. the figure of the **drawings** to be published with the abstract is Figure No. 1

   ☒ as suggested by the applicant.

   ☐ as selected by this Authority, because the applicant failed to suggest a figure.

   ☐ as selected by this Authority, because this figure better characterizes the invention.

   b. ☐ none of the figures is to be published with the abstract.

InductEV, Inc.
Exhibit 1002
Page 308

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US 09/58499

A. CLASSIFICATION OF SUBJECT MATTER
IPC(8) - H03B 19/00 (2009.01)
USPC - 327/113
According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
USPC: 327/113

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched
USPC: 327/113, 306, 530, 555; 375/323; 307/134 (keyword limited - see terms below)

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
PubWEST (PGPB, USPT, USOC, EPAB, JPAB); GOOGLE
Search Terms: energy, power, power generator, generator, wireless, resonator, first resonator, second resonator, third resonator, Q-factor, distance, tunable, oscillating, impedance, capacitance, load

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	US 2007/0222542 A1 (Joannopoulos et al.) 27 September 2007 (27.09.2007), entire document, especially; abstract, para. [0004], [0005], [0013], [0014], [0019], [0023], [0025], [0029], [0033]	1 - 26
Y	US 6,452,465 B1 (Brown et al.) 17 September 2002 (17.09.2002), entire document, especially; abstract, col. 2, ln 4-6, col. 3, ln 7-12, 66-67	1 - 26

☐ Further documents are listed in the continuation of Box C. ☐

* Special categories of cited documents:
"A" document defining the general state of the art which is not considered to be of particular relevance
"E" earlier application or patent but published on or after the international filing date
"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)
"O" document referring to an oral disclosure, use, exhibition or other means
"P" document published prior to the international filing date but later than the priority date claimed
"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
24 November 2009 (24.11.2009)	10 DEC 2009
Name and mailing address of the ISA/US Mail Stop PCT, Attn: ISA/US, Commissioner for Patents P.O. Box 1450, Alexandria, Virginia 22313-1450 Facsimile No. 571-273-3201	Authorized officer: Lee W. Young PCT Helpdesk: 571-272-4300 PCT OSP: 571-272-7774

Form PCT/ISA/210 (second sheet) (July 2009)

PATENT COOPERATION TREATY

From the
INTERNATIONAL SEARCHING AUTHORITY

To: ROBERT A. MAZZARESE
STRATEGIC PATENTS, P.C.
C/O INTELLEVATE
P.O. BOX 52050
MINNEAPOLIS, MN 55402

PCT

WRITTEN OPINION OF THE
INTERNATIONAL SEARCHING AUTHORITY

(PCT Rule 43*bis*.1)

Date of mailing *(day/month/year)*	10 DEC 2009

Applicant's or agent's file reference	FOR FURTHER ACTION
WTCY0026PWO	See paragraph 2 below

International application No.	International filing date *(day/month/year)*	Priority date *(day/month/year)*
PCT/US 09/58499	25 September 2009 (25.09.2009)	27 September 2008 (27.09.2008)

International Patent Classification (IPC) or both national classification and IPC
IPC(8) - H03B 19/00 (2009.01)
USPC - 327/113

Applicant WITRICITY CORPORATION

1. This opinion contains indications relating to the following items:

- [X] Box No. I Basis of the opinion
- [ ] Box No. II Priority
- [ ] Box No. III Non-establishment of opinion with regard to novelty, inventive step and industrial applicability
- [ ] Box No. IV Lack of unity of invention
- [X] Box No. V Reasoned statement under Rule 43*bis*.1(a)(i) with regard to novelty, inventive step or industrial applicability; citations and explanations supporting such statement
- [ ] Box No. VI Certain documents cited
- [ ] Box No. VII Certain defects in the international application
- [ ] Box No. VIII Certain observations on the international application

2. **FURTHER ACTION**

If a demand for international preliminary examination is made, this opinion will be considered to be a written opinion of the International Preliminary Examining Authority ("IPEA") except that this does not apply where the applicant chooses an Authority other than this one to be the IPEA and the chosen IPEA has notified the International Bureau under Rule 66.1*bis*(b) that written opinions of this International Searching Authority will not be so considered.

If this opinion is, as provided above, considered to be a written opinion of the IPEA, the applicant is invited to submit to the IPEA a written reply together, where appropriate, with amendments, before the expiration of 3 months from the date of mailing of Form PCT/ISA/220 or before the expiration of 22 months from the priority date, whichever expires later.

For further options, see Form PCT/ISA/220.

3. For further details, see notes to Form PCT/ISA/220.

Name and mailing address of the ISA/US	Date of completion of this opinion	Authorized officer:
Mail Stop PCT, Attn: ISA/US Commissioner for Patents P.O. Box 1450, Alexandria, Virginia 22313-1450 Facsimile No. 571-273-3201	27 November 2009 (27.11.2009)	Lee W. Young PCT Helpdesk: 571-272-4300 PCT OSP: 571-272-7774

Form PCT/ISA/237 (cover sheet) (July 2009)

WRITTEN OPINION OF THE
INTERNATIONAL SEARCHING AUTHORITY

International application No.
PCT/US 09/58499

Box No. I Basis of this opinion

1. With regard to the **language**, this opinion has been established on the basis of:

   ☒ the international application in the language in which it was filed.

   ☐ a translation of the international application into _____ which is the language of a translation furnished for the purposes of international search (Rules 12.3(a) and 23.1(b)).

2. ☐ This opinion has been established taking into account the **rectification of an obvious mistake** authorized by or notified to this Authority under Rule 91 (Rule 43*bis*.1(a))

3. With regard to any **nucleotide and/or amino acid sequence** disclosed in the international application, this opinion has been established on the basis of a sequence listing filed or furnished:

   a. (means)

      ☐ on paper

      ☐ in electronic form

   b. (time)

      ☐ in the international application as filed

      ☐ together with the international application in electronic form

      ☐ subsequently to this Authority for the purposes of search

4. ☐ In addition, in the case that more than one version or copy of a sequence listing has been filed or furnished, the required statements that the information in the subsequent or additional copies is identical to that in the application as filed or does not go beyond the application as filed, as appropriate, were furnished.

5. Additional comments:

InductEV, Inc.
Exhibit 1002
Page 311

WRITTEN OPINION OF THE INTERNATIONAL SEARCHING AUTHORITY

International application No.
PCT/US 09/58499

Box No. V **Reasoned statement under Rule 43*bis*.1(a)(i) with regard to novelty, inventive step or industrial applicability; citations and explanations supporting such statement**

1. Statement

Novelty (N)	Claims	1 - 26	YES
	Claims	None.	NO
Inventive step (IS)	Claims	None.	YES
	Claims	1 - 26	NO
Industrial applicability (IA)	Claims	1 - 26	YES
	Claims	None.	NO

2. Citations and explanations:

Claims 1 - 26 lack an inventive step under PCT Article 33(3) as being obvious over US 2007/0222542 A1 to Joannopoulos et al. (hereinafter 'Joannopoulos'), in view of US 6,452,465 B1 to Brown et al. (hereinafter 'Brown').

Regarding claim 1, Joannopoulos teaches a system, comprising: a source resonator having a Q-factor Q1 and a characteristic size X1 (abstract, para. [0005]), coupled to a power generator (external power supply, para. [0005]), and a second resonator having a Q-factor Q2 and a characteristic size X2 (para. [0005]), coupled to a load located a distance D from the source resonator (distance between the two resonators can be larger than the characteristic size of each resonator, para. [0005]), wherein the source resonator and the second resonator are coupled to exchange energy wirelessly among the source resonator and the second resonator (abstract, para. [0004], [0013]). Joannopoulos does not teach that the square root of Q1Q2 > 100. However, Brown teaches multiple resonators that are tunable (abstract), and that filters may be fabricated with low quality factor resonators (col. 2, ln 4-6). It would have been obvious to one skilled in the art to combine the teachings of Joannopoulos with those of Brown in order to provide an inexpensive resonator structure. Neither Joannopoulos nor Brown specifically teach that the square root of Q1Q2 > 100. However, this configuration could have been determined via routine experimentation, and provided based on the specific application of the system.

Regarding claims 2 and 3, neither Joannopoulos nor Brown teaches that Q1 (or Q2 - claim 3) < 100. However, it was well known it the art at the time of the invention that resonator materials were available with low quality factors, e.g. Q1 (or Q2 - claim 3) < 100. It would have been obvious to one skilled in the art to provide Q1 (or Q2 - claim 3) < 100, in order to provide an inexpensive resonator structure.

Regarding claims 4 and 5, neither Joannopoulos nor Brown specifically teaches a third resonator having a Q-factor Q3 configured to transfer energy non-raditively with the source and second resonators, wherein the square root of Q1Q3 > 100 and the square root of Q2Q3 > 100, wherein Q3 < 100 (claim - 5). However, this configuration could have been determined via routine experimentation, and provided based on the specific application of the system.

Regarding claim 6, Joannopoulos teaches that the source resonator is coupled to the power generator with direct electrical connections (para. [0014]).

Regarding claim 7, Joannopoulos teaches that the source resonator is coupled and impedance matched to the power generator with direct electrical connections (para. [0014]).

Regarding claim 8, Brown teaches a tunable circuit wherein the source resonator is coupled to the power generator through the tunable circuit with direct electrical connections (abstract, col. 3, ln 7-12).

Regarding claim 9, Joannopoulos teaches that at least one of the direct electrical connections is configured to substantially preserve a resonant mode of the source resonator (resonant cavity, para. [0033]).

Regarding claim 10, neither Joannopoulos nor Brown specifically teaches that the source resonator has a first terminal, a second terminal, and a center terminal, and wherein an impedance between the first terminal and the center terminal and between the second terminal and the center terminal are substantially equal. However, this configuration could have been determined via routine experimentation and provided to maximize power transfer.

Regarding claim 11, Joannopoulos teaches that the source resonator includes a capacitive loaded loop having a first terminal, a second terminal, and a center terminal (para. [0019]), and wherein an impedance between the first terminal and the center terminal and between the second terminal and the center terminal are substantially equal (para. [0019]).

Regarding claim 12, neither Joannopoulos nor Brown specifically teaches that the source resonator is coupled to an impedance matching network and the impedance matching network further comprises a first terminal, a second terminal, and a center terminal, and wherein an impedance between the first terminal and the center terminal and between the second terminal and the center terminal are substantially equal. However, this configuration could have been determined via routine experimentation and provided to maximize power transfer.

---(continued in Supplemental Box)---

Supplemental Box

In case **the space in any of the preceding boxes is not sufficient.**
Continuation of:

V.2 Citations and explanations:

Regarding claim 13, neither Joannopoulos nor Brown teaches that the first terminal and the second terminal are directly coupled to the power generator and driven with oscillating signals that are near 180 degrees out of phase. However, this configuration was well known in the art at the time of the invention, and could have been provided based on the specific application.

Regarding claim 14, Joannopoulos teaches that the source resonator has a resonant frequency WI and the first terminal and the second terminal are directly coupled to the power generator and driven with oscillating signals that are substantially equal to the resonant frequency omega sub 1 (para. [0023], [0025]).

Regarding claim 15, neither Joannopoulos nor Brown specifically that the center terminal is connected to an electrical ground. However, this configuration was well known in the art at the time of the invention, and could have been provided in order to provide a voltage reference point.

Regarding claim 16, neither Joannopoulos nor Brown teach that the source resonator has a resonant frequency omega sub 1 and the first terminal and the second terminal are directly coupled to the power generator and driven with a frequency substantially equal to the resonant frequency omega sub 1. However, this configuration could have been determined via routine experimentation and provided to maximize power transfer.

Regarding claim 17, Brown teaches a plurality of capacitors coupled to the power generator and the load (col., 3, ln 66-67).

Regarding claim 18, Joannopoulos that the source resonator and the second resonator are each enclosed in a low loss tangent material (para. [0023]).

Regarding claim 19, Joannopoulos teaches a power conversion circuit wherein the second resonator is coupled to the power conversion circuit to deliver DC power to the load (abstract).

Regarding claim 20, Joannopoulos teaches a power conversion circuit wherein the second resonator is coupled to the power conversion circuit to deliver AC power to the load (power, abstract, para. [0029]).

Regarding claim 21, Joannopoulos teaches a power conversion circuit, wherein the second resonator is coupled to the power conversion circuit to deliver both AC and DC power to the load (power, abstract, para. [0029]).

Regarding claim 22, Joannopoulos teaches a power conversion circuit and a plurality of loads, wherein the second resonator is coupled to the power conversion circuit (abstract), and the power conversion circuit is coupled to the plurality of loads (abstract).

Regarding claim 23, Brown teaches the system, wherein the impedance matching network comprises capacitors (col., 3, ln 66-67).

Regarding claim 24, Joannopoulos teaches that the impedance matching network comprises inductors (coils, para. [0025]).

Regarding claim 25, Brown teaches that the tunable circuit comprises variable capacitors (col., 3, ln 66-67).

Regarding claim 26, Joannopoulos teaches that the tunable circuit comprises variable inductors (para. [0025]).

Claims 1 - 26 have industrial applicability as defined by PCT Article 33(4) because the subject matter can be made or used in industry.

NOTES TO FORM PCT/ISA/220

These Notes are intended to give the basic instructions concerning the filing of amendments under Article 19. The Notes are based on the requirements of the Patent Cooperation Treaty, the Regulations and the Administrative Instructions under that Treaty. In case of discrepancy between these Notes and those requirements, the latter are applicable. For more detailed information, see also the *PCT Applicant's Guide*.

In these Notes, "Article," "Rule" and "Section" refer to the provisions of the PCT, the PCT Regulations and the PCT Administrative Instructions, respectively.

INSTRUCTIONS CONCERNING AMENDMENTS UNDER ARTICLE 19

The applicant has, after having received the international search report and the written opinion of the International Searching Authority, one opportunity to amend the claims of the international application. It should however be emphasized that, since all parts of the international application (claims, description and drawings) may be amended during the international preliminary examination procedure, there is usually no need to file amendments of the claims under Article 19 except where, e.g. the applicant wants the latter to be published for the purposes of provisional protection or has another reason for amending the claims before international publication. Furthermore, it should be emphasized that provisional protection is available in some States only (see *PCT Applicant's Guide*, Annex B).

The attention of the applicant is drawn to the fact that amendments to the claims under Article 19 are not allowed where the International Searching Authority has declared, under Article 17(2), that no international search report would be established (see *PCT Applicant's Guide*, International Phase, paragraph 296).

What parts of the international application may be amended?

Under Article 19, only the claims may be amended.

During the international phase, the claims may also be amended (or further amended) under Article 34 before the International Preliminary Examining Authority. The description and drawings may only be amended under Article 34 before the International Preliminary Examining Authority.

Upon entry into the national phase, all parts of the international application may be amended under Article 28 or, where applicable, Article 41.

When? Within 2 months from the date of transmittal of the international search report or 16 months from the priority date, whichever time limit expires later. It should be noted, however, that the amendments will be considered as having been received on time if they are received by the International Bureau after the expiration of the applicable time limit but before the completion of the technical preparations for international publication (Rule 46.1).

Where not to file the amendments?

The amendments may only be filed with the International Bureau and not with the receiving Office or the International Searching Authority (Rule 46.2).

Where a demand for international preliminary examination has been/is filed, see below.

How? Either by cancelling one or more entire claims, by adding one or more new claims or by amending the text of one or more of the claims as filed.

A replacement sheet or sheets containing a complete set of claims in replacement of all the claims previously filed must be submitted.

Where a claim is cancelled, no renumbering of the other claims is required. In all cases where claims are renumbered, they must be renumbered consecutively in Arabic numerals (Section 205(a)).

The amendments must be made in the language in which the international application is to be published.

What documents must/may accompany the amendments?

Letter (Section 205(b)):

The amendments must be submitted with a letter.

The letter will not be published with the international application and the amended claims. It should not be confused with the "Statement under Article 19(1)" (see below, under "Statement under Article 19(1)").

The letter must be in English or French, at the choice of the applicant. However, if the language of the international application is English, the letter must be in English; if the language of the international application is French, the letter must be in French.

InductEV, Inc.
Exhibit 1002
Page 314

ons concerning several claims may be grouped), whether

he claim is unchanged;

he claim is cancelled;

he claim is new;

he claim replaces one or more claims as filed;

ne claim is the result of the division of a claim as filed.

)les illustrate the manner in which amendments must be explained in the accompanying

there were 48 claims and after amendment of some claims there are 51]:
31, 32, 34, 35, 37 to 48 replaced by amended claims bearing the same numbers;
36 unchanged; new claims 49 to 51 added."

there were 15 claims and after amendment of all claims there are 11]:
:placed by amended claims 1 to 11."

there were 14 claims and the amendments consist in cancelling some claims and in adding

1 14 unchanged; claims 7 to 13 cancelled; new claims 15, 16 and 17 added." or
ncelled; new claims 15, 16 and 17 added; all other claims unchanged."

nds of amendments are made]:
anged; claims 11 to 13, 18 and 19 cancelled; claims 14, 15 and 16 replaced by amended
7 subdivided into amended claims 15, 16 and 17; new claims 20 and 21 added."

-ticle 19(1)" (Rule 46.4)

be accompanied by a statement explaining the amendments and indicating any impact that
ht have on the description and the drawings (which cannot be amended under Article 19(1)).

published with the international application and the amended claims.

guage in which the international application is to be published.

ceeding 500 words if in English or if translated into English.

ed with and does not replace the letter indicating the differences between the claims as filed
ust be filed on a separate sheet and must be identified as such by a heading, preferably by
ment under Article 19(1)."

y disparaging comments on the international search report or the relevance of citations
t. Reference to citations, relevant to a given claim, contained in the international search
ly in connection with an amendment of that claim.

ternational preliminary examination has already been filed

g any amendments and any accompanying statement, under Article 19, a demand for
ry examination has already been submitted, the applicant must preferably, at the time of
(and any statement) with the International Bureau, also file with the International
Authority a copy of such amendments (and of any statement) and, where required, a
endments for the procedure before that Authority (see Rules 55.3(a) and 62.2, first
information, see the Notes to the demand form (PCT/IPEA/401).

ional preliminary examination is made, the written opinion of the International Searching
in certain cases where the International Preliminary Examining Authority did not act as
Authority and where it has notified the International Bureau under Rule 66.1*bis*(b), be
n opinion of the International Preliminary Examining Authority. If a demand is made, the
the International Preliminary Examining Authority a reply to the written opinion together,
h amendments before the expiration of 3 months from the date of mailing of Form
he expiration of 22 months from the priority date, whichever expires later (Rule 43*bis*.1(c)).

slation of the international application for entry into the national phase

n is drawn to the fact that, upon entry into the national phase, a translation of the claims as
19 may have to be furnished to the designated/elected Offices, instead of, or in addition to,
ims as filed.

the requirements of each designated/elected Office, see the *PCT Applicant's Guide*.

InductEV, Inc.
Exhibit 1002
Page 315

SEQUENCE LISTINGS AND TABLES RELATED THERETO IN INTERNATIONAL APPLICATIONS FILED IN THE U.S. RECEIVING OFFICE

The Administrative Instructions (AIs) under the Patent Cooperation Treaty (PCT), in force as of **July 1, 2009**, contain important changes relating to the manner of filing, and applicable fees for, sequence listings and/or tables related thereto (sequence-related tables) in international applications. The complete text may be accessed at http://www.wipo.int/pct/en/texts/index.htm.

Effective **July 1, 2009**, Part 8 and Annex C-*bis* will no longer form part of the AIs. Part 8 was introduced in 2001 as a temporary solution to problems arising from the filing of very large sequence listings on paper and provided for a *sequence listing forming part of the international application* to be filed in electronic form on physical medium (*e.g.*, CD), together with the remainder of the application on paper. In 2002, Part 8 was expanded to include sequence-related tables and Annex C-*bis* was added to provide technical requirements. All applicants may now file complete international applications in electronic form, eliminating the need for these temporary provisions.

I. AIS PART 8 AND ANNEX C-*BIS DELETED AS OF JULY 1, 2009*

A) **Sequence-related tables cannot be filed as a separate part of the description or in text format.** They must be provided as an integral part of the international application either:
- in PDF format as part of an international application filed in electronic form via EFS-Web; or
- on paper as part of an international application filed on paper.

B) A ***sequence listing forming part of an international application*** may be provided either:
- in electronic form, as part of an international application filed in electronic form via EFS-Web, in
  - Annex C/ST.25 text format (preferred), or
  - PDF format; or
- on paper as part of an international application filed on paper.

C) **A *sequence listing not forming part of the international application* (for search under PCT Rule 13*ter*) in Annex C/ST.25 text format**
- is not required where the *sequence listing forming part of the international application* was filed in Annex C/ST.25 text format as part of an international application filed in electronic form via EFS-Web
- is required for search where the *sequence listing forming part of the international application* was filed in PDF
- is required for search on physical medium (*e.g.*, CD) where the *sequence listing forming part of the international application* was filed on paper as part of an international application filed on paper.

II. CALCULATION OF THE INTERNATIONAL FILING FEE AND FEE REDUCTION UNDER AI § 707

A) A **sequence-related table** must form an integral part of the international application and will incur FULL page fees with no upper limit.

B) A ***sequence listing forming part of an international application*** filed:
- via EFS-Web in Annex C/ST.25 text format will incur NO page fees;
- on paper or in PDF format will incur FULL page fees with no upper limit.

III. AVAILABILITY OF SEQUENCE LISTINGS SUBMITTED FOR SEARCH UNDER PCT RULE *13TER*

International Searching Authorities will be required to transmit to the International Bureau a copy of an Annex C/ST.25 text format sequence listing provided for search under PCT Rule 13*ter*. Any such sequence listing will be made available on PATENTSCOPE® (*sequence listings forming part of the international application* are already available).

IV. JULY 2009 REQUEST (PCT/RO/101)

The Request now has two options for the last sheet: one for paper filings; and one for EFS-Web filings. The July 2009 Request may be accessed at http://www.wipo.int/pct/en/forms/index.htm

PTO/SB/08a (01-08)
Approved for use through 05/31/2008. OMB 0651-0031
U.S. Patent and Trademark Office; U.S. DEPARTMENT OF COMMERCE
Under the Paperwork Reduction Act of 1995, no persons are required to respond to a collection of information unless it contains a valid OMB control number..

Substitute for form 1449A/PTO

INFORMATION DISCLOSURE STATEMENT BY APPLICANT

(Use as many sheets as necessary)

Complete if Known	
Application Number	12/567,716
Filing Date	Sep 25, 2009
First Named Inventor	Morris P. Kesler
Art Unit	2828
Examiner Name	Not Yet Known

Sheet	1	of	1	Attorney Docket No: WTCY-0026-P01

US PATENT DOCUMENTS

Examiner Initial *	Cite No	Document Number	Publication Date	Name of Patentee or Applicant of Cited Document	Pages, Columns, Lines, Where Relevant Passages or RelevantFigures Appear
		20070222542A1	Sep 27, 2007	Joannopoulos, J. D., et al.	
		20090085706	Apr 2, 2009	Baarman, David W., et al.	
		20090230777	Sep 17, 2009	Baarman, David W., et al.	
		6452465B1	Sep 17, 2002	Brown, B. et al.	
		7492247	Feb 17, 2009	Schmidt, Josef et al.	

FOREIGN PATENT DOCUMENTS

Examiner Initials*	Cite No	Foreign Patent Document	Publication Date	Name of Patentee or Applicant of cited Document	Pages, Columns, Lines, Where Relevant Passages or RelevantFigures Appear	T^2

OTHER DOCUMENTS -- NON PATENT LITERATURE DOCUMENTS

Examiner Initials*	Cite No [1]	Include name of the author (in CAPITAL LETTERS), title of the article (when appropriate), title of the item (book, magazine, journal, serial, symposium, catalog, etc.), date, page(s), volume-issue number(s), publisher, city and/or country where published.	T^2
	NPL-1	, "International Application Serial No. PCT/US09/58499, Search Report and Written Opinion mailed 12-10-2009",	

EXAMINER **DATE CONSIDERED**

Substitute Disclosure Statement Form (PTO-1449)
* EXAMINER: Initial if reference considered, whether or not citation is in conformance with MPEP 609. Draw line through citation if not in conformance and not considered. Include copy of this form with next communication to applicant. 1 Applicant's unique citation designation number (optional) 2 Applicant is to place a check mark here if English language Translation is attached

PATENT COOPERATION TREATY

From the INTERNATIONAL SEARCHING AUTHORITY

To:
ROBERT A. MAZZARESE
STRATEGIC PATENTS, P.C.
C/O INTELLEVATE
P.O. BOX 52050
MINNEAPOLIS, MN 55402

PCT

NOTIFICATION OF TRANSMITTAL OF THE INTERNATIONAL SEARCH REPORT AND THE WRITTEN OPINION OF THE INTERNATIONAL SEARCHING AUTHORITY, OR THE DECLARATION

(PCT Rule 44.1)

	Date of mailing *(day/month/year)*
Applicant's or agent's file reference WTCY0026PWO	**FOR FURTHER ACTION** See paragraphs 1 and 4 below
International application No. PCT/US 09/58499	International filing date *(day/month/year)* 25 September 2009 (25.09.2009)
Applicant WITRICITY CORPORATION	

80157.E92W01

1. ☒ The applicant is hereby notified that the international search report and the written opinion of the International Searching Authority have been established and are transmitted herewith.

   Filing of amendments and statement under Article 19:
   The applicant is entitled, if he so wishes, to amend the claims of the international application (see Rule 46):

   When? The time limit for filing such amendments is normally two months from the date of transmittal of the international search report.

   Where? Directly to the International Bureau of WIPO, 34 chemin des Colombettes 1211 Geneva 20, Switzerland, Facsimile No.: +41 22 338 8270

   For more detailed instructions, see the notes on the accompanying sheet.

2. ☐ The applicant is hereby notified that no international search report will be established and that the declaration under Article 17(2)(a) to that effect and the written opinion of the International Searching Authority are transmitted herewith.

3. ☐ **With regard to the protest** against payment of (an) additional fee(s) under Rule 40.2, the applicant is notified that:

   ☐ the protest together with the decision thereon has been transmitted to the International Bureau together with the applicant's request to forward the texts of both the protest and the decision thereon to the designated Offices.

   ☐ no decision has been made yet on the protest; the applicant will be notified as soon as a decision is made.

4. **Reminders**

   Shortly after the expiration of **18 months** from the priority date, the international application will be published by the International Bureau. If the applicant wishes to avoid or postpone publication, a notice of withdrawal of the international application, or of the priority claim, must reach the International Bureau as provided in Rules 90*bis*.1 and 90*bis*.3, respectively, before the completion of the technical preparations for international publication.

   The applicant may submit comments on an informal basis on the written opinion of the International Searching Authority to the International Bureau. The International Bureau will send a copy of such comments to all designated Offices unless an international preliminary examination report has been or is to be established. These comments would also be made available to the public but not before the expiration of 30 months from the priority date.

   Within **19 months** from the priority date, but only in respect of some designated Offices, a demand for international preliminary examination must be filed if the applicant wishes to postpone the entry into the national phase **until 30 months** from the priority date (in some Offices even later); otherwise, the applicant must, **within 20 months** from the priority date, perform the prescribed acts for entry into the national phase before those designated Offices.

   In respect of other designated Offices, the time limit of **30 months** (or later) will apply even if no demand is filed within 19 months.

   See the Annex to Form PCT/IB/301 and, for details about the applicable time limits, Office by Office, see the *PCT Applicant's Guide*, Volume II, National Chapters and the WIPO Internet site.

Name and mailing address of the ISA/US Mail Stop PCT, Attn: ISA/US Commissioner for Patents P.O. Box 1450, Alexandria, Virginia 22313-1450 Facsimile No. 571-273-3201	Authorized officer: Lee W. Young PCT Helpdesk: 571-272-4300 PCT OSP: 571-272-7774

Form PCT/ISA/220 (January 2004) *(See notes on accompanying sheet)*

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PATENT COOPERATION TREATY

From the INTERNATIONAL SEARCHING AUTHORITY

To:
ROBERT A. MAZZARESE
STRATEGIC PATENTS, P.C.
C/O INTELLEVATE
P.O. BOX 52050
MINNEAPOLIS, MN 55402

PCT

NOTIFICATION OF TRANSMITTAL OF THE INTERNATIONAL SEARCH REPORT AND THE WRITTEN OPINION OF THE INTERNATIONAL SEARCHING AUTHORITY, OR THE DECLARATION

(PCT Rule 44.1)

	Date of mailing *(day/month/year)* 10 DEC 2009
Applicant's or agent's file reference WTCY0026PWO	**FOR FURTHER ACTION** See paragraphs 1 and 4 below
International application No. PCT/US 09/58499	International filing date *(day/month/year)* 25 September 2009 (25.09.2009)
Applicant WITRICITY CORPORATION	

1. ☒ The applicant is hereby notified that the international search report and the written opinion of the International Searching Authority have been established and are transmitted herewith.

   Filing of amendments and statement under Article 19:
   The applicant is entitled, if he so wishes, to amend the claims of the international application (see Rule 46):

   When? The time limit for filing such amendments is normally two months from the date of transmittal of the international search report.

   Where? Directly to the International Bureau of WIPO, 34 chemin des Colombettes 1211 Geneva 20, Switzerland, Facsimile No.: +41 22 338 8270

   For more detailed instructions, see the notes on the accompanying sheet.

2. ☐ The applicant is hereby notified that no international search report will be established and that the declaration under Article 17(2)(a) to that effect and the written opinion of the International Searching Authority are transmitted herewith.

3. ☐ **With regard to the protest** against payment of (an) additional fee(s) under Rule 40.2, the applicant is notified that:

   ☐ the protest together with the decision thereon has been transmitted to the International Bureau together with the applicant's request to forward the texts of both the protest and the decision thereon to the designated Offices.

   ☐ no decision has been made yet on the protest; the applicant will be notified as soon as a decision is made.

4. **Reminders**

   Shortly after the expiration of **18 months** from the priority date, the international application will be published by the International Bureau. If the applicant wishes to avoid or postpone publication, a notice of withdrawal of the international application, or of the priority claim, must reach the International Bureau as provided in Rules 90*bis*.1 and 90*bis*.3, respectively, before the completion of the technical preparations for international publication.

   The applicant may submit comments on an informal basis on the written opinion of the International Searching Authority to the International Bureau. The International Bureau will send a copy of such comments to all designated Offices unless an international preliminary examination report has been or is to be established. These comments would also be made available to the public but not before the expiration of 30 months from the priority date.

   Within **19 months** from the priority date, but only in respect of some designated Offices, a demand for international preliminary examination must be filed if the applicant wishes to postpone the entry into the national phase **until 30 months** from the priority date (in some Offices even later); otherwise, the applicant must, **within 20 months** from the priority date, perform the prescribed acts for entry into the national phase before those designated Offices.

   In respect of other designated Offices, the time limit of **30 months** (or later) will apply even if no demand is filed within 19 months.

   See the Annex to Form PCT/IB/301 and, for details about the applicable time limits, Office by Office, see the *PCT Applicant's Guide*, Volume II, National Chapters and the WIPO Internet site.

Name and mailing address of the ISA/US Mail Stop PCT, Attn: ISA/US Commissioner for Patents P.O. Box 1450, Alexandria, Virginia 22313-1450 Facsimile No. 571-273-3201	Authorized officer: Lee W. Young PCT Helpdesk: 571-272-4300 PCT OSP: 571-272-7774

Form PCT/ISA/220 (January 2004) *(See notes on accompanying sheet)*

PATENT COOPERATION TREATY

PCT

INTERNATIONAL SEARCH REPORT

(PCT Article 18 and Rules 43 and 44)

Applicant's or agent's file reference WTCY0026PWO	**FOR FURTHER ACTION**	see Form PCT/ISA/220 as well as, where applicable, item 5 below.
International application No. PCT/US 09/58499	International filing date *(day/month/year)* 25 September 2009 (25.09.2009)	(Earliest) Priority Date *(day/month/year)* 27 September 2008 (27.09.2008)
Applicant WITRICITY CORPORATION		

This international search report has been prepared by this International Searching Authority and is transmitted to the applicant according to Article 18. A copy is being transmitted to the International Bureau.

This international search report consists of a total of 2 sheets.

☐ It is also accompanied by a copy of each prior art document cited in this report.

1. **Basis of the report**

   a. With regard to the **language**, the international search was carried out on the basis of:

   ☒ the international application in the language in which it was filed.

   ☐ a translation of the international application into _____ which is the language of a translation furnished for the purposes of international search (Rules 12.3(a) and 23.1(b)).

   b. ☐ This international search report has been established taking into account the **rectification of an obvious mistake** authorized by or notified to this Authority under Rule 91 (Rule 43.6*bis*(a)).

   c. ☐ With regard to any **nucleotide and/or amino acid sequence** disclosed in the international application, see Box No. I.

2. ☐ **Certain claims were found unsearchable** (see Box No. II).

3. ☐ **Unity of invention is lacking** (see Box No. III).

4. With regard to the **title**,

   ☒ the text is approved as submitted by the applicant.

   ☐ the text has been established by this Authority to read as follows:

5. With regard to the **abstract**,

   ☒ the text is approved as submitted by the applicant.

   ☐ the text has been established, according to Rule 38.2, by this Authority as it appears in Box No. IV. The applicant may, within one month from the date of mailing of this international search report, submit comments to this Authority.

6. With regard to the **drawings**,

   a. the figure of the **drawings** to be published with the abstract is Figure No. 1

   ☒ as suggested by the applicant.

   ☐ as selected by this Authority, because the applicant failed to suggest a figure.

   ☐ as selected by this Authority, because this figure better characterizes the invention.

   b. ☐ none of the figures is to be published with the abstract.

InductEV, Inc.
Exhibit 1002
Page 320

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US 09/58499

A. CLASSIFICATION OF SUBJECT MATTER
IPC(8) - H03B 19/00 (2009.01)
USPC - 327/113
According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
USPC: 327/113

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched
USPC: 327/113, 306, 530, 555; 375/323; 307/134 (keyword limited - see terms below)

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
PubWEST (PGPB, USPT, USOC, EPAB, JPAB); GOOGLE
Search Terms: energy, power, power generator, generator, wireless, resonator, first resonator, second resonator, third resonator, Q-factor, distance, tunable, oscillating, impedance, capacitance, load

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	US 2007/0222542 A1 (Joannopoulos et al.) 27 September 2007 (27.09.2007), entire document, especially; abstract, para. [0004], [0005], [0013], [0014], [0019], [0023], [0025], [0029], [0033]	1 - 26
Y	US 6,452,465 B1 (Brown et al.) 17 September 2002 (17.09.2002), entire document, especially; abstract, col. 2, ln 4-6, col. 3, ln 7-12, 66-67	1 - 26

☐ Further documents are listed in the continuation of Box C. ☐

* Special categories of cited documents:
"A" document defining the general state of the art which is not considered to be of particular relevance
"E" earlier application or patent but published on or after the international filing date
"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)
"O" document referring to an oral disclosure, use, exhibition or other means
"P" document published prior to the international filing date but later than the priority date claimed
"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
24 November 2009 (24.11.2009)	10 DEC 2009
Name and mailing address of the ISA/US Mail Stop PCT, Attn: ISA/US, Commissioner for Patents P.O. Box 1450, Alexandria, Virginia 22313-1450 Facsimile No. 571-273-3201	Authorized officer: Lee W. Young PCT Helpdesk: 571-272-4300 PCT OSP: 571-272-7774

Form PCT/ISA/210 (second sheet) (July 2009)

PATENT COOPERATION TREATY

From the
INTERNATIONAL SEARCHING AUTHORITY

To: ROBERT A. MAZZARESE
STRATEGIC PATENTS, P.C.
C/O INTELLEVATE
P.O. BOX 52050
MINNEAPOLIS, MN 55402

PCT

WRITTEN OPINION OF THE
INTERNATIONAL SEARCHING AUTHORITY

(PCT Rule 43*bis*.1)

Date of mailing *(day/month/year)*	10 DEC 2009

Applicant's or agent's file reference	FOR FURTHER ACTION
WTCY0026PWO	See paragraph 2 below

International application No.	International filing date *(day/month/year)*	Priority date *(day/month/year)*
PCT/US 09/58499	25 September 2009 (25.09.2009)	27 September 2008 (27.09.2008)

International Patent Classification (IPC) or both national classification and IPC
IPC(8) - H03B 19/00 (2009.01)
USPC - 327/113

Applicant WITRICITY CORPORATION

1. This opinion contains indications relating to the following items:

- [X] Box No. I Basis of the opinion
- [ ] Box No. II Priority
- [ ] Box No. III Non-establishment of opinion with regard to novelty, inventive step and industrial applicability
- [ ] Box No. IV Lack of unity of invention
- [X] Box No. V Reasoned statement under Rule 43*bis*.1(a)(i) with regard to novelty, inventive step or industrial applicability; citations and explanations supporting such statement
- [ ] Box No. VI Certain documents cited
- [ ] Box No. VII Certain defects in the international application
- [ ] Box No. VIII Certain observations on the international application

2. **FURTHER ACTION**

If a demand for international preliminary examination is made, this opinion will be considered to be a written opinion of the International Preliminary Examining Authority ("IPEA") except that this does not apply where the applicant chooses an Authority other than this one to be the IPEA and the chosen IPEA has notified the International Bureau under Rule 66.1*bis*(b) that written opinions of this International Searching Authority will not be so considered.

If this opinion is, as provided above, considered to be a written opinion of the IPEA, the applicant is invited to submit to the IPEA a written reply together, where appropriate, with amendments, before the expiration of 3 months from the date of mailing of Form PCT/ISA/220 or before the expiration of 22 months from the priority date, whichever expires later.

For further options, see Form PCT/ISA/220.

3. For further details, see notes to Form PCT/ISA/220.

Name and mailing address of the ISA/US	Date of completion of this opinion	Authorized officer:
Mail Stop PCT, Attn: ISA/US Commissioner for Patents P.O. Box 1450, Alexandria, Virginia 22313-1450 Facsimile No. 571-273-3201	27 November 2009 (27.11.2009)	Lee W. Young PCT Helpdesk: 571-272-4300 PCT OSP: 571-272-7774

Form PCT/ISA/237 (cover sheet) (July 2009)

WRITTEN OPINION OF THE INTERNATIONAL SEARCHING AUTHORITY

International application No.
PCT/US 09/58499

Box No. I Basis of this opinion

1. With regard to the **language**, this opinion has been established on the basis of:

   ☒ the international application in the language in which it was filed.

   ☐ a translation of the international application into _____ which is the language of a translation furnished for the purposes of international search (Rules 12.3(a) and 23.1(b)).

2. ☐ This opinion has been established taking into account the **rectification of an obvious mistake** authorized by or notified to this Authority under Rule 91 (Rule 43*bis*.1(a))

3. With regard to any **nucleotide and/or amino acid sequence** disclosed in the international application, this opinion has been established on the basis of a sequence listing filed or furnished:

   a. (means)

      ☐ on paper

      ☐ in electronic form

   b. (time)

      ☐ in the international application as filed

      ☐ together with the international application in electronic form

      ☐ subsequently to this Authority for the purposes of search

4. ☐ In addition, in the case that more than one version or copy of a sequence listing has been filed or furnished, the required statements that the information in the subsequent or additional copies is identical to that in the application as filed or does not go beyond the application as filed, as appropriate, were furnished.

5. Additional comments:

InductEV, Inc.
Exhibit 1002
Page 323

Box No. V **Reasoned statement under Rule 43*bis*.1(a)(i) with regard to novelty, inventive step or industrial applicability; citations and explanations supporting such statement**

1. Statement

Novelty (N)	Claims	1 - 26	YES
	Claims	None.	NO
Inventive step (IS)	Claims	None.	YES
	Claims	1 - 26	NO
Industrial applicability (IA)	Claims	1 - 26	YES
	Claims	None.	NO

2. Citations and explanations:

Claims 1 - 26 lack an inventive step under PCT Article 33(3) as being obvious over US 2007/0222542 A1 to Joannopoulos et al. (hereinafter 'Joannopoulos'), in view of US 6,452,465 B1 to Brown et al. (hereinafter 'Brown').

Regarding claim 1, Joannopoulos teaches a system, comprising: a source resonator having a Q-factor Q1 and a characteristic size X1 (abstract, para. [0005]), coupled to a power generator (external power supply, para. [0005]), and a second resonator having a Q-factor Q2 and a characteristic size X2 (para. [0005]), coupled to a load located a distance D from the source resonator (distance between the two resonators can be larger than the characteristic size of each resonator, para. [0005]), wherein the source resonator and the second resonator are coupled to exchange energy wirelessly among the source resonator and the second resonator (abstract, para. [0004], [0013]). Joannopoulos does not teach that the square root of Q1Q2 > 100. However, Brown teaches multiple resonators that are tunable (abstract), and that filters may be fabricated with low quality factor resonators (col. 2, ln 4-6). It would have been obvious to one skilled in the art to combine the teachings of Joannopoulos with those of Brown in order to provide an inexpensive resonator structure. Neither Joannopoulos nor Brown specifically teach that the square root of Q1Q2 > 100. However, this configuration could have been determined via routine experimentation, and provided based on the specific application of the system.

Regarding claims 2 and 3, neither Joannopoulos nor Brown teaches that Q1 (or Q2 - claim 3) < 100. However, it was well known it the art at the time of the invention that resonator materials were available with low quality factors, e.g. Q1 (or Q2 - claim 3) < 100. It would have been obvious to one skilled in the art to provide Q1 (or Q2 - claim 3) < 100, in order to provide an inexpensive resonator structure.

Regarding claims 4 and 5, neither Joannopoulos nor Brown specifically teaches a third resonator having a Q-factor Q3 configured to transfer energy non-raditively with the source and second resonators, wherein the square root of Q1Q3 > 100 and the square root of Q2Q3 > 100, wherein Q3 < 100 (claim - 5). However, this configuration could have been determined via routine experimentation, and provided based on the specific application of the system.

Regarding claim 6, Joannopoulos teaches that the source resonator is coupled to the power generator with direct electrical connections (para. [0014]).

Regarding claim 7, Joannopoulos teaches that the source resonator is coupled and impedance matched to the power generator with direct electrical connections (para. [0014]).

Regarding claim 8, Brown teaches a tunable circuit wherein the source resonator is coupled to the power generator through the tunable circuit with direct electrical connections (abstract, col. 3, ln 7-12).

Regarding claim 9, Joannopoulos teaches that at least one of the direct electrical connections is configured to substantially preserve a resonant mode of the source resonator (resonant cavity, para. [0033]).

Regarding claim 10, neither Joannopoulos nor Brown specifically teaches that the source resonator has a first terminal, a second terminal, and a center terminal, and wherein an impedance between the first terminal and the center terminal and between the second terminal and the center terminal are substantially equal. However, this configuration could have been determined via routine experimentation and provided to maximize power transfer.

Regarding claim 11, Joannopoulos teaches that the source resonator includes a capacitive loaded loop having a first terminal, a second terminal, and a center terminal (para. [0019]), and wherein an impedance between the first terminal and the center terminal and between the second terminal and the center terminal are substantially equal (para. [0019]).

Regarding claim 12, neither Joannopoulos nor Brown specifically teaches that the source resonator is coupled to an impedance matching network and the impedance matching network further comprises a first terminal, a second terminal, and a center terminal, and wherein an impedance between the first terminal and the center terminal and between the second terminal and the center terminal are substantially equal. However, this configuration could have been determined via routine experimentation and provided to maximize power transfer.

---(continued in Supplemental Box)---

Supplemental Box

In case **the space in any of the preceding boxes is not sufficient.**
Continuation of:

V.2 Citations and explanations:

Regarding claim 13, neither Joannopoulos nor Brown teaches that the first terminal and the second terminal are directly coupled to the power generator and driven with oscillating signals that are near 180 degrees out of phase. However, this configuration was well known in the art at the time of the invention, and could have been provided based on the specific application.

Regarding claim 14, Joannopoulos teaches that the source resonator has a resonant frequency WI and the first terminal and the second terminal are directly coupled to the power generator and driven with oscillating signals that are substantially equal to the resonant frequency omega sub 1 (para. [0023], [0025]).

Regarding claim 15, neither Joannopoulos nor Brown specifically that the center terminal is connected to an electrical ground. However, this configuration was well known in the art at the time of the invention, and could have been provided in order to provide a voltage reference point.

Regarding claim 16, neither Joannopoulos nor Brown teach that the source resonator has a resonant frequency omega sub 1 and the first terminal and the second terminal are directly coupled to the power generator and driven with a frequency substantially equal to the resonant frequency omega sub 1. However, this configuration could have been determined via routine experimentation and provided to maximize power transfer.

Regarding claim 17, Brown teaches a plurality of capacitors coupled to the power generator and the load (col., 3, ln 66-67).

Regarding claim 18, Joannopoulos that the source resonator and the second resonator are each enclosed in a low loss tangent material (para. [0023]).

Regarding claim 19, Joannopoulos teaches a power conversion circuit wherein the second resonator is coupled to the power conversion circuit to deliver DC power to the load (abstract).

Regarding claim 20, Joannopoulos teaches a power conversion circuit wherein the second resonator is coupled to the power conversion circuit to deliver AC power to the load (power, abstract, para. [0029]).

Regarding claim 21, Joannopoulos teaches a power conversion circuit, wherein the second resonator is coupled to the power conversion circuit to deliver both AC and DC power to the load (power, abstract, para. [0029]).

Regarding claim 22, Joannopoulos teaches a power conversion circuit and a plurality of loads, wherein the second resonator is coupled to the power conversion circuit (abstract), and the power conversion circuit is coupled to the plurality of loads (abstract).

Regarding claim 23, Brown teaches the system, wherein the impedance matching network comprises capacitors (col., 3, ln 66-67).

Regarding claim 24, Joannopoulos teaches that the impedance matching network comprises inductors (coils, para. [0025]).

Regarding claim 25, Brown teaches that the tunable circuit comprises variable capacitors (col., 3, ln 66-67).

Regarding claim 26, Joannopoulos teaches that the tunable circuit comprises variable inductors (para. [0025]).

Claims 1 - 26 have industrial applicability as defined by PCT Article 33(4) because the subject matter can be made or used in industry.

NOTES TO FORM PCT/ISA/220

These Notes are intended to give the basic instructions concerning the filing of amendments under Article 19. The Notes are based on the requirements of the Patent Cooperation Treaty, the Regulations and the Administrative Instructions under that Treaty. In case of discrepancy between these Notes and those requirements, the latter are applicable. For more detailed information, see also the *PCT Applicant's Guide*.

In these Notes, "Article," "Rule" and "Section" refer to the provisions of the PCT, the PCT Regulations and the PCT Administrative Instructions, respectively.

INSTRUCTIONS CONCERNING AMENDMENTS UNDER ARTICLE 19

The applicant has, after having received the international search report and the written opinion of the International Searching Authority, one opportunity to amend the claims of the international application. It should however be emphasized that, since all parts of the international application (claims, description and drawings) may be amended during the international preliminary examination procedure, there is usually no need to file amendments of the claims under Article 19 except where, e.g. the applicant wants the latter to be published for the purposes of provisional protection or has another reason for amending the claims before international publication. Furthermore, it should be emphasized that provisional protection is available in some States only (see *PCT Applicant's Guide*, Annex B).

The attention of the applicant is drawn to the fact that amendments to the claims under Article 19 are not allowed where the International Searching Authority has declared, under Article 17(2), that no international search report would be established (see *PCT Applicant's Guide*, International Phase, paragraph 296).

What parts of the international application may be amended?

Under Article 19, only the claims may be amended.

During the international phase, the claims may also be amended (or further amended) under Article 34 before the International Preliminary Examining Authority. The description and drawings may only be amended under Article 34 before the International Preliminary Examining Authority.

Upon entry into the national phase, all parts of the international application may be amended under Article 28 or, where applicable, Article 41.

When? Within 2 months from the date of transmittal of the international search report or 16 months from the priority date, whichever time limit expires later. It should be noted, however, that the amendments will be considered as having been received on time if they are received by the International Bureau after the expiration of the applicable time limit but before the completion of the technical preparations for international publication (Rule 46.1).

Where not to file the amendments?

The amendments may only be filed with the International Bureau and not with the receiving Office or the International Searching Authority (Rule 46.2).

Where a demand for international preliminary examination has been/is filed, see below.

How? Either by cancelling one or more entire claims, by adding one or more new claims or by amending the text of one or more of the claims as filed.

A replacement sheet or sheets containing a complete set of claims in replacement of all the claims previously filed must be submitted.

Where a claim is cancelled, no renumbering of the other claims is required. In all cases where claims are renumbered, they must be renumbered consecutively in Arabic numerals (Section 205(a)).

The amendments must be made in the language in which the international application is to be published.

What documents must/may accompany the amendments?

Letter (Section 205(b)):

The amendments must be submitted with a letter.

The letter will not be published with the international application and the amended claims. It should not be confused with the "Statement under Article 19(1)" (see below, under "Statement under Article 19(1)").

The letter must be in English or French, at the choice of the applicant. However, if the language of the international application is English, the letter must be in English; if the language of the international application is French, the letter must be in French.

InductEV, Inc.
Exhibit 1002
Page 326

ons concerning several claims may be grouped), whether

he claim is unchanged;

he claim is cancelled;

he claim is new;

he claim replaces one or more claims as filed;

ne claim is the result of the division of a claim as filed.

)les illustrate the manner in which amendments must be explained in the accompanying

there were 48 claims and after amendment of some claims there are 51]:
31, 32, 34, 35, 37 to 48 replaced by amended claims bearing the same numbers;
36 unchanged; new claims 49 to 51 added."

there were 15 claims and after amendment of all claims there are 11]:
:placed by amended claims 1 to 11."

there were 14 claims and the amendments consist in cancelling some claims and in adding

1 14 unchanged; claims 7 to 13 cancelled; new claims 15, 16 and 17 added." or
ıncelled; new claims 15, 16 and 17 added; all other claims unchanged."

nds of amendments are made]:
ıanged; claims 11 to 13, 18 and 19 cancelled; claims 14, 15 and 16 replaced by amended
7 subdivided into amended claims 15, 16 and 17; new claims 20 and 21 added."

-ticle 19(1)" (Rule 46.4)

be accompanied by a statement explaining the amendments and indicating any impact that
ht have on the description and the drawings (which cannot be amended under Article 19(1)).

published with the international application and the amended claims.

;uage in which the international application is to be published.

:ceeding 500 words if in English or if translated into English.

ed with and does not replace the letter indicating the differences between the claims as filed
ust be filed on a separate sheet and must be identified as such by a heading, preferably by
ment under Article 19(1)."

y disparaging comments on the international search report or the relevance of citations
t. Reference to citations, relevant to a given claim, contained in the international search
ly in connection with an amendment of that claim.

ternational preliminary examination has already been filed

g any amendments and any accompanying statement, under Article 19, a demand for
ry examination has already been submitted, the applicant must preferably, at the time of
; (and any statement) with the International Bureau, also file with the International
; Authority a copy of such amendments (and of any statement) and, where required, a
ıendments for the procedure before that Authority (see Rules 55.3(a) and 62.2, first
information, see the Notes to the demand form (PCT/IPEA/401).

.ional preliminary examination is made, the written opinion of the International Searching
in certain cases where the International Preliminary Examining Authority did not act as
Authority and where it has notified the International Bureau under Rule 66.1*bis*(b), be
:n opinion of the International Preliminary Examining Authority. If a demand is made, the
the International Preliminary Examining Authority a reply to the written opinion together,
h amendments before the expiration of 3 months from the date of mailing of Form
:he expiration of 22 months from the priority date, whichever expires later (Rule 43*bis*.1(c)).

:slation of the international application for entry into the national phase

ı is drawn to the fact that, upon entry into the national phase, a translation of the claims as
19 may have to be furnished to the designated/elected Offices, instead of, or in addition to,
ıims as filed.

the requirements of each designated/elected Office, see the *PCT Applicant's Guide*.

InductEV, Inc.
Exhibit 1002
Page 327

SEQUENCE LISTINGS AND TABLES RELATED THERETO IN INTERNATIONAL APPLICATIONS FILED IN THE U.S. RECEIVING OFFICE

The Administrative Instructions (AIs) under the Patent Cooperation Treaty (PCT), in force as of **July 1, 2009**, contain important changes relating to the manner of filing, and applicable fees for, sequence listings and/or tables related thereto (sequence-related tables) in international applications. The complete text may be accessed at http://www.wipo.int/pct/en/texts/index.htm.

Effective **July 1, 2009**, Part 8 and Annex C-*bis* will no longer form part of the AIs. Part 8 was introduced in 2001 as a temporary solution to problems arising from the filing of very large sequence listings on paper and provided for a *sequence listing forming part of the international application* to be filed in electronic form on physical medium (*e.g.*, CD), together with the remainder of the application on paper. In 2002, Part 8 was expanded to include sequence-related tables and Annex C-*bis* was added to provide technical requirements. All applicants may now file complete international applications in electronic form, eliminating the need for these temporary provisions.

I. AIS PART 8 AND ANNEX C-*BIS DELETED AS OF JULY 1, 2009*

A) **Sequence-related tables cannot be filed as a separate part of the description or in text format.** They must be provided as an integral part of the international application either:
- in PDF format as part of an international application filed in electronic form via EFS-Web; or
- on paper as part of an international application filed on paper.

B) A ***sequence listing forming part of an international application*** may be provided either:
- in electronic form, as part of an international application filed in electronic form via EFS-Web, in
  - Annex C/ST.25 text format (preferred), or
  - PDF format; or
- on paper as part of an international application filed on paper.

C) **A *sequence listing not forming part of the international application* (for search under PCT Rule 13*ter*) in Annex C/ST.25 text format**
- is not required where the *sequence listing forming part of the international application* was filed in Annex C/ST.25 text format as part of an international application filed in electronic form via EFS-Web
- is required for search where the *sequence listing forming part of the international application* was filed in PDF
- is required for search on physical medium (*e.g.*, CD) where the *sequence listing forming part of the international application* was filed on paper as part of an international application filed on paper.

II. CALCULATION OF THE INTERNATIONAL FILING FEE AND FEE REDUCTION UNDER AI § 707

A) A **sequence-related table** must form an integral part of the international application and will incur FULL page fees with no upper limit.

B) A ***sequence listing forming part of an international application*** filed:
- via EFS-Web in Annex C/ST.25 text format will incur NO page fees;
- on paper or in PDF format will incur FULL page fees with no upper limit.

III. AVAILABILITY OF SEQUENCE LISTINGS SUBMITTED FOR SEARCH UNDER PCT RULE *13TER*

International Searching Authorities will be required to transmit to the International Bureau a copy of an Annex C/ST.25 text format sequence listing provided for search under PCT Rule 13*ter*. Any such sequence listing will be made available on PATENTSCOPE® (*sequence listings forming part of the international application* are already available).

IV. JULY 2009 REQUEST (PCT/RO/101)

The Request now has two options for the last sheet: one for paper filings; and one for EFS-Web filings. The July 2009 Request may be accessed at http://www.wipo.int/pct/en/forms/index.htm

Electronic Acknowledgement Receipt

EFS ID:	7304994
Application Number:	12567716
International Application Number:	
Confirmation Number:	4901
Title of Invention:	WIRELESS ENERGY TRANSFER SYSTEMS
First Named Inventor/Applicant Name:	Morris P. Kesler
Customer Number:	43520
Filer:	John H. Nortrop/Elizabeth Nortrup
Filer Authorized By:	John H. Nortrop
Attorney Docket Number:	WTCY-0026-P01
Receipt Date:	29-MAR-2010
Filing Date:	25-SEP-2009
Time Stamp:	14:41:17
Application Type:	Utility under 35 USC 111(a)

Payment information:

Submitted with Payment	no

File Listing:

Document Number	Document Description	File Name	File Size(Bytes)/ Message Digest	Multi Part /.zip	Pages (if appl.)
1	Transmittal Letter	WTCY-0026-P01_032910_IDSCommunication.pdf	89662 a6ffc5758b0eb5790fbd917d9ece190bf5f79b81	no	2

Warnings:	
Information:	

2	Information Disclosure Statement (IDS) Filed (SB/08)	WTCY-0026-P01_032910_Form1449.pdf	128330 2e4d0288c91b6921ebc56d68ae719b71664e9b97	no	1
Warnings:					
Information:					
This is not an USPTO supplied IDS fillable form					
3	NPL Documents	NPL-1_PCTUS0958499_ISR-121009.pdf	1734426 7b273cea5fbcd6d360a04814 3213c8c0fe1238f9	no	11
Warnings:					
Information:					
		Total Files Size (in bytes):	1952418		

This Acknowledgement Receipt evidences receipt on the noted date by the USPTO of the indicated documents, characterized by the applicant, and including page counts, where applicable. It serves as evidence of receipt similar to a Post Card, as described in MPEP 503.

New Applications Under 35 U.S.C. 111
If a new application is being filed and the application includes the necessary components for a filing date (see 37 CFR 1.53(b)-(d) and MPEP 506), a Filing Receipt (37 CFR 1.54) will be issued in due course and the date shown on this Acknowledgement Receipt will establish the filing date of the application.

National Stage of an International Application under 35 U.S.C. 371
If a timely submission to enter the national stage of an international application is compliant with the conditions of 35 U.S.C. 371 and other applicable requirements a Form PCT/DO/EO/903 indicating acceptance of the application as a national stage submission under 35 U.S.C. 371 will be issued in addition to the Filing Receipt, in due course.

New International Application Filed with the USPTO as a Receiving Office
If a new international application is being filed and the international application includes the necessary components for an international filing date (see PCT Article 11 and MPEP 1810), a Notification of the International Application Number and of the International Filing Date (Form PCT/RO/105) will be issued in due course, subject to prescriptions concerning national security, and the date shown on this Acknowledgement Receipt will establish the international filing date of the application.

ATTORNEY'S DOCKET NO. WTCY-0026-P01

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

Serial No.:	12/567,716
Filing Date:	September 25, 2009
Applicant:	Morris P. Kesler et al.
Title:	WIRELESS ENERGY TRANSFER SYSTEMS
Group Art Unit:	2828
Examiner:	Not Yet Known
Conf. No.:	4901

INFORMATION DISCLOSURE STATEMENT

Commissioner for Patents
P.O. Box 1450
Alexandria, VA 22313-1450

In compliance with the duty imposed by 37 C.F.R. § 1.56, and in accordance with 37 C.F.R. §§ 1.97 *et seq.*, the referenced materials are brought to the attention of the Examiner for consideration in connection with the above-identified patent application. Applicants respectfully request that this Information Disclosure Statement be entered and the documents listed on the attached Form 1449 be considered by the Examiner and made of record. Pursuant to the provisions of MPEP 609, Applicants request that a copy of the 1449 form, initialed as being considered by the Examiner, be returned to the Applicants with the next official communication.

Pursuant to 37 C.F.R. §1.97(b), it is believed that no fee or statement is required with the Information Disclosure Statement. However, if an Office Action on the merits has been mailed, the Commissioner is hereby authorized to charge the required fees to Deposit Account No. 50-4262 in order to have this Information Disclosure Statement considered.

Pursuant to 37 C.F.R. 1.98(a)(2), Applicant believes that copies of cited U.S. Patents and Published and Non-Published Applications identifiable by USPTO Serial Number are no longer required to be provided to the Office. Notification of this change to this effect was provided in the United States Patent and Trademark Office OG Notices dated October 12, 2004 and October 19, 2004. Thus, Applicant has not included copies of any US Patents or US Patent Applications

identifiable by serial number that may be cited with this submission. Should the Office require copies to be provided, Applicant respectfully requests that notice of such requirement be directed to Applicant's below-signed representative. Applicant acknowledges the requirement to submit copies of foreign patent documents and non-patent literature in accordance with 37 C.F.R. 1.98(a)(2).

The Examiner is invited to contact the Applicants' Representative at the below-listed telephone number if there are any questions regarding this communication.

Respectfully submitted on March 29, 2010,

STRATEGIC PATENTS, P.C.

/John Nortrup, Reg. No. 59,063/
John H. Nortrup
Telephone: 207-985-2126

Customer Number 43520

UNITED STATES PATENT AND TRADEMARK OFFICE

UNITED STATES DEPARTMENT OF COMMERCE
United States Patent and Trademark Office
Address: COMMISSIONER FOR PATENTS
P.O. Box 1450
Alexandria, Virginia 22313-1450
www.uspto.gov

APPLICATION NUMBER	FILING OR 371(C) DATE	FIRST NAMED APPLICANT	ATTY. DOCKET NO./TITLE
12/567,716	09/25/2009	Morris P. Kesler	WTCY-0026-P01

CONFIRMATION NO. 4901

43520
STRATEGIC PATENTS P.C..
C/O PORTFOLIOIP
P.O. BOX 52050
MINNEAPOLIS, MN 55402

PUBLICATION NOTICE

OC000000042027296

Title:WIRELESS ENERGY TRANSFER SYSTEMS

Publication No.US-2010-0141042-A1
Publication Date:06/10/2010

NOTICE OF PUBLICATION OF APPLICATION

The above-identified application will be electronically published as a patent application publication pursuant to 37 CFR 1.211, et seq. The patent application publication number and publication date are set forth above.

The publication may be accessed through the USPTO's publically available Searchable Databases via the Internet at www.uspto.gov. The direct link to access the publication is currently http://www.uspto.gov/patft/.

The publication process established by the Office does not provide for mailing a copy of the publication to applicant. A copy of the publication may be obtained from the Office upon payment of the appropriate fee set forth in 37 CFR 1.19(a)(1). Orders for copies of patent application publications are handled by the USPTO's Office of Public Records. The Office of Public Records can be reached by telephone at (703) 308-9726 or (800) 972-6382, by facsimile at (703) 305-8759, by mail addressed to the United States Patent and Trademark Office, Office of Public Records, Alexandria, VA 22313-1450 or via the Internet.

In addition, information on the status of the application, including the mailing date of Office actions and the dates of receipt of correspondence filed in the Office, may also be accessed via the Internet through the Patent Electronic Business Center at www.uspto.gov using the public side of the Patent Application Information and Retrieval (PAIR) system. The direct link to access this status information is currently http://pair.uspto.gov/. Prior to publication, such status information is confidential and may only be obtained by applicant using the private side of PAIR.

Further assistance in electronically accessing the publication, or about PAIR, is available by calling the Patent Electronic Business Center at 1-866-217-9197.

Office of Data Managment, Application Assistance Unit (571) 272-4000, or (571) 272-4200, or 1-888-786-0101

PATENT COOPERATION TREATY

From the INTERNATIONAL SEARCHING AUTHORITY

To:
MARC M. WEFERS
FISH & RICHARDSON P.C.
P.O. BOX 1022
MINNEAPOLIS, MN 55440-1022

PCT

NOTIFICATION OF TRANSMITTAL OF THE INTERNATIONAL SEARCH REPORT AND THE WRITTEN OPINION OF THE INTERNATIONAL SEARCHING AUTHORITY, OR THE DECLARATION

(PCT Rule 44.1)

Date of mailing *(day/month/year)*	07 DEC 2009
Applicant's or agent's file reference 019970366WO1	**FOR FURTHER ACTION** See paragraphs 1 and 4 below
International application No. PCT/US 09/59244	International filing date *(day/month/year)* 01 October 2009 (01.10.2009)
Applicant MASSACHUSETTS INSTITUTE OF TECHNOLOGY	

1. ☒ The applicant is hereby notified that the international search report and the written opinion of the International Searching Authority have been established and are transmitted herewith.

   Filing of amendments and statement under Article 19:
   The applicant is entitled, if he so wishes, to amend the claims of the international application (see Rule 46):

   When? The time limit for filing such amendments is normally two months from the date of transmittal of the international search report.

   Where? Directly to the International Bureau of WIPO, 34 chemin des Colombettes 1211 Geneva 20, Switzerland, Facsimile No.: +41 22 740 14 35

   For more detailed instructions, see the notes on the accompanying sheet.

2. ☐ The applicant is hereby notified that no international search report will be established and that the declaration under Article 17(2)(a) to that effect and the written opinion of the International Searching Authority are transmitted herewith.

3. ☐ **With regard to the protest** against payment of (an) additional fee(s) under Rule 40.2, the applicant is notified that:

   ☐ the protest together with the decision thereon has been transmitted to the International Bureau together with the applicant's request to forward the texts of both the protest and the decision thereon to the designated Offices.

   ☐ no decision has been made yet on the protest; the applicant will be notified as soon as a decision is made.

4. **Reminders**

   Shortly after the expiration of **18 months** from the priority date, the international application will be published by the International Bureau. If the applicant wishes to avoid or postpone publication, a notice of withdrawal of the international application, or of the priority claim, must reach the International Bureau as provided in Rules 90*bis*.1 and 90*bis*.3, respectively, before the completion of the technical preparations for international publication.

   The applicant may submit comments on an informal basis on the written opinion of the International Searching Authority to the International Bureau. The International Bureau will send a copy of such comments to all designated Offices unless an international preliminary examination report has been or is to be established. These comments would also be made available to the public but not before the expiration of 30 months from the priority date.

   Within **19 months** from the priority date, but only in respect of some designated Offices, a demand for international preliminary examination must be filed if the applicant wishes to postpone the entry into the national phase **until 30 months** from the priority date (in some Offices even later); otherwise, the applicant must, **within 20 months** from the priority date, perform the prescribed acts for entry into the national phase before those designated Offices.

   In respect of other designated Offices, the time limit of **30 months** (or later) will apply even if no demand is filed within 19 months.

   See the Annex to Form PCT/IB/301 and, for details about the applicable time limits, Office by Office, see the *PCT Applicant's Guide*, Volume II, National Chapters and the WIPO Internet site.

Name and mailing address of the ISA/US Mail Stop PCT, Attn: ISA/US Commissioner for Patents P.O. Box 1450, Alexandria, Virginia 22313-1450 Facsimile No. 571-273-3201	Authorized officer: Lee W. Young PCT Helpdesk: 571-272-4300 PCT OSP: 571-272-7774

Form PCT/ISA/220 (January 2004) *(See notes on accompanying sheet)*

PATENT COOPERATION TREATY

PCT

INTERNATIONAL SEARCH REPORT

(PCT Article 18 and Rules 43 and 44)

Applicant's or agent's file reference 019970366WO1	**FOR FURTHER ACTION**	see Form PCT/ISA/220 as well as, where applicable, item 5 below.
International application No. PCT/US 09/59244	International filing date *(day/month/year)* 01 October 2009 (01.10.2009)	(Earliest) Priority Date *(day/month/year)* 01 October 2008 (01.10.2008)
Applicant MASSACHUSETTS INSTITUTE OF TECHNOLOGY		

This international search report has been prepared by this International Searching Authority and is transmitted to the applicant according to Article 18. A copy is being transmitted to the International Bureau.

This international search report consists of a total of 3 sheets.

☐ It is also accompanied by a copy of each prior art document cited in this report.

1. **Basis of the report**

   a. With regard to the **language**, the international search was carried out on the basis of:

   ☒ the international application in the language in which it was filed.

   ☐ a translation of the international application into _____ which is the language of a translation furnished for the purposes of international search (Rules 12.3(a) and 23.1(b)).

   b. ☐ This international search report has been established taking into account the **rectification of an obvious mistake** authorized by or notified to this Authority under Rule 91 (Rule 43.6*bis*(a)).

   c. ☐ With regard to any **nucleotide and/or amino acid sequence** disclosed in the international application, see Box No. I.

2. ☒ **Certain claims were found unsearchable** (see Box No. II).

3. ☐ **Unity of invention is lacking** (see Box No. III).

4. With regard to the **title**,

   ☒ the text is approved as submitted by the applicant.

   ☐ the text has been established by this Authority to read as follows:

5. With regard to the **abstract**,

   ☒ the text is approved as submitted by the applicant.

   ☐ the text has been established, according to Rule 38.2(b), by this Authority as it appears in Box No. IV. The applicant may, within one month from the date of mailing of this international search report, submit comments to this Authority.

6. With regard to the **drawings**,

   a. the figure of the **drawings** to be published with the abstract is Figure No. 1

   ☒ as suggested by the applicant.

   ☐ as selected by this Authority, because the applicant failed to suggest a figure.

   ☐ as selected by this Authority, because this figure better characterizes the invention.

   b. ☐ none of the figures is to be published with the abstract.

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US 09/59244

Box No. II Observations where certain claims were found unsearchable (Continuation of item 2 of first sheet)

This international search report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:

1. ☐ Claims Nos.:
because they relate to subject matter not required to be searched by this Authority, namely:

2. ☐ Claims Nos.:
because they relate to parts of the international application that do not comply with the prescribed requirements to such an extent that no meaningful international search can be carried out, specifically:

3. ☒ Claims Nos.: 5, 7-12, 14-19, 25-27, 33-49 and 54-79
because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a).

Box No. III Observations where unity of invention is lacking (Continuation of item 3 of first sheet)

This International Searching Authority found multiple inventions in this international application, as follows:

1. ☐ As all required additional search fees were timely paid by the applicant, this international search report covers all searchable claims.

2. ☐ As all searchable claims could be searched without effort justifying additional fees, this Authority did not invite payment of additional fees.

3. ☐ As only some of the required additional search fees were timely paid by the applicant, this international search report covers only those claims for which fees were paid, specifically claims Nos.:

4. ☐ No required additional search fees were timely paid by the applicant. Consequently, this international search report is restricted to the invention first mentioned in the claims; it is covered by claims Nos.:

Remark on Protest

☐ The additional search fees were accompanied by the applicant's protest and, where applicable, the payment of a protest fee.

☐ The additional search fees were accompanied by the applicant's protest but the applicable protest fee was not paid within the time limit specified in the invitation.

☐ No protest accompanied the payment of additional search fees.

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US 09/59244

A. CLASSIFICATION OF SUBJECT MATTER
IPC(8) - H01P 7/00 (2009.01)
USPC - 333/219
According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
USPC - 333/219

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched
USPC - 333/219; 307/126; 455/522 (keyword limited - see terms below)

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
pubwest (DB=PGPB,USPT,EPAB,JPAB), Google Scholar
Terms - wireless energy, coupling rate, resonate, energy accumulation, near-field, transfer, intermediate

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	US 2007/0222542 A1 (Joannopoulos et al.) 27 September 2007 (27.09.2007), abstract, para [0013], [0015], [0016], [0026], [0027], [0035]	1-4, 6, 13, 20-24, 28-32, 50-53, 80, 81
Y	US 3,517,350 A (Beaver) 23 June 1970 (23.06.1970), col 2, ln 69-72; col 7, ln 22-39	1-4, 6, 13, 20-24, 28-32, 50-53, 80, 81
X, P	US 2009/0153273 A1 (Chen) 18 June 2009 (18.06.2009), entire document	1-4, 6, 13, 20-24, 28-32, 50-53, 80, 81
X, P	WO 2008/118178 A1 (Karalis et al.) 02 October 2008 (02.10.2008), entire document	1-4, 6, 13, 20-24, 28-32, 50-53, 80, 81
A	US 6,960,968 B2 (Odendaal et al.) 01 November 2005 (01.11.2005), entire document	1-4, 6, 13, 20-24, 28-32, 50-53, 80, 81
A	US 7,069,064 B2 (Gevorgian et al.) 27 June 2006 (27.06.2006), entire document	1-4, 6, 13, 20-24, 28-32, 50-53, 80, 81
A	US 1,119,732 A (Tesla) 01 December 1914 (01.12.1914), entire document	1-4, 6, 13, 20-24, 28-32, 50-53, 80, 81

☐ Further documents are listed in the continuation of Box C. ☐

* Special categories of cited documents:
"A" document defining the general state of the art which is not considered to be of particular relevance
"E" earlier application or patent but published on or after the international filing date
"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)
"O" document referring to an oral disclosure, use, exhibition or other means
"P" document published prior to the international filing date but later than the priority date claimed
"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
16 November 2009 (16.11.2009)	07 DEC 2009

Name and mailing address of the ISA/US	Authorized officer:
Mail Stop PCT, Attn: ISA/US, Commissioner for Patents P.O. Box 1450, Alexandria, Virginia 22313-1450 Facsimile No. 571-273-3201	Lee W. Young PCT Helpdesk: 571-272-4300 PCT OSP: 571-272-7774

Form PCT/ISA/210 (second sheet) (April 2007)

PATENT COOPERATION TREATY

From the
INTERNATIONAL SEARCHING AUTHORITY

To:
MARC M. WEFERS
FISH & RICHARDSON P.C.
P.O. BOX 1022
MINNEAPOLIS, MN 55440-1022

PCT

WRITTEN OPINION OF THE
INTERNATIONAL SEARCHING AUTHORITY

(PCT Rule 43*bis*.1)

Date of mailing *(day/month/year)*	07 DEC 2009
Applicant's or agent's file reference 019970366WO1	**FOR FURTHER ACTION** See paragraph 2 below

International application No.	International filing date *(day/month/year)*	Priority date *(day/month/year)*
PCT/US 09/59244	01 October 2009 (01.10.2009)	01 October 2008 (01.10.2008)

International Patent Classification (IPC) or both national classification and IPC
IPC(8) - H01P 7/00 (2009.01)
USPC - 333/219

Applicant MASSACHUSETTS INSTITUTE OF TECHNOLOGY

1. This opinion contains indications relating to the following items:

- ☒ Box No. I Basis of the opinion
- ☐ Box No. II Priority
- ☒ Box No. III Non-establishment of opinion with regard to novelty, inventive step and industrial applicability
- ☐ Box No. IV Lack of unity of invention
- ☒ Box No. V Reasoned statement under Rule 43*bis*.1(a)(i) with regard to novelty, inventive step or industrial applicability; citations and explanations supporting such statement
- ☒ Box No. VI Certain documents cited
- ☐ Box No. VII Certain defects in the international application
- ☐ Box No. VIII Certain observations on the international application

2. **FURTHER ACTION**

If a demand for international preliminary examination is made, this opinion will be considered to be a written opinion of the International Preliminary Examining Authority ("IPEA") except that this does not apply where the applicant chooses an Authority other than this one to be the IPEA and the chosen IPEA has notified the International Bureau under Rule 66.1*bis*(b) that written opinions of this International Searching Authority will not be so considered.

If this opinion is, as provided above, considered to be a written opinion of the IPEA, the applicant is invited to submit to the IPEA a written reply together, where appropriate, with amendments, before the expiration of 3 months from the date of mailing of Form PCT/ISA/220 or before the expiration of 22 months from the priority date, whichever expires later.

For further options, see Form PCT/ISA/220.

3. For further details, see notes to Form PCT/ISA/220.

Name and mailing address of the ISA/US	Date of completion of this opinion	Authorized officer:
Mail Stop PCT, Attn: ISA/US Commissioner for Patents P.O. Box 1450, Alexandria, Virginia 22313-1450 Facsimile No. 571-273-3201	24 November 2009 (24.11.2009)	Lee W. Young PCT Helpdesk: 571-272-4300 PCT OSP: 571-272-7774

Form PCT/ISA/237 (cover sheet) (April 2007)

WRITTEN OPINION OF THE INTERNATIONAL SEARCHING AUTHORITY

International application No.
PCT/US 09/59244

Box No. I Basis of this opinion

1. With regard to the **language**, this opinion has been established on the basis of:

   ☒ the international application in the language in which it was filed.

   ☐ a translation of the international application into _____ which is the language of a translation furnished for the purposes of international search (Rules 12.3(a) and 23.1(b)).

2. ☐ This opinion has been established taking into account the **rectification of an obvious mistake** authorized by or notified to this Authority under Rule 91 (Rule 43*bis*.1(a))

3. With regard to any **nucleotide and/or amino acid sequence** disclosed in the international application, this opinion has been established on the basis of:

   a. type of material

      ☐ a sequence listing

      ☐ table(s) related to the sequence listing

   b. format of material

      ☐ on paper

      ☐ in electronic form

   c. time of filing/furnishing

      ☐ contained in the international application as filed

      ☐ filed together with the international application in electronic form

      ☐ furnished subsequently to this Authority for the purposes of search

4. ☐ In addition, in the case that more than one version or copy of a sequence listing and/or table(s) relating thereto has been filed or furnished, the required statements that the information in the subsequent or additional copies is identical to that in the application as filed or does not go beyond the application as filed, as appropriate, were furnished.

5. Additional comments:

WRITTEN OPINION OF THE INTERNATIONAL SEARCHING AUTHORITY

International application No.
PCT/US 09/59244

Box No. III Non-establishment of opinion with regard to novelty, inventive step and industrial applicability

The questions whether the claimed invention appears to be novel, to involve an inventive step (to be non obvious), or to be industrially applicable have not been examined in respect of

☐ the entire international application

☒ claims Nos. 5, 7-12, 14-19, 25-27, 33-49, 54-79

because:

☐ the said international application, or the said claims Nos. _____ relate to the following subject matter which does not require an international search *(specify)*:

☒ the description, claims or drawings *(indicate particular elements below)* or said claims Nos. See below. are so unclear that no meaningful opinion could be formed *(specify)*:

Claims 5, 7-12, 14-19, 25-27, 33-49 and 54-79 are unsearchable because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a).

☐ the claims, or said claims Nos. _____ are so inadequately supported by the description that no meaningful opinion could be formed *(specify)*:

☒ no international search report has been established for said claims Nos. 5, 7-12, 14-19, 25-27, 33-49, 54-79

☐ a meaningful opinion could not be formed without the sequence listing; the applicant did not, within the prescribed time limit:

- ☐ furnish a sequence listing on paper complying with the standard provided for in Annex C of the Administrative Instructions, and such listing was not available to the International Searching Authority in a form and manner acceptable to it.
- ☐ furnish a sequence listing in electronic form complying with the standard provided for in Annex C of the Administrative Instructions, and such listing was not available to the International Searching Authority in a form and manner acceptable to it.
- ☐ pay the required late furnishing fee for the furnishing of a sequence listing in response to an invitation under Rule 13*ter*.1(a) or (b).

☐ a meaningful opinion could not be formed without the tables related to the sequence listings; the applicant did not, within the prescribed time limit, furnish such tables in electronic form complying with the technical requirements provided for in Annex C-*bis* of the Administrative Instructions, and such tables were not available to the International Searching Authority in a form and manner acceptable to it.

☐ the tables related to the nucleotide and/or amino acid sequence listing, if in electronic form only, do not comply with the technical requirements provided for in Annex C-*bis* of the Administrative Instructions.

☐ See Supplemental Box for further details.

WRITTEN OPINION OF THE INTERNATIONAL SEARCHING AUTHORITY

International application No.
PCT/US 09/59244

Box No. V **Reasoned statement under Rule 43*bis*.1(a)(i) with regard to novelty, inventive step or industrial applicability; citations and explanations supporting such statement**

1. Statement

Novelty (N)	Claims	1-4, 6, 13, 20-24, 28-32, 50-53, 80, 81	YES
	Claims	None.	NO
Inventive step (IS)	Claims	None.	YES
	Claims	1-4, 6, 13, 20-24, 28-32, 50-53, 80, 81	NO
Industrial applicability (IA)	Claims	1-4, 6, 13, 20-24, 28-32, 50-53, 80, 81	YES
	Claims	None.	NO

2. Citations and explanations:

Claims 1-4, 6, 13, 20-24, 28-32, 50-53, 80 and 81 lack an inventive step under PCT Article 33(3) as being obvious over US 2007/0222542 A1 to Joannopoulos et al. (hereinafter 'Joannopoulos'), in view of US 3,517,350 A (Beaver).

As per claim 1, Joannopoulos discloses a method for transferring energy wirelessly (Abstract, para [0013]), and a first resonator structure and a second resonator structure with coupling rates being optimized for low loss rates (Abstract, para [0015], [0016], [0035]), but does not disclose transferring energy wirelessly from a first resonator structure to an intermediate resonator structure, wherein the coupling rate between the first resonator structure and the intermediate resonator structure is K_1B; transferring energy wirelessly from the intermediate resonator structure to a second resonator structure, wherein the coupling rate between the intermediate resonator structure and the second resonator structure is K_B2; and during the wireless energy transfers, adjusting at least one of the coupling rates K_1B and K_B2 to reduce energy accumulation in the intermediate resonator structure and improve wireless energy transfer from the first resonator structure to the second resonator structure through the intermediate resonator structure. Beaver discloses wireless energy transfer (col 2, ln 69-72) and utilizing intermediate resonators (col 7, ln 22-39). It would have been obvious to a person of ordinary skill in the art to utilize Joannopoulos wireless energy transfer with two resonator structures with optimized coupling rate and Beaver's intermediate resonator for transferring wireless energy from primary to secondary resonator since it creates a device that allows for the wireless transfer of energy from a primary to a secondary resonator via an intermediate resonator and acts as a filter. It also would have been obvious to a person of ordinary skill in the art to have the optimization of the coupling rate to minimize losses by Joannopoulos be such that adjusting at least one of the coupling rates K_1B and K_B2 to reduce energy accumulation in the intermediate resonator structure and improve wireless energy transfer from the first resonator structure to the second resonator structure through the intermediate resonator structure, in order to improve wireless energy transfer.

As per claims 2-4, dependent on claim 1, neither Joannopoulos nor Beaver specifically disclose wherein the adjustment of at least one of the coupling rates K_1B and K_B2 minimizes energy accumulation in the intermediate resonator structure and causes wireless energy transfer from the first resonator structure to the second resonator structure; maintains energy distribution in the field of the three resonator system in an eigenstate having substantially no energy in the intermediate resonator structure; and further causes the eigenstate to evolve substantially adiabatically from an initial state with substantially all energy in the resonator structures in the first resonator structure to a final state with substantially all of the energy in the resonator structures in the second resonator structure. However, Joannopoulos discloses coupling rates being optimized (Abstract, para [0015], [0016]). It would have been obvious to a person of ordinary skill in the art to have the optimization of Joannopoulos be such that the adjustment of at least one of the coupling rates K_1B and K_B2 minimizes energy accumulation in the intermediate resonator structure and causes wireless energy transfer from the first resonator structure to the second resonator structure; maintains energy distribution in the field of the three resonator system in an eigenstate having substantially no energy in the intermediate resonator structure, and further causes the eigenstate to evolve substantially adiabatically from an initial state with substantially all energy in the resonator structures in the first resonator structure to a final state with substantially all of the energy in the resonator structures in the second resonator structure as a means of optimizing energy transfer and coupling rates.

As per claim 6, dependent on claim 1, Joannopoulos further discloses wherein the resonator structures each have a quality factor larger than 10 (para [0026], [0027]).

As per claim 13, dependent on claim 1, Joannopoulos further discloses wherein the first and second resonator structures are substantially identical (para [0013]).

----------(continued on supplemental pages)----------

WRITTEN OPINION OF THE INTERNATIONAL SEARCHING AUTHORITY

International application No.
PCT/US 09/59244

Box No. VI Certain documents cited

1. Certain published documents (Rules 43*bis*.1 and 70.10)

Application No. Patent No.	Publication date *(day/month/year)*	Filing date *(day/month/year)*	Priority date (valid claim) *(day/month/year)*
US 2009/0153273 A1	18/06/2009	19/06/2008	14/12/2007

2. Non-written disclosures (Rules 43*bis*.1 and 70.9)

Kind of non-written disclosure	Date of non-written disclosure *(day/month/year)*	Date of written disclosure referring to non-written disclosure *(day/month/year)*

WRITTEN OPINION OF THE
INTERNATIONAL SEARCHING AUTHORITY

International application No.
PCT/US 09/59244

Box No. VIII Certain observations on the international application

The following observations on the clarity of the claims, description, and drawings or on the question whether the claims are fully supported by the description, are made:

Box V.2. Citations and explanations:

As per claim 20, Joannopoulos discloses a method for transferring energy wirelessly (Abstract, para [0013]), and a first resonator structure and a second resonator structure with coupling rates being optimized for low loss rates (Abstract, para [0015], [0016], [0035]), but does not disclose first, intermediate, and second resonator structures, wherein a coupling rate between the first resonator structure and the intermediate resonator structure is K_1B and a coupling rate between the intermediate resonator structure and the second resonator structure is K_B2; and means for adjusting at least one of the coupling rates K_1B and K_B2 during wireless energy transfers among the resonator structures to reduce energy accumulation in the intermediate resonator structure and improve wireless energy transfer from the first resonator structure to the second resonator structure through the intermediate resonator structure. Beaver discloses wireless energy transfer (col 2, ln 69-72) and utilizing intermediate resonators (col 7, ln 22-39). It would have been obvious to a person of ordinary skill in the art to utilize Joannopoulos's wireless energy transfer with two resonator structures with optimized coupling rate and Beaver's intermediate resonator for transferring wireless energy from primary to secondary resonator since it creates a device that allows for the wireless transfer of energy from a primary to a secondary resonator via an intermediate resonator and acts as a filter. It also would have been obvious to a person of ordinary skill in the art to have the optimization of the coupling rate by Joannopoulos be such that adjusting at least one of the coupling rates K_1B and K_B2 during wireless energy transfers among the resonator structures to reduce energy accumulation in the intermediate resonator structure and improve wireless energy transfer from the first resonator structure to the second resonator structure through the intermediate resonator structure, thereby optimizing energy transfer.

As per claims 21-23, dependent on claim 20, neither Joannopoulos nor Beaver disclose wherein the means for adjusting comprises a rotation stage for adjusting the relative orientation, a translation stage for moving, or a mechanical, electro-mechanical or electrical staging system for adjusting of the intermediate resonator structure with respect to the first and second resonator structures. However, such configurations were well known in the art at the time of the invention and could have been provided as a means of positioning the resonators for optimizing energy transfer.

As per claim 24, dependent on claim 4, neither Joannopoulos nor Beaver disclose wherein the adjustment of at least one of the coupling rates K_1B and K_B2 causes peak energy accumulation in the intermediate resonator structure during the wireless energy transfers to be less than ten percent (10%) of the peak total energy in the three resonator structures. It would have been obvious to a person of ordinary skill in the art to have the adjustment of at least one of the coupling rates K_1B and K_B2 causes peak energy accumulation in the intermediate resonator structure during the wireless energy transfers to be less than ten percent (10%) of the peak total energy in the three resonator structures, based on the requirements of the system.

As per claim 28, Joannopoulos discloses a method for transferring energy wirelessly (Abstract, para [0013]), and a first resonator structure and a second resonator structure with coupling rates being optimized for low loss rates (Abstract, para [0015], [0016], [0035]), but does not disclose transferring energy wirelessly from a first resonator structure to a intermediate resonator structure, wherein the coupling rate between the first resonator structure and the intermediate resonator structure is K_B1; transferring energy wirelessly from the intermediate resonator structure to a second resonator, wherein the coupling rate between the intermediate resonator structure and the second resonator structure is K_B2; and during the wireless energy transfers, adjusting at least one of the coupling rates K_1B and K_B2 to cause an energy distribution in the field of the three-resonator system to have substantially no energy in the intermediate resonator structure while wirelessly transferring energy from the first resonator structure to the second resonator structure through the intermediate resonator structure. Beaver discloses wireless energy transfer (col 2, ln 69-72) and utilizing intermediate resonators (col 7, ln 22-39). It would have been obvious to a person of ordinary skill in the art to utilize Joannopoulos's wireless energy transfer with two resonator structure with optimized coupling rate and Beaver's intermediate resonator for transferring wireless energy from primary to secondary resonator since it creates a device that allows for the wireless transfer of energy from a primary to a secondary resonator via an intermediate resonator and acts as a filter. It also would have been obvious to a person of ordinary skill in the art to have the optimization of the coupling rate to minimize losses by Joannopoulos be such that during the wireless energy transfers, adjusting at least one of the coupling rates K_1B and K_B2 to cause an energy distribution in the field of the three-resonator system to have substantially no energy in the intermediate resonator structure while wirelessly transferring energy from the first resonator structure to the second resonator structure through the intermediate resonator structure since it would optimize energy flow between primary and secondary resonator, in order to improve wireless energy transfer.

----------(continued on next page)----------

WRITTEN OPINION OF THE INTERNATIONAL SEARCHING AUTHORITY

International application No.
PCT/US 09/59244

Supplemental Box

In case **the space in any of the preceding boxes is not sufficient.**
Continuation of:

Box V.2. Citations and explanations:

As per claim 29, dependent on claim 28, neither Joannopoulos nor Beaver disclose wherein having substantially no energy in the intermediate resonator structure means that peak energy accumulation in the intermediate resonator structure is less than ten percent (10%) of the peak total energy in the three resonator structures throughout the wireless energy transfer. However, this configuration could have been determined based on routine experimentation and provided based on the requirements of the system.

As per claim 30, dependent on claim 28, neither Joannopoulos nor Beaver disclose wherein having substantially no energy in the intermediate resonator structure means that peak energy accumulation in the intermediate resonator structure is less than five percent (5%) of the peak total energy in the three resonator structures throughout the wireless energy transfer. IHowever, this configuration could have been determined based on routine experimentation and provided based on the requirements of the system.

As per claim 31, dependent on claims 28 to 30, neither Joannopoulos nor Beaver disclose wherein the adjustment of at least one of the coupling rates K_1B and K_B2 maintains the energy distribution in the field of the three resonator system in an eigenstate having the substantially no energy in the intermediate resonator structure. However Joannopoulos discloses coupling rates being optimized to minimize losses (Abstract, para [0015], [0016]). It would have been obvious to a person of ordinary skill in the art to have the coupling rate optimization of Joannopoulos be such that the adjustment of at least one of the coupling rates K_1B and K_B2 maintains energy distribution in the field of the three resonator system in an eigenstate having substantially no energy in the intermediate resonator structure, in order to improve energy transfer.

As per claim 32, dependent on 31, neither Joannopoulos nor Beaver disclose wherein the adjustment of at least one of the coupling rates K_1B and K_B2 further causes the eigenstate to evolve substantially adiabatically from an initial state with substantially all energy in the resonator structures in the first resonator structure to a final state with substantially all of the energy in the resonator structures in the second resonator structure. However Joannopoulos discloses coupling rates being optimized to mimimize losses (Abstract, para [0015], [0016]). It would have been obvious to a person of ordinary skill in the art to have the coupling rate optimization of Joannopoulos be such that the adjustment of at least one of the coupling rates K_1B and K_B2 further causes the eigenstate to evolve substantially adiabatically from an initial state with substantially all energy in the resonator structures in the first resonator structure to a final state with substantially all of the energy in the resonator structures in the second resonator structure, in order to improve energy transfer.

As per claim 50, Joannopoulos discloses a method for transferring energy wirelessly (Abstract, para [0013]), and a first resonator structure and a second resonator structure with coupling rates being optimized for low loss rates (Abstract, para [0015], [0016], [0035]), but does not disclose first, intermediate, and second resonator structures, wherein a coupling rate between the first resonator structure and the intermediate resonator structure is K_1B and a coupling rate between the intermediate resonator structure and the second resonator structure is K_B2; and means for adjusting at least one of the coupling rates K_1B and K_B2 during wireless energy transfers among the resonator structures to cause an energy distribution in the field of the three-resonator system to have substantially no energy in the intermediate resonator structure while wirelessly transferring energy from the first resonator structure to the second resonator structure through the intermediate resonator structure. Beaver discloses wireless energy transfer (col 2, ln 69-72) and utilizing intermediate resonators (col 7, ln 22-39). It would have been obvious to a person of ordinary skill in the art to utilize Joannopoulos's wireless energy transfer with two resonator structure with optimized coupling rate and Beaver's intermediate resonator for transferring wireless energy from primary to secondary resonator since it creates a device that allows for the wireless transfer of energy from a primary to a secondary resonator via an intermediate resonator and acts as a filter. It also would have been obvious to a person of ordinary skill in the art to have the optimization of the coupling rate by Joannopoulos be such that adjusting at least one of the coupling rates K_1B and K_B2 during wireless energy transfers among the resonator structures to cause an energy distribution in the field of the three-resonator system to have substantially no energy in the intermediate resonator structure while wirelessly transferring energy from the first resonator structure to the second resonator structure through the intermediate resonator structure since it maximizes energy transferred from first resonator to second resonator, in order to improve energy transfer.

As per claim 51, dependent on claim 50, neither Joannopoulos nor Beaver disclose wherein having substantially no energy in the intermediate resonator structure means that peak energy accumulation in the intermediate resonator structure is less than ten percent (10%) of the peak total energy in the three resonator structures throughout the wireless energy transfer. However, this configuration could have been determined based on routine experimentation and provided based on the requirements of the system.

As per claim 52, dependent on claim 50, neither Joannopoulos nor Beaver disclose wherein having substantially no energy in the intermediate resonator structure means that peak energy accumulation in the intermediate resonator structure is less than five percent (5%) of the peak total energy in the three resonator structures throughout the wireless energy transfer. However, this configuration could have been determined based on routine experimentation and provided based on the requirements of the system.

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WRITTEN OPINION OF THE INTERNATIONAL SEARCHING AUTHORITY

International application No.
PCT/US 09/59244

Supplemental Box

In case **the space in any of the preceding boxes is not sufficient.**
Continuation of:

Box V.2. Citations and explanations:

As per claim 53, dependent on claims 50 to 52, neither Joannopoulos nor Beaver disclose wherein the means for adjusting is configured to maintain the energy distribution in the field of the three-resonator system in an eigenstate having the substantially no energy in the intermediate resonator structure. However Joannopoulos discloses coupling rates being optimized (Abstract, para [0015], [0016]). It would have been obvious to a person of ordinary skill in the art to combine the teacheing os Joannopoulos and Beaver to have the optimization of Joannopoulos be such that the adjusting is configured to maintain the energy distribution in the field of the three-resonator system in an eigenstate having the substantially no energy in the intermediate resonator structure, thereby improving energy transfer..

As per claim 80, Joannopoulos discloses a method for transferring energy wirelessly (Abstract, para [0013]), and a first resonator structure and a second resonator structure with coupling rates being optimized for low loss rates (Abstract, para [0015], [0016], [0035]), but does not disclose transferring energy wirelessly from a first resonator structure to a intermediate resonator structure, wherein the coupling rate between the first resonator structure and the intermediate resonator structure is K_1B; transferring energy wirelessly from the intermediate resonator structure to a second resonator, wherein the coupling rate between the intermediate resonator structure and the second resonator structure with a coupling rate is K_B2; and during the wireless energy transfers, adjusting at least one of the coupling rates K_1B and K_B2 to define a first mode of operation in which energy accumulation in the intermediate resonator structure is reduced relative to that for a second mode of operation of wireless energy transfer among the three resonator structures having a coupling rate K'_1B for wireless energy transfer from the first resonator structure to the intermediate resonator structure and a coupling rate K'_B2 for wireless energy transfer from the intermediate resonator structure to the second resonator structure with K'_1B and K'_B2 each being substantially constant during the second mode of wireless energy transfer, and wherein the adjustment of the coupling rates K_1B and K_B2 in the first mode of operation satisfies K_1B, K_2B<SQRT((K'_1B^2+K'_2B^2)/2). Beaver discloses wireless energy transfer (col 2, ln 69-72) and utilizing intermediate resonators (col 7, ln 22-39). It would have been obvious to a person of ordinary skill in the art to utilize Joannopoulos's wireless energy transfer with two resonator structure with optimized coupling rate and Beaver's intermediate resonator for transferring wireless energy from primary to secondary resonator since it creates a device that allows for the wireless transfer of energy from a primary to a secondary resonator via an intermediate resonator and acts as a filter. It also would have been obvious to a person of ordinary skill in the art to have adjusted at least one of the coupling rates K_1B and K_B2 to define a first mode of operation in which energy accumulation in the intermediate resonator structure is reduced relative to that for a second mode of operation of wireless energy transfer among the three resonator structures having a coupling rate K'_1B for wireless energy transfer from the first resonator structure to the intermediate resonator structure and a coupling rate K'_B2 for wireless energy transfer from the intermediate resonator structure to the second resonator structure with K'_1B and K'_B2 each being substantially constant during the second mode of wireless energy transfer, and wherein the adjustment of the coupling rates K_1B and K_B2 in the first mode of operation satisfies K_1B, K_2B<SQRT((K'_1B^2+K'_2B^2)/2), where SQRT((K'_1B^2+K'_2B^2)/2) is just the Root-Mean-Square of the coupling rate for the second mode of operation and the magnitude of K_1B and K_B2 in the first mode is less than the RMS value of the coupling rates K'_1B and K'_B2 in the second mode. It would have been obvious to one skilled in the art to combine the teachings of Joannopoulos with those of Beaver in order to improve energy transfer.

As per claim 81, Joannopoulos discloses a method for transferring energy wirelessly (Abstract, para [0013]), and a first resonator structure and a second resonator structure with coupling rates being optimized for low loss rates (Abstract, para [0015], [0016], [0035]), but does not disclose first, intermediate, and second resonator structures, wherein a coupling rate between the first resonator structure and the intermediate resonator structure is K_1B and a coupling rate between the intermediate resonator structure and the second resonator structure is K_B2 ; and means for adjusting at least one of the coupling rates K_1B and K_B2 during wireless energy transfers among the resonator structures to define a first mode of operation in which energy accumulation in the intermediate resonator structure is reduced relative to that for a second mode of operation for wireless energy transfer among the three resonator structures having a coupling rate K'_1B for wireless energy transfer from the first resonator structure to the intermediate resonator structure and a coupling rate K'_B2 for wireless energy transfer from the intermediate resonator structure to the second resonator structure with K'_1B and K'_B2 each being substantially constant during the second mode of wireless energy transfer, and wherein the adjustment of the coupling rates K_1B and K_B2 in the first mode of operation satisfies K_1B, K_2B<SQRT((K'_1B^2+K'_2B^2)/2). Beaver discloses wireless energy transfer (col 2, ln 69-72) and utilizing intermediate resonators (col 7, ln 22-39). It would have been obvious to a person of ordinary skill in the art to utilize Joannopoulos's wireless energy transfer with two resonator structure with optimized coupling rate and Beaver's intermediate resonator for transferring wireless energy from primary to secondary resonator since it creates a device that allows for the wireless transfer of energy from a primary to a secondary resonator via an intermediate resonator and acts as a filter. It also would have been obvious to a person of ordinary skill in the art to have the means for adjusting at least one of the coupling rates K_1B and K_B2 during wireless energy transfers among the resonator structures to define a first mode of operation in which energy accumulation in the intermediate resonator structure is reduced relative to that for a second mode of operation for wireless energy transfer among the three resonator structures having a coupling rate K'_1B for wireless energy transfer from the first resonator structure to the intermediate resonator structure and a coupling rate K'_B2 for wireless energy transfer from the intermediate resonator structure to the second resonator structure with K'_1B and K'_B2 each being substantially constant during the second mode of wireless energy transfer, and wherein the adjustment of the coupling rates K_1B and K_B2 in the first mode of operation satisfies K_1B, K_2B<SQRT((K'_1B^2+K'_2B^2)/2), where SQRT((K'_1B^2+K'_2B^2)/2) is just the Root-Mean-Square of the coupling rate for the second mode of operation and the magnitude of K_1B and K_B2 in the first mode is less than the RMS value of the coupling rates K'_1B and K'_B2 in the second mode. It would have been obvious to one skilled in the art to combine the teachings of Joannopoulos with those of Beaver in order to improve energy transfer.

Claims 1-4, 6, 13, 20-24, 28-32, 50-53, 80 and 81 have industrial applicability as defined by PCT Article 33(4) because the subject matter can be made or used in industry.

Electronic Acknowledgement Receipt

EFS ID:	9188002
Application Number:	12567716
International Application Number:	
Confirmation Number:	4901
Title of Invention:	WIRELESS ENERGY TRANSFER SYSTEMS
First Named Inventor/Applicant Name:	Morris P. Kesler
Customer Number:	43520
Filer:	John H. Nortrop/Elizabeth Nortrup
Filer Authorized By:	John H. Nortrop
Attorney Docket Number:	WTCY-0026-P01
Receipt Date:	07-JAN-2011
Filing Date:	25-SEP-2009
Time Stamp:	14:28:22
Application Type:	Utility under 35 USC 111(a)

Payment information:

Submitted with Payment	no

File Listing:

Document Number	Document Description	File Name	File Size(Bytes)/ Message Digest	Multi Part /.zip	Pages (if appl.)
1	Transmittal Letter	WTCY-0026-P01_010711_IDSCommunication.pdf	89889 0b74859bef96db25826215e091b83106f2254e97	no	2

Warnings:	
Information:	

2	Information Disclosure Statement (IDS) Filed (SB/08)	WTCY-0026-P01_010711_Form1449.pdf	224635 1ca1bd0c13d6b9ebf718fa985fccb8cce42c1592	no	14
Warnings:					
Information:					
This is not an USPTO supplied IDS fillable form					
3	Foreign Reference	WO2000077910.pdf	1257033 e8a5d66dfe226f9e0697d421a50a024cb89cfd2c	no	35
Warnings:					
Information:					
4	Foreign Reference	WO2003092329.pdf	2136281 72c58bc5808c993cb3c13053fdb95577061ce63e	no	58
Warnings:					
Information:					
5	Foreign Reference	WO2003096361.pdf	1240426 a0c7535e6b31c304d63e0014909b9830061ff264	no	36
Warnings:					
Information:					
6	Foreign Reference	WO2003096512.pdf	3489340 fc0da9e00e658fe09c7d5585b3d4eb32979475e8	no	83
Warnings:					
Information:					
7	Foreign Reference	WO2004038888.pdf	1458442 8813a0724e30c422160f850da164f4e6a797f45c	no	44
Warnings:					
Information:					
8	Foreign Reference	WO2004055654.pdf	1661010 0bb41501a574a2d2de4b79bb4aa878340469e1bd	no	39
Warnings:					
Information:					
9	Foreign Reference	WO2004073150.pdf	1420020 31ca0e377d27a95f75b4be3df02934a3dd7ab37e	no	35
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Information:					
10	Foreign Reference	WO2004073166.pdf	1671880 c28229b2674b399f442b81d801057d3cb862bb7f	no	42

Warnings:					
Information:					
11	Foreign Reference	WO2004073176.pdf	1152835 57bdfc2dfbc9129e558152f29693b28b9860857f	no	29
Warnings:					
Information:					
12	Foreign Reference	WO2004073177.pdf	3513573 ebe7c5bb8fa1c5dc245d257e44ef045588a2b406	no	91
Warnings:					
Information:					
13	Foreign Reference	WO2004112216.pdf	872354 e6df8cf6285b18366f1a70969e6a1225406b63ca	no	19
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Information:					
14	Foreign Reference	WO2005024865.pdf	1237512 1992dfd24b798c39fe257bbce096a1f7b2d21d21	no	30
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15	Foreign Reference	WO2005060068.pdf	1485048 23ba324a2665df1f0d7ec2a4350efc5a3d6d12a2	no	33
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Information:					
16	Foreign Reference	WO2005109597.pdf	2917726 51c08cbb78f051cf21925a5e5207fde686312d8f	no	62
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Information:					
17	Foreign Reference	WO2005109598.pdf	2222858 c562f25fc179fbe04e4db62c6998d097921530c1	no	48
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Information:					
18	Foreign Reference	WO2007020583.pdf	1177194 427485ded74fb35c5b0e5ed7538caab500f16b8b	no	22
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Information:					
19	Foreign Reference	WO2007042952.pdf	1277471 2cff565ec8d4ec1e52e296a64ac448f4c16884bd	no	23

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20	Foreign Reference	DE10029147_A1.pdf	237119 424c2299dba31c9905e012994274b6c402120997	no	6
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21	Foreign Reference	DE102005036290_B4.pdf	208969 1feaebfaaa30736bc47bbff1941a34da8f76a745	no	8
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22	Foreign Reference	DE10304584_A1.pdf	172584 c6d8a9b1a3a6ed0ae960e643dd69596efb8df440	no	8
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23	Foreign Reference	EP1335477.pdf	351343 ec6d73df9fbdfcb01d4f336faa8c5dc28e7e02ee	no	20
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24	Foreign Reference	CA142352.pdf	798847 93dae7d4bb3eeb5ce1ae16bfc8317efa088f53a7	no	18
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25	Foreign Reference	WO2007084716.pdf	1861798 8bf9e5e4a435194d88593a39e98aef300d8f22a2	no	46
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26	Foreign Reference	WO2007084717.pdf	1242263 38392bd2fbbca86ac3785f0ad07990946be5e564	no	23
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Information:					
27	Foreign Reference	WO2008109489.pdf	2221824 e3248078348dc4241e43eae9472c3dbc67ec244e	no	77
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28	Foreign Reference	WO2008118178.pdf	64701 46d77f672f38b08465c28884914b307243bbb538	no	1

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29	Foreign Reference	WO2009009559.pdf	1015708 2f5dd419a98b049be34341b4f378cd3f5e00e32b	no	43
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30	Foreign Reference	WO2009018568.pdf	459181 74a640574d3313c71a4be53dd5a66bbcb00c7daf	no	16
Warnings:					
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31	Foreign Reference	WO2009023155.pdf	1015539 7b36a66579865b390c524fc1d2b96b42d74454f6	no	34
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Information:					
32	Foreign Reference	WO2009023646.pdf	722961 2c97adcd0d883b29285fc04765b075daabad3d02	no	24
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Information:					
33	Foreign Reference	WO2A036980A1.pdf	9667123 b3a2dd6e996d5c94a44aaa09aaafebfaf7654e31	no	198
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Information:					
35	Foreign Reference	WO1992017929_A1.pdf	3303478 7520e5a4b1882298a2853a9ed9625e00b452e65d	no	71
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Information:					
36	Foreign Reference	WO1993023908_A1.pdf	1134279 3dc12a463a86ea647be08aa38872d9296ffaedb1	no	28
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Information:					
37	Foreign Reference	WO1994028560_A1.pdf	1612620 b79e919509a010b1cef7b422c6563d184eef9f24	no	49

Warnings:					
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38	Foreign Reference	WO1996002970_A1.pdf	1325800 a92c8371a11be20fc821d031a61996ba47c0a9b1	no	33
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Information:					
39	Foreign Reference	WO1998050993.pdf	1515804 e8fd71064cff170e6aaeb7c6741f568173acf7e2	no	34
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Information:					
40	NPL Documents	NPL-82_TexasInstruments-HFAntennaDesignNotes.pdf	1793369 9d116bf1c145d72c18a4e240dc52b08114c10f81	no	47
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Information:					
41	NPL Documents	NPL-7_InPictures-AYearinTechnology-BBCNews.pdf	55390 b5f97abd9ef5c2fb11ec675f89cb57ed23e36639	no	1
Warnings:					
Information:					
42	NPL Documents	NPL-8_IntelCTOSaysGap-IntelNewsRelease.pdf	371678 614a452ad3cee35db17a374f6759e8123ad90510	no	3
Warnings:					
Information:					
43	NPL Documents	NPL-51_MicrochipTechnologyInc-MicroID_13_56MHz.pdf	1434881 46360d2d817f8d650a1fd847961afffc2e59dc3a	no	31
Warnings:					
Information:					
44	NPL Documents	NPL-63_PhysicsUpdate-UnwiredEnergy-PhysicsToday.pdf	1342904 9ce195a9440d41da0f37398bcd66c8dce2e144a8	no	1
Warnings:					
Information:					
45	NPL Documents	NPL-65_RechargingGadgetsWithoutCables-InfotechOnline.pdf	47035 d8542fbb97a339af4f26b4c6538dc1ead7b8cdc8	no	1
Warnings:					
Information:					
46	NPL Documents	NPL-71_ScientistsLightBulbWithWirelessElectricity-chinaview.pdf	141337 d30ec67860cba970356b4c3c477d3d8aca3a071c	no	3

Warnings:					
Information:					
47	NPL Documents	NPL-83_TheBigStoryforCES2007.pdf	84135 d93bd258647d3ae753f2cd123a0e07ad4c00f39a	no	2
Warnings:					
Information:					
48	NPL Documents	NPL-88_TheWorldsFirstSheetTypeWirelessPower.pdf	9246360 59a87b23f66f68be7647908da780600855d67925	no	4
Warnings:					
Information:					
49	NPL Documents	NPL-90_TutorialOverview-UPMRafsec.pdf	410551 a566a32f12be3a66d3d3e23be2555ea2dcf89f80	no	7
Warnings:					
Information:					
50	NPL Documents	NPL-89_UnwiredEnergyQuestionsAsked-PhysicsToday.pdf	1225003 6991ba4aaddc92fd25a0011d787349ef707fef9b	no	2
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Information:					
51	NPL Documents	NPL-64_WhitePaper-Powercast.pdf	88827 3dac27bf1722ba68169dfdfe119d3ccefc4dc91d	no	2
Warnings:					
Information:					
52	NPL Documents	NPL-96_WirelessEnergyTransferCanPotentiallyRechargeLaptops.pdf	948102 77f1855390639ea830c7fddd70080e6d1eeb3fa9	no	3
Warnings:					
Information:					
53	NPL Documents	NPL-98_WirelessPowerTransferPossible-PressTV.pdf	57424 fca704b5956be400571201e1c010edf4e5f5cf64	no	1
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Information:					
54	NPL Documents	NPL-97_WirelessEnergyTransferMayPowerDevicesataDistance.pdf	197190 127ab4e34d7f80a18ca3fbc76636000f45a809da	no	2
Warnings:					
Information:					
55	NPL Documents	NPL-67_AU2006269374_ISR-091808.pdf	81408 0c0a2764f515f4513d3ed35d41f59e484087ef65	no	2

Warnings:					
Information:					
56	NPL Documents	NPL-16_ElectricityUnplugged-WirelessEnergy-PhysicsWorld.pdf	954113 8afbfcf20546cff3c2d0aab4c0c67ea2c236d843	no	4
Warnings:					
Information:					
57	NPL Documents	NPL-18_EPExamReport_06786 5881-011509.pdf	241627 5f1045ed9e4142b006e1ac7988ce657f79a3a16c	no	5
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Information:					
58	NPL Documents	NPL-36_PCTUS0958499_ISR-121009.pdf	1734428 a1586867bb90d74b13903ed94a5c272f4f0f1e6f	no	11
Warnings:					
Information:					
59	NPL Documents	NPL-33_PCTUS09943970_ISR-WO_071709.pdf	895695 3ccf364bdf8ee04272029413c8aef58cd7e255f2	no	12
Warnings:					
Information:					
60	NPL Documents	NPL-37_PCTUS0959244_ISR-120709.pdf	795137 aa03bd2375d9789662a50b1c7d353ed15bda88a0	no	12
Warnings:					
Information:					
		Total Files Size (in bytes):	82152353		

This Acknowledgement Receipt evidences receipt on the noted date by the USPTO of the indicated documents, characterized by the applicant, and including page counts, where applicable. It serves as evidence of receipt similar to a Post Card, as described in MPEP 503.

New Applications Under 35 U.S.C. 111

If a new application is being filed and the application includes the necessary components for a filing date (see 37 CFR 1.53(b)-(d) and MPEP 506), a Filing Receipt (37 CFR 1.54) will be issued in due course and the date shown on this Acknowledgement Receipt will establish the filing date of the application.

National Stage of an International Application under 35 U.S.C. 371

If a timely submission to enter the national stage of an international application is compliant with the conditions of 35 U.S.C. 371 and other applicable requirements a Form PCT/DO/EO/903 indicating acceptance of the application as a national stage submission under 35 U.S.C. 371 will be issued in addition to the Filing Receipt, in due course.

New International Application Filed with the USPTO as a Receiving Office

If a new international application is being filed and the international application includes the necessary components for an international filing date (see PCT Article 11 and MPEP 1810), a Notification of the International Application Number and of the International Filing Date (Form PCT/RO/105) will be issued in due course, subject to prescriptions concerning national security, and the date shown on this Acknowledgement Receipt will establish the international filing date of the application.

PATENT COOPERATION TREATY

From the INTERNATIONAL SEARCHING AUTHORITY

To:
MARC M. WEFERS
FISH & RICHARDSON P.C.
PO BOX 1022
MINNEAPOLIS, MN 55440-1022

PCT

NOTIFICATION OF TRANSMITTAL OF THE INTERNATIONAL SEARCH REPORT AND THE WRITTEN OPINION OF THE INTERNATIONAL SEARCHING AUTHORITY, OR THE DECLARATION

(PCT Rule 44.1)

	Date of mailing *(day/month/year)* 14 JUL 2009
Applicant's or agent's file reference 019970364WO1	**FOR FURTHER ACTION** See paragraphs 1 and 4 below
International application No. PCT/US 09/43970	International filing date *(day/month/year)* 14 May 2009 (14.05.2009)
Applicant MASSACHUSETTS INSTITUTE OF TECHNOLOGY	

1. ☒ The applicant is hereby notified that the international search report and the written opinion of the International Searching Authority have been established and are transmitted herewith.

   Filing of amendments and statement under Article 19:
   The applicant is entitled, if he so wishes, to amend the claims of the international application (see Rule 46):

   When? The time limit for filing such amendments is normally two months from the date of transmittal of the international search report.

   Where? Directly to the International Bureau of WIPO, 34 chemin des Colombettes 1211 Geneva 20, Switzerland, Facsimile No.: +41 22 338 8270

   For more detailed instructions, see the notes on the accompanying sheet.

2. ☐ The applicant is hereby notified that no international search report will be established and that the declaration under Article 17(2)(a) to that effect and the written opinion of the International Searching Authority are transmitted herewith.

3. ☐ **With regard to the protest** against payment of (an) additional fee(s) under Rule 40.2, the applicant is notified that:

   ☐ the protest together with the decision thereon has been transmitted to the International Bureau together with the applicant's request to forward the texts of both the protest and the decision thereon to the designated Offices.

   ☐ no decision has been made yet on the protest; the applicant will be notified as soon as a decision is made.

4. **Reminders**

   Shortly after the expiration of **18 months** from the priority date, the international application will be published by the International Bureau. If the applicant wishes to avoid or postpone publication, a notice of withdrawal of the international application, or of the priority claim, must reach the International Bureau as provided in Rules 90*bis*.1 and 90*bis*.3, respectively, before the completion of the technical preparations for international publication.

   The applicant may submit comments on an informal basis on the written opinion of the International Searching Authority to the International Bureau. The International Bureau will send a copy of such comments to all designated Offices unless an international preliminary examination report has been or is to be established. These comments would also be made available to the public but not before the expiration of 30 months from the priority date.

   Within **19 months** from the priority date, but only in respect of some designated Offices, a demand for international preliminary examination must be filed if the applicant wishes to postpone the entry into the national phase **until 30 months** from the priority date (in some Offices even later); otherwise, the applicant must, **within 20 months** from the priority date, perform the prescribed acts for entry into the national phase before those designated Offices.

   In respect of other designated Offices, the time limit of **30 months** (or later) will apply even if no demand is filed within 19 months.

   See the Annex to Form PCT/IB/301 and, for details about the applicable time limits, Office by Office, see the *PCT Applicant's Guide*, Volume II, National Chapters and the WIPO Internet site.

Name and mailing address of the ISA/US Mail Stop PCT, Attn: ISA/US Commissioner for Patents P.O. Box 1450, Alexandria, Virginia 22313-1450 Facsimile No. 571-273-3201	Authorized officer: Lee W. Young PCT Helpdesk: 571-272-4300 PCT OSP: 571-272-7774

Form PCT/ISA/220 (January 2004) *(See notes on accompanying sheet)*

PATENT COOPERATION TREATY

PCT

INTERNATIONAL SEARCH REPORT

(PCT Article 18 and Rules 43 and 44)

Applicant's or agent's file reference 019970364WO1	FOR FURTHER ACTION	see Form PCT/ISA/220 as well as, where applicable, item 5 below.
International application No. PCT/US 09/43970	International filing date *(day/month/year)* 14 May 2009 (14.05.2009)	(Earliest) Priority Date *(day/month/year)* 14 May 2008 (14.05.2008)
Applicant MASSACHUSETTS INSTITUTE OF TECHNOLOGY		

This international search report has been prepared by this International Searching Authority and is transmitted to the applicant according to Article 18. A copy is being transmitted to the International Bureau.

This international search report consists of a total of 8 sheets.

☐ It is also accompanied by a copy of each prior art document cited in this report.

1. **Basis of the report**

a. With regard to the **language**, the international search was carried out on the basis of:

☒ the international application in the language in which it was filed.

☐ a translation of the international application into _____ which is the language of a translation furnished for the purposes of international search (Rules 12.3(a) and 23.1(b)).

b. ☐ This international search report has been established taking into account the **rectification of an obvious mistake** authorized by or notified to this Authority under Rule 91 (Rule 43.6*bis*(a)).

c. ☐ With regard to any **nucleotide and/or amino acid sequence** disclosed in the international application, see Box No. I.

2. ☐ **Certain claims were found unsearchable** (see Box No. II).

3. ☐ **Unity of invention is lacking** (see Box No. III).

4. With regard to the **title**,

☒ the text is approved as submitted by the applicant.

☐ the text has been established by this Authority to read as follows:

5. With regard to the **abstract**,

☒ the text is approved as submitted by the applicant.

☐ the text has been established, according to Rule 38.2(b), by this Authority as it appears in Box No. IV. The applicant may, within one month from the date of mailing of this international search report, submit comments to this Authority.

6. With regard to the **drawings**,

a. the figure of the **drawings** to be published with the abstract is Figure No. 1

☒ as suggested by the applicant.

☐ as selected by this Authority, because the applicant failed to suggest a figure.

☐ as selected by this Authority, because this figure better characterizes the invention.

b. ☐ none of the figures is to be published with the abstract.

Form PCT/ISA/210 (first sheet) (April 2007)

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US 09/43970

A. CLASSIFICATION OF SUBJECT MATTER
IPC(8) - H01P 7/00 (2009.01)
USPC - 333/219
According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC(8) - H01P 7/00 (2009.01)
USPC - 333/219

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched
USPC - 333/219, 230

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
PubWEST (PGPB,USPT,EPAB,JPAB); Google Patents; Google Scholar
Search Terms Used: resonance, resonator, energy, electricity, power, transfer, wireless, frequency, wavelength, angular, width, quality, factor, far, field, interference, generator, source, driving, drive

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X --- Y	US 2007/0222542 A1 (JOANNOPOULOS et al.) 27 September 2007 (27.09.2007), para [0005], [0006], [0012], [0015], [0016], [0019], [0021], [0022], [0024], [0027], [0028], [0029], [0031], [0035], [0042]	1-8 --- 9-63
Y	US 2004/0113847 A1 (QI et al.) 17 June 2004 (17.06.2004), para [0015], [0023]	9-63
Y	US 5,437,057 A (RICHLEY et al.) 25 July 1995 (25.07.1995), col 9, ln 6-18	15-25, 37-47, 57, 58, 61, 62

☐ Further documents are listed in the continuation of Box C. ☐

* Special categories of cited documents:
"A" document defining the general state of the art which is not considered to be of particular relevance
"E" earlier application or patent but published on or after the international filing date
"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)
"O" document referring to an oral disclosure, use, exhibition or other means
"P" document published prior to the international filing date but later than the priority date claimed
"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
07 July 2009 (07.07.2009)	14 JUL 2009
Name and mailing address of the ISA/US Mail Stop PCT, Attn: ISA/US, Commissioner for Patents P.O. Box 1450, Alexandria, Virginia 22313-1450 Facsimile No. 571-273-3201	Authorized officer: Lee W. Young PCT Helpdesk: 571-272-4300 PCT OSP: 571-272-7774

Form PCT/ISA/210 (second sheet) (April 2007)

PATENT COOPERATION TREATY

From the
INTERNATIONAL SEARCHING AUTHORITY

To:
MARC M. WEFERS
FISH & RICHARDSON P.C.
PO BOX 1022
MINNEAPOLIS, MN 55440-1022

PCT

WRITTEN OPINION OF THE
INTERNATIONAL SEARCHING AUTHORITY

(PCT Rule 43*bis*.1)

Date of mailing *(day/month/year)*	14 JUL 2009
Applicant's or agent's file reference 019970364WO1	**FOR FURTHER ACTION** See paragraph 2 below

International application No.	International filing date *(day/month/year)*	Priority date *(day/month/year)*
PCT/US 09/43970	14 May 2009 (14.05.2009)	14 May 2008 (14.05.2008)

International Patent Classification (IPC) or both national classification and IPC
IPC(8) - H01P 7/00 (2009.01)
USPC - 333/219

Applicant MASSACHUSETTS INSTITUTE OF TECHNOLOGY

1. This opinion contains indications relating to the following items:

- ☒ Box No. I Basis of the opinion
- ☐ Box No. II Priority
- ☐ Box No. III Non-establishment of opinion with regard to novelty, inventive step and industrial applicability
- ☐ Box No. IV Lack of unity of invention
- ☒ Box No. V Reasoned statement under Rule 43*bis*.1(a)(i) with regard to novelty, inventive step or industrial applicability; citations and explanations supporting such statement
- ☐ Box No. VI Certain documents cited
- ☐ Box No. VII Certain defects in the international application
- ☐ Box No. VIII Certain observations on the international application

2. **FURTHER ACTION**

If a demand for international preliminary examination is made, this opinion will be considered to be a written opinion of the International Preliminary Examining Authority ("IPEA") except that this does not apply where the applicant chooses an Authority other than this one to be the IPEA and the chosen IPEA has notified the International Bureau under Rule 66.1*bis*(b) that written opinions of this International Searching Authority will not be so considered.

If this opinion is, as provided above, considered to be a written opinion of the IPEA, the applicant is invited to submit to the IPEA a written reply together, where appropriate, with amendments, before the expiration of 3 months from the date of mailing of Form PCT/ISA/220 or before the expiration of 22 months from the priority date, whichever expires later.

For further options, see Form PCT/ISA/220.

3. For further details, see notes to Form PCT/ISA/220.

Name and mailing address of the ISA/US	Date of completion of this opinion	Authorized officer:
Mail Stop PCT, Attn: ISA/US Commissioner for Patents P.O. Box 1450, Alexandria, Virginia 22313-1450 Facsimile No. 571-273-3201	07 July 2009 (07.07.2009)	Lee W. Young PCT Helpdesk: 571-272-4300 PCT OSP: 571-272-7774

Form PCT/ISA/237 (cover sheet) (April 2007)

WRITTEN OPINION OF THE INTERNATIONAL SEARCHING AUTHORITY

International application No.
PCT/US 09/43970

Box No. I Basis of this opinion

1. With regard to the **language**, this opinion has been established on the basis of:
   - [X] the international application in the language in which it was filed.
   - [ ] a translation of the international application into _____ which is the language of a translation furnished for the purposes of international search (Rules 12.3(a) and 23.1(b)).

2. [ ] This opinion has been established taking into account the **rectification of an obvious mistake** authorized by or notified to this Authority under Rule 91 (Rule 43*bis*.1(a))

3. With regard to any **nucleotide and/or amino acid sequence** disclosed in the international application, this opinion has been established on the basis of:

   a. type of material
      - [ ] a sequence listing
      - [ ] table(s) related to the sequence listing

   b. format of material
      - [ ] on paper
      - [ ] in electronic form

   c. time of filing/furnishing
      - [ ] contained in the international application as filed
      - [ ] filed together with the international application in electronic form
      - [ ] furnished subsequently to this Authority for the purposes of search

4. [ ] In addition, in the case that more than one version or copy of a sequence listing and/or table(s) relating thereto has been filed or furnished, the required statements that the information in the subsequent or additional copies is identical to that in the application as filed or does not go beyond the application as filed, as appropriate, were furnished.

5. Additional comments:

WRITTEN OPINION OF THE INTERNATIONAL SEARCHING AUTHORITY

International application No.
PCT/US 09/43970

Box No. V **Reasoned statement under Rule 43*bis*.1(a)(i) with regard to novelty, inventive step or industrial applicability; citations and explanations supporting such statement**

1. Statement

Novelty (N)	Claims	1 - 63	YES
	Claims	None.	NO
Inventive step (IS)	Claims	None.	YES
	Claims	1 - 63	NO
Industrial applicability (IA)	Claims	1 - 63	YES
	Claims	None.	NO

2. Citations and explanations:

Claims 1-8 lack an inventive step under PCT Article 33(3) as being obvious over US 2007/0222542 A1 to Joannopoulos et al. (hereinafter 'Joannopoulos').

Regarding claim 1, Joannopoulos discloses an apparatus for use in wireless energy transfer, the apparatus comprising: a first resonator structure configured for energy transfer with a second resonator structure, over a distance D larger than a characteristic size L1 of said first resonator structure and larger than a characteristic size L2 of said second resonator structure (para [0005]), wherein the energy transfer has a rate kappa and is mediated by evanescent-tail coupling of a resonant field of the first resonator structure and a resonant field of the second resonator structure (para [0006]), wherein said resonant field of the first resonator structure has a resonance angular frequency omega1 (para [0015]), a resonance frequency-width gamma1 (para [0015]), and a resonance quality factor Q1 = omega1/2gamma1 at least larger than 300 (para [0027]), and said resonant field of the first resonator structure has a resonance angular frequency omega2 (para [0015]), a resonance frequency-width gamma2 (para [0015]), and a resonance quality factor Q2 = omega2/2gamma2 at least larger than 300 (para [0027]), wherein the absolute value of the difference of said angular frequencies omega1 and omega2 is smaller than the broader of said resonant widths gamma1 and gamma2 (para [0016]), and further comprising a power supply coupled to the first structure and configured to drive the first resonator structure or the second resonator structure at an angular frequency away from the resonance angular frequencies and shifted towards a frequency corresponding to an odd normal mode for the resonator structures (para [0024]) to reduce radiation from the resonator structures by destructive far-field interference (para [0029]). Joannopoulos does not specifically disclose wherein the quantity kappa/sqrt(gamma1gamma2) is at least larger than 20. However, it does disclose wherein the quantity kappa is much greater than the quantity sqrt(gamma1gamma2) (para [0028]). It would have been obvious to one of ordinary skill in the art to provide wherein the quantity kappa/sqrt(gamma1gamma2) is at least larger than 20 based on experiment and design to give the quantities their optimum values (para [0028]).

Regarding claim 2, Joannopoulos discloses the apparatus of claim 1, wherein the power supply is configured to drive the first resonator structure or the second resonator structure at the angular frequency away from the resonance angular frequencies and shifted towards the frequency corresponding to an odd normal mode for the resonator structures (para [0024]) to substantially suppress radiation from the resonator structures by destructive far-field interference (para [0029]).

Regarding claim 3, Joannopoulos discloses a method for wireless energy transfer involving a first resonator structure configured for energy transfer with a second resonator structure, over a distance D larger than a characteristic size L1 of said first resonator structure and larger than a characteristic size L2 of said second resonator structure (para [0005]), wherein the energy transfer has a rate kappa and is mediated by evanescent-tail coupling of a resonant field of the first resonator structure and a resonant field of the second resonator structure (para [0006]), wherein said resonant field of the first resonator structure has a resonance angular frequency omega1 (para [0015]), a resonance frequency-width gamma1 (para [0015]), and a resonance quality factor Q1 = omega1/2gamma1 at least larger than 300 (para [0027]), and said resonant field of the first resonator structure has a resonance angular frequency omega2 (para [0015]), a resonance frequency-width gamma2 (para [0015]), and a resonance quality factor Q2 = omega2/2gamma2 at least larger than 300 (para [0027]), wherein the absolute value of the difference of said angular frequencies omega1 and omega2 is smaller than the broader of said resonant widths gamma1 and gamma2 (para [0016]), the method comprising: driving the first resonator structure or the second resonator structure at an angular frequency away from the resonance angular frequencies and shifted towards a frequency corresponding to an odd normal mode for the resonator structures (para [0024]) to reduce radiation from the resonator structures by destructive far-field interference (para [0029]). Joannopoulos does not specifically disclose wherein the quantity kappa/sqrt(gamma1gamma2) is at least larger than 20. However, it does disclose wherein the quantity kappa is much greater than the quantity sqrt(gamma1gamma2) (para [0028]). It would have been obvious to one of ordinary skill in the art to provide wherein the quantity kappa/sqrt(gamma1gamma2) is at least larger than 20 based on experiment and design to give the quantities their optimum values (para [0028]).

Regarding claim 4, Joannopoulos discloses the method of claim 3, wherein the first resonator structure or the second resonator structure is driven at the angular frequency away from the resonance angular frequencies and shifted towards the frequency corresponding to an odd normal mode for the resonator structures (para [0024]) to substantially suppress radiation from the resonator structures by destructive far-field interference (para [0029]).

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WRITTEN OPINION OF THE INTERNATIONAL SEARCHING AUTHORITY

International application No.
PCT/US 09/43970

Supplemental Box

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Continuation of:

Box V.2. Citations and explanations:

Regarding claim 5, Joannopoulos discloses an apparatus for use in wireless energy transfer, the apparatus comprising: a first resonator structure configured for energy transfer with a second resonator structure, over a distance D larger than a characteristic size L1 of said first resonator structure and larger than a characteristic size L2 of said second resonator structure (para [0005]), wherein the energy transfer has a rate kappa and is mediated by evanescent-tail coupling of a resonant field of the first resonator structure and a resonant field of the second resonator structure (para [0006]), wherein said resonant field of the first resonator structure has a resonance angular frequency omega1 (para [0015]), a resonance frequency-width gamma1 (para [0015]), and a resonance quality factor Q1 = omega1/2gamma1 at least larger than 300 (para [0027]), and said resonant field of the first resonator structure has a resonance angular frequency omega2 (para [0015]), a resonance frequency-width gamma2 (para [0015]), and a resonance quality factor Q2 = omega2/2gamma2 at least larger than 300 (para [0027]), wherein the absolute value of the difference of said angular frequencies omega1 and omega2 is smaller than the broader of said resonant widths gamma1 and gamma2 (para [0016]), wherein for a desired range of the distances D, the resonance angular frequencies for the resonator structures increase transmission efficiency T by accounting for radiative interference, wherein the increase is relative to a transmission efficiency T calculated without accounting for the radiative interference (para [0042]). Joannopoulos does not specifically disclose wherein the quantity kappa/sqrt(gamma1gamma2) is at least larger than 20. However, it does disclose wherein the quantity kappa is much greater than the quantity sqrt(gamma1gamma2) (para [0028]). It would have been obvious to one of ordinary skill in the art to provide wherein the quantity kappa/sqrt(gamma1gamma2) is at least larger than 20 based on experiment and design to give the quantities their optimum values (para [0028]). Joannopoulos does not specifically disclose wherein the quantity kappa/sqrt(gamma1gamma2) is at least larger than 20. However, it does disclose wherein the quantity kappa is much greater than the quantity sqrt(gamma1gamma2) (para [0028]). It would have been obvious to one of ordinary skill in the art to provide wherein the quantity kappa/sqrt(gamma1gamma2) is at least larger than 20 based on experiment and design to give the quantities their optimum values (para [0028]).

Regarding claim 6, Joannopoulos discloses the apparatus of claim 5, wherein the resonance angular frequencies for the resonator structures are selected by optimizing the transmission efficiency T to account for both a resonance quality factor U and an interference factor V (para [0035]).

Regarding claim 7, Joannopoulos discloses a method for designing a wireless energy transfer apparatus, the apparatus including a first resonator structure configured for energy transfer with a second resonator structure, over a distance D larger than a characteristic size L1 of said first resonator structure and larger than a characteristic size L2 of said second resonator structure (para [0005]), wherein the energy transfer has a rate kappa and is mediated by evanescent-tail coupling of a resonant field of the first resonator structure and a resonant field of the second resonator structure (para [0006]), wherein said resonant field of the first resonator structure has a resonance angular frequency omega1 (para [0015]), a resonance frequency-width gamma1 (para [0015]), and a resonance quality factor Q1 = omega1/2gamma1 at least larger than 300 (para [0027]), and said resonant field of the first resonator structure has a resonance angular frequency omega2 (para [0015]), a resonance frequency-width gamma2 (para [0015]), and a resonance quality factor Q2 = omega2/2gamma2 at least larger than 300 (para [0027]), wherein the absolute value of the difference of said angular frequencies omega1 and omega2 is smaller than the broader of said resonant widths gamma1 and gamma2 (para [0016]), the method comprising: selecting the resonance angular frequencies for the resonator structures to substantially optimize the transmission efficiency by accounting for radiative interference between the resonator structures (para [0042]). Joannopoulos does not specifically disclose wherein the quantity kappa/sqrt(gamma1gamma2) is at least larger than 20. However, it does disclose wherein the quantity kappa is much greater than the quantity sqrt(gamma1gamma2) (para [0028]). It would have been obvious to one of ordinary skill in the art to provide wherein the quantity kappa/sqrt(gamma1gamma2) is at least larger than 20 based on experiment and design to give the quantities their optimum values (para [0028]). Joannopoulos does not specifically disclose wherein the quantity kappa/sqrt(gamma1gamma2) is at least larger than 20. However, it does disclose wherein the quantity kappa is much greater than the quantity sqrt(gamma1gamma2) (para [0028]). It would have been obvious to one of ordinary skill in the art to provide wherein the quantity kappa/sqrt(gamma1gamma2) is at least larger than 20 based on experiment and design to give the quantities their optimum values (para [0028]).

Regarding claim 8, Joannopoulos discloses the method of claim 7, wherein the resonance angular frequencies for the resonator structures are selected by optimizing the transmission efficiency T to account for both a resonance quality factor U and an interference factor V (para [0035]).

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WRITTEN OPINION OF THE INTERNATIONAL SEARCHING AUTHORITY

International application No.
PCT/US 09/43970

Supplemental Box

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Box V.2. Citations and explanations:

Claims 9-14, 26-36, 48-56, 59, 60 and 63 lack an inventive step under PCT Article 33(3) as being obvious over Joannopoulos, in view of US 2004/0113847 A1 to Qi et al. (hereinafter 'Qi').

Regarding claim 9, Joannopoulos discloses an apparatus for use in wireless energy transfer, the apparatus comprising: a first resonator structure configured for energy transfer with a second resonator structure over a distance D (para [0005]), wherein the energy transfer is mediated by evanescent-tail coupling of a resonant field of the first resonator structure and a resonant field of the second resonator structure, with a coupling factor k (para [0006]), wherein said resonant field of the first resonator structure has a resonance angular frequency omega1 (para [0015]), a resonance frequency-width gamma1 (para [0015]), and a resonance quality factor Q1 = omega1/2gamma1 (para [0027]), with an associated radiation quality factor Q1,rad >= Q1 (para [0022]), said resonant field of the second resonator structure has a resonance angular frequency omega2 (para [0015]), a resonance frequency-width gamma2 (para [0015]), and a resonance quality factor Q2 = omega2/2gamma2 (para [0027]), with an associated radiation quality factor Q2,rad >= Q2 (para [0022]), wherein an absolute value of a difference of said angular frequencies omega1 and omega2 is smaller than broader of said resonant widths gamma1 and gamma2 (para [0016]), and an average resonant angular frequency is defined as omegao = sqrt(omega1omega2) (para [0024]), corresponding to an average resonant wavelength lambdao = 2pic/omegao, where c is the speed of light in free space (para [0026]), and a strong-coupling factor being defined as U = ksqrt(Q1Q2) (para [0028]). Joannopoulos does not specifically disclose wherein said resonant field of the first resonator structure is radiative in the far field, wherein said resonant field of the second resonator structure is radiative in the far field, and wherein the apparatus is configured to employ interference between said radiative far fields of the resonant fields of the first and second resonator, with an interference factor Vrad, to reduce a total amount of radiation from the apparatus compared to an amount of radiation from the apparatus in the absence of interference, a strong-interference factor being defined as V = Vradsqrt((Q1/Q1,rad)(Q2/Q2,rad)). However, Qi does disclose wherein said resonant field of the first resonator structure is radiative in the far field (para [0015]), wherein said resonant field of the second resonator structure is radiative in the far field (para [0015]), and wherein the apparatus is configured to employ interference between said radiative far fields of the resonant fields of the first and second resonator (para [0015]), with an interference factor Vrad, to reduce a total amount of radiation from the apparatus compared to an amount of radiation from the apparatus in the absence of interference (para [0023]), a strong-interference factor being defined as V = Vradsqrt((Q1/Q1,rad)(Q2/Q2,rad)) (para [0015]). It would have been obvious to one of ordinary skill in the art to combine the apparatus of Joannopoulos with the element of Qi because Qi discloses that its element addresses an ongoing need in the art for improving operating characteristics (Qi para [0015]).

Regarding claim 10, the combination of Joannopoulos and Qi discloses the apparatus of claim 9, and Joannopoulos further discloses wherein Q1/Q1,rad >= 0.01 and Q2/Q2,rad >= 0.01 (para [0027]).

Regarding claim 11, the combination of Joannopoulos and Qi discloses the apparatus of claim 9, and Joannopoulos further discloses wherein Q1/Q1,rad >= 0.1 and Q2/Q2,rad >= 0.1 (para [0027]).

Regarding claim 12, the combination of Joannopoulos and Qi discloses the apparatus of claim 9, and Joannopoulos further discloses wherein D/lambdao is larger than 0.001 (para [0024]) and the strong-interference factor V is larger than 0.01 (para [0027]).

Regarding claim 13, the combination of Joannopoulos and Qi discloses the apparatus of claim 9, and Joannopoulos further discloses wherein D/lambdao is larger than 0.001 (para [0024]) and the strong-interference factor V is larger than 0.1 (para [0027]).

Regarding claim 14, the combination of Joannopoulos and Qi discloses the apparatus of claim 9, and Joannopoulos further discloses the second resonator structure (para [0005]).

Regarding claim 26, the combination of Joannopoulos and Qi discloses the apparatus of claim 9, and Joannopoulos further discloses wherein at least one of the first and second resonator structures comprises a capacitively loaded loop of a conducting wire (para [0019]).

Regarding claim 27, the combination of Joannopoulos and Qi discloses the apparatus of claim 26, and Joannopoulos further discloses where the characteristic size of said loop is less than 30 cm and the width of said conducting wire is less than 2 cm (para [0027]).

Regarding claim 28, the combination of Joannopoulos and Qi discloses the apparatus of claim 26, and Joannopoulos further discloses where the characteristic size of said loop is less than 1 m and the width of said conducting wire is less than 2 cm (para [0027]).

Regarding claim 29, the combination of Joannopoulos and Qi discloses the apparatus of claim 9, and Joannopoulos further discloses a feedback mechanism for maintaining the resonant frequency of one or more of the resonant objects (para [0031]).

Regarding claim 30, the combination of Joannopoulos and Qi discloses the apparatus of claim 29, and Joannopoulos further discloses wherein the feedback mechanism comprises an oscillator with a fixed driving frequency and is configured to adjust the resonant frequency of the one or more resonant objects to be detuned by a fixed amount with respect to the fixed frequency (para [0031]).

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WRITTEN OPINION OF THE INTERNATIONAL SEARCHING AUTHORITY

International application No.
PCT/US 09/43970

Supplemental Box

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Box V.2. Citations and explanations:

Regarding claim 31, Joannopoulos discloses an apparatus for use in wireless energy transfer, the apparatus comprising: a first resonator structure configured for energy transfer with a second resonator structure over a distance D (para [0005]), wherein the energy transfer is mediated by evanescent-tail coupling of a resonant field of the first resonator structure and a resonant field of the second resonator structure, with a coupling factor k (para [0006]), wherein said resonant field of the first resonator structure has a resonance angular frequency omega1 (para [0015]), a resonance frequency-width gamma1 (para [0015]), and a resonance quality factor Q1 = omega1/2gamma1 (para [0027]), with an associated radiation quality factor Q1,rad >= Q1 (para [0022]), said resonant field of the second resonator structure has a resonance angular frequency omega2 (para [0015]), a resonance frequency-width gamma2 (para [0015]), and a resonance quality factor Q2 = omega2/2gamma2 (para [0027]), with an associated radiation quality factor Q2,rad >= Q2 (para [0022]), wherein an absolute value of a difference of said angular frequencies omega1 and omega2 is smaller than broader of said resonant widths gamma1 and gamma2 (para [0016]), and an average resonant angular frequency is defined as omegao = sqrt(omega1omega2) (para [0024]), corresponding to an average resonant wavelength lambdao = 2pic/omegao, where c is the speed of light in free space (para [0026]), and a strong-coupling factor being defined as U = ksqrt(Q1Q2) (para [0028]). Joannopoulos does not specifically disclose wherein said resonant field of the first resonator structure is radiative in the far field, wherein said resonant field of the second resonator structure is radiative in the far field, and wherein the apparatus is configured to employ interference between said radiative far fields of the resonant fields of the first and second resonator, with an interference factor Vrad, to reduce a total amount of radiation from the apparatus compared to an amount of radiation from the apparatus in the absence of interference, a strong-interference factor being defined as V = Vradsqrt((Q1/Q1,rad)(Q2/Q2,rad)). However, Qi does disclose wherein said resonant field of the first resonator structure is radiative in the far field (para [0015]), wherein said resonant field of the second resonator structure is radiative in the far field (para [0015]), and wherein the apparatus is configured to employ interference between said radiative far fields of the resonant fields of the first and second resonator (para [0015]), with an interference factor Vrad, to reduce a total amount of radiation from the apparatus compared to an amount of radiation from the apparatus in the absence of interference (para [0023]), a strong-interference factor being defined as V = Vradsqrt((Q1/Q1,rad)(Q2/Q2,rad)) (para [0015]). It would have been obvious to one of ordinary skill in the art to combine the apparatus of Joannopoulos with the element of Qi because Qi discloses that its element addresses an ongoing need in the art for improving operating characteristics (Qi para [0015]).

Regarding claim 32, the combination of Joannopoulos and Qi discloses the apparatus of claim 31, and Joannopoulos further discloses wherein Q1/Q1,rad >= 0.05 and Q2/Q2,rad >= 0.05 (para [0027]).

Regarding claim 33, the combination of Joannopoulos and Qi discloses the apparatus of claim 31, and Joannopoulos further discloses wherein Q1/Q1,rad >= 0.5 and Q2/Q2,rad >= 0.5 (para [0027]).

Regarding claim 34, the combination of Joannopoulos and Qi discloses the apparatus of claim 31, and Joannopoulos further discloses wherein D/lambdao is larger than 0.01 (para [0024]) and the strong-interference factor V is larger than 0.05 (para [0027]).

Regarding claim 35, the combination of Joannopoulos and Qi discloses the apparatus of claim 31, and Joannopoulos further discloses wherein D/lambdao is larger than 0.01 (para [0024]) and the strong-interference factor V is larger than 0.5 (para [0027]).

Regarding claim 36, the combination of Joannopoulos and Qi discloses the apparatus of claim 31, and Joannopoulos further discloses the second resonator structure (para [0005]).

Regarding claim 48, the combination of Joannopoulos and Qi discloses the apparatus of claim 31, and Joannopoulos further discloses wherein at least one of the first and second resonator structures comprises a capacitively loaded loop of a conducting wire (para [0019]).

Regarding claim 49, the combination of Joannopoulos and Qi discloses the apparatus of claim 48, and Joannopoulos further discloses where the characteristic size of said loop is less than 30 cm and the width of said conducting wire is less than 2 cm (para [0027]).

Regarding claim 50, the combination of Joannopoulos and Qi discloses the apparatus of claim 48, and Joannopoulos further discloses where the characteristic size of said loop is less than 1 m and the width of said conducting wire is less than 2 cm (para [0027]).

Regarding claim 51, the combination of Joannopoulos and Qi discloses the apparatus of claim 31, and Joannopoulos further discloses a feedback mechanism for maintaining the resonant frequency of one or more of the resonant objects (para [0031]).

Regarding claim 52, the combination of Joannopoulos and Qi discloses the apparatus of claim 51, and Joannopoulos further discloses wherein the feedback mechanism comprises an oscillator with a fixed driving frequency and is configured to adjust the resonant frequency of the one or more resonant objects to be detuned by a fixed amount with respect to the fixed frequency (para [0031]).

Regarding claim 53, the combination of Joannopoulos and Qi discloses the apparatus of claim 51, and Joannopoulos further discloses where the feedback mechanism is configured to monitor an efficiency of the energy transfer, and adjust the resonant frequency of the one or more resonant objects to maximize the efficiency (para [0031]).

Regarding claim 54, the combination of Joannopoulos and Qi discloses the apparatus of claim 31, and Joannopoulos further discloses wherein the resonance angular frequencies for the resonator structures are selected to optimize the energy-transfer efficiency by accounting for both the strong-coupling factor U and the strong-interference interference factor V (para [0016]).

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WRITTEN OPINION OF THE INTERNATIONAL SEARCHING AUTHORITY

International application No.
PCT/US 09/43970

Supplemental Box

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Box V.2. Citations and explanations:

Regarding claim 55, the combination of Joannopoulos and Qi discloses a method for wireless energy transfer, the method comprising: providing a first resonator structure configured for energy transfer with a second resonator structure over a distance D (para [0005]), wherein the energy transfer is mediated by evanescent-tail coupling of a resonant field of the first resonator structure and a resonant field of the second resonator structure, with a coupling factor k (para [0006]), wherein said resonant field of the first resonator structure has a resonance angular frequency omega1 (para [0015]), a resonance frequency-width gamma1 (para [0015]), and a resonance quality factor Q1 = omega1/2gamma1 (para [0027]), with an associated radiation quality factor Q1,rad >= Q1 (para [0022]), said resonant field of the second resonator structure has a resonance angular frequency omega2 (para [0015]), a resonance frequency-width gamma2 (para [0015]), and a resonance quality factor Q2 = omega2/2gamma2 (para [0027]), with an associated radiation quality factor Q2,rad >= Q2 (para [0022]), wherein an absolute value of a difference of said angular frequencies omega1 and omega2 is smaller than broader of said resonant widths gamma1 and gamma2 (para [0016]), and an average resonant angular frequency is defined as omegao = sqrt(omega1omega2) (para [0024]), corresponding to an average resonant wavelength lambdao = 2pic/omegao, where c is the speed of light in free space (para [0026]), and a strong-coupling factor being defined as U = ksqrt(Q1Q2) (para [0028]). Joannopoulos does not specifically disclose wherein said resonant field of the first resonator structure is radiative in the far field, wherein said resonant field of the second resonator structure is radiative in the far field, and employing interference between said radiative far fields of the resonant fields of the first and second resonator, with an interference factor Vrad, to reduce a total amount of radiation from the apparatus compared to an amount of radiation from the apparatus in the absence of interference, a strong-interference factor being defined as V = Vradsqrt((Q1/Q1,rad)(Q2/Q2,rad)). However, Qi does disclose wherein said resonant field of the first resonator structure is radiative in the far field (para [0015]), wherein said resonant field of the second resonator structure is radiative in the far field (para [0015]), and employing interference between said radiative far fields of the resonant fields of the first and second resonator (para [0015]), with an interference factor Vrad, to reduce a total amount of radiation from the apparatus compared to an amount of radiation from the apparatus in the absence of interference (para [0023]), a strong-interference factor being defined as V = Vradsqrt((Q1/Q1,rad)(Q2/Q2,rad)) (para [0015]). It would have been obvious to one of ordinary skill in the art to combine the method of Joannopoulos with the element of Qi because Qi discloses that its element addresses an ongoing need in the art for improving operating characteristics (Qi para [0015]).

Regarding claim 56, the combination of Joannopoulos and Qi discloses the method of claim 55, and Joannopoulos further discloses wherein Q1/Q1,rad >= 0.01 and Q2/Q2,rad >= 0.01 (para [0027]).

Regarding claim 59, the combination of Joannopoulos and Qi discloses a method for wireless energy transfer, the method comprising: providing a first resonator structure configured for energy transfer with a second resonator structure over a distance D (para [0005]), wherein the energy transfer is mediated by evanescent-tail coupling of a resonant field of the first resonator structure and a resonant field of the second resonator structure, with a coupling factor k (para [0006]), wherein said resonant field of the first resonator structure has a resonance angular frequency omega1 (para [0015]), a resonance frequency-width gamma1 (para [0015]), and a resonance quality factor Q1 = omega1/2gamma1 (para [0027]), with an associated radiation quality factor Q1,rad >= Q1 (para [0022]), said resonant field of the second resonator structure has a resonance angular frequency omega2 (para [0015]), a resonance frequency-width gamma2 (para [0015]), and a resonance quality factor Q2 = omega2/2gamma2 (para [0027]), with an associated radiation quality factor Q2,rad >= Q2 (para [0022]), wherein an absolute value of a difference of said angular frequencies omega1 and omega2 is smaller than broader of said resonant widths gamma1 and gamma2 (para [0016]), and an average resonant angular frequency is defined as omegao = sqrt(omega1omega2) (para [0024]), corresponding to an average resonant wavelength lambdao = 2pic/omegao, where c is the speed of light in free space (para [0026]), and a strong-coupling factor being defined as U = ksqrt(Q1Q2) (para [0028]). Joannopoulos does not specifically disclose wherein said resonant field of the first resonator structure is radiative in the far field, wherein said resonant field of the second resonator structure is radiative in the far field, and employing interference between said radiative far fields of the resonant fields of the first and second resonator, with an interference factor Vrad, to reduce a total amount of radiation from the apparatus compared to an amount of radiation from the apparatus in the absence of interference, a strong-interference factor being defined as V = Vradsqrt((Q1/Q1,rad)(Q2/Q2,rad)). However, Qi does disclose wherein said resonant field of the first resonator structure is radiative in the far field (para [0015]), wherein said resonant field of the second resonator structure is radiative in the far field (para [0015]), and employing interference between said radiative far fields of the resonant fields of the first and second resonator (para [0015]), with an interference factor Vrad, to reduce a total amount of radiation from the apparatus compared to an amount of radiation from the apparatus in the absence of interference (para [0023]), a strong-interference factor being defined as V = Vradsqrt((Q1/Q1,rad)(Q2/Q2,rad)) (para [0015]). It would have been obvious to one of ordinary skill in the art to combine the method of Joannopoulos with the element of Qi because Qi discloses that its element addresses an ongoing need in the art for improving operating characteristics (Qi para [0015]).

Regarding claim 60, the combination of Joannopoulos and Qi discloses the method of claim 59, and Joannopoulos further discloses wherein Q1/Q1,rad >= 0.01 and Q2/Q2,rad >= 0.05 (para [0027]).

Regarding claim 63, the combination of Joannopoulos and Qi discloses the method of claim 59, and Joannopoulos further discloses wherein the resonance angular frequencies for the resonator structures are selected to optimize the energy-transfer efficiency by accounting for both the strong-coupling factor U and the strong-interference interference factor V (para [0016]).

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WRITTEN OPINION OF THE INTERNATIONAL SEARCHING AUTHORITY

International application No.
PCT/US 09/43970

Supplemental Box

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Box V.2. Citations and explanations:

Claims 15-25, 37-47, 57, 58, 61 and 62 lack an inventive step under PCT Article 33(3) as being obvious over Joannopoulos in view of Qi and in further view of US 5,437,057 A to Richley et al. (hereinafter 'Richley').

Regarding claim 15, the combination of Joannopoulos and Qi discloses the apparatus of claim 9, and Joannopoulos further discloses wherein, during operation, a power generator is coupled to one of the first and second resonant structure (para [0005]), with a coupling rate kappag (para [0006]), wherein Ug is defined as kappag/gamma1, if the power generator is coupled to the first resonator structure and defined as kappag/gamma2 if the power generator is coupled to the second resonator structure (para [0024]). Neither specifically discloses wherein a power generator is configured to drive the resonator structure, to which it is coupled, at a driving frequency f, corresponding to a driving angular frequency omega = 2pif. However, Richley does disclose wherein a power generator is configured to drive the resonator structure, to which it is coupled, at a driving frequency f, corresponding to a driving angular frequency omega = 2pif (col 9, ln 6-18). It would have been obvious to one of ordinary skill in the art to combine the apparatus of Joannopoulos and Qi with the element of Richley because Richley teaches that its element addresses an ongoing need in the art for driving the resonators (Richley col 9, ln 6-18).

Regarding claim 16, the combination of Joannopoulos, Qi and Richely discloses the apparatus of claim 15, and Joannopoulos further discloses wherein the driving frequency is different from the resonance frequencies of the first and second resonator structures and is closer to a frequency corresponding to an odd normal mode of the system of the two resonator structures (para [0024]), wherein the detuning of the first resonator from the driving frequency is defined as D1 = (omega - omega1)/gamma1 and the detuning of the second resonator structure from the driving frequency is defined as D2 = (omega - omega2)/gamma2 (para [0024]).

Regarding claim 17, the combination of Joannopoulos, Qi and Richely discloses the apparatus of claim 16, and Qi further discloses wherein D1 is approximately equal to UVrad and D2 is approximately equal to UVrad (para [0015]).

Regarding claim 18, the combination of Joannopoulos, Qi and Richley discloses the apparatus of claim 15, and Joannopoulos further discloses wherein Ug is chosen to maximize the ratio of the energy-transfer efficiency to the radiation efficiency (para [0012]).

Regarding claim 19, the combination of Joannopoulos, Qi and Richley discloses the apparatus of claim 17, and Joannopoulos further discloses wherein Ug is approximately equal to sqrt(1 + U^2 - Vrad^2 U^2 + V^2 - 2VVrad) (para [0028]).

Regarding claim 20, the combination of Joannopoulos, Qi and Richley discloses the apparatus of claim 17, and Joannopoulos further discloses wherein f is at least larger than 100 kHz and smaller than 500MH (para [0027]).

Regarding claim 21, the combination of Joannopoulos, Qi and Richley discloses the apparatus of claim 17, and Joannopoulos further discloses wherein f is at least larger than 1MHz and smaller than 50MHz (para [0027]).

Regarding claim 22, the combination of Joannopoulos, Qi and Richley discloses the apparatus of claim 15, and Joannopoulos further discloses the power generator (para [0005]).

Regarding claim 23, the combination of Joannopoulos, Qi and Richley discloses the apparatus of claim 15, and Joannopoulos further discloses wherein, during operation, a power load is coupled to the resonant structure to which the power generator is not coupled, with a coupling rate kappa1 (para [0021]), and is configured to receive from the resonator structure, to which it is coupled, a usable power (para [0005]), wherein U1 is defined as kappa1/gamma1, if the power load is coupled to the first resonator structure and defined as kappa1/gamma2 if the power load is coupled to the second resonator structure (para [0024]).

Regarding claim 24, the combination of Joannopoulos, Qi and Richley discloses the apparatus of claim 23, and Joannopoulos further discloses wherein U1 is chosen to maximize the ratio of the energy-transfer efficiency to the radiation efficiency (para [0012]).

Regarding claim 25, the combination of Joannopoulos, Qi and Richley discloses the apparatus of claim 24, and Joannopoulos further discloses wherein the driving frequency is different from the resonance frequencies of the first and second resonator structures and is closer to a frequency corresponding to an odd normal mode of the system of the two resonator structures (para [0024]), wherein the detuning of the first resonator from the driving frequency is defined as D1 = (omega - omega1)/gamma1 and is approximately equal to UVrad and the detuning of the second resonator structure from the driving frequency is defined as D2 = (omega - omega2)/gamma2 and is approximately equal to UVrad (para [0024]), wherein U1 is approximately equal to sqrt(1 + U^2 - Vrad^2 U^2 + V^2 - 2VVrad) (para [0028]).

Regarding claim 37, the combination of Joannopoulos and Qi discloses the apparatus of claim 31, and Joannopoulos further discloses wherein, during operation, a power generator is coupled to one of the first and second resonant structure (para [0005]), with a coupling rate kappag (para [0006]), wherein Ug is defined as kappag/gamma1, if the power generator is coupled to the first resonator structure and defined as kappag/gamma2 if the power generator is coupled to the second resonator structure (para [0024]). Neither specifically discloses wherein a power generator is configured to drive the resonator structure, to which it is coupled, at a driving frequency f, corresponding to a driving angular frequency omega = 2pif. However, Richley does disclose wherein a power generator is configured to drive the resonator structure, to which it is coupled, at a driving frequency f, corresponding to a driving angular frequency omega = 2pif (col 9, ln 6-18). It would have been obvious to one of ordinary skill in the art to combine the apparatus of Joannopoulos and Qi with the element of Richley because Richley teaches that its element addresses an ongoing need in the art for driving the resonators (Richley col 9, ln 6-18).

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WRITTEN OPINION OF THE INTERNATIONAL SEARCHING AUTHORITY

International application No.
PCT/US 09/43970

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Box V.2. Citations and explanations:

Regarding claim 38, the combination of Joannopoulos, Qi and Richely discloses the apparatus of claim 37, and Joannopoulos further discloses wherein the driving frequency is different from the resonance frequencies of the first and second resonator structures and is closer to a frequency corresponding to an odd normal mode of the system of the two resonator structures (para [0024]), wherein the detuning of the first resonator from the driving frequency is defined as D1 = (omega - omega1)/gamma1 and the detuning of the second resonator structure from the driving frequency is defined as D2 = (omega - omega2)/gamma2 (para [0024]).

Regarding claim 39, the combination of Joannopoulos, Qi and Richely discloses the apparatus of claim 38, and Qi further discloses wherein D1 is approximately equal to UV and D2 is approximately equal to UV (para [0015]).

Regarding claim 40, the combination of Joannopoulos, Qi and Richley discloses the apparatus of claim 37, and Joannopoulos further discloses wherein Ug is chosen to maximize the ratio of the energy-transfer efficiency to the radiation efficiency (para [0012]).

Regarding claim 41, the combination of Joannopoulos, Qi and Richely discloses the apparatus of claim 39, and Joannopoulos further discloses wherein Ug is approximately equal to sqrt((1 + U^2)(1 - V^2)) (para [0028]).

Regarding claim 42, the combination of Joannopoulos, Qi and Richley discloses the apparatus of claim 37, and Joannopoulos further discloses wherein f is at least larger than 100 kHz and smaller than 500MH (para [0027]).

Regarding claim 43, the combination of Joannopoulos, Qi and Richley discloses the apparatus of claim 37, and Joannopoulos further discloses wherein f is at least larger than 1MHz and smaller than 50MHz (para [0027]).

Regarding claim 44, the combination of Joannopoulos, Qi and Richley discloses the apparatus of claim 37, and Joannopoulos further discloses the power generator (para [0005]).

Regarding claim 45, the combination of Joannopoulos, Qi and Richley discloses the apparatus of claim 37, and Joannopoulos further discloses wherein, during operation, a power load is coupled to the resonant structure to which the power generator is not coupled, with a coupling rate kappa1 (para [0021]), and is configured to receive from the resonator structure, to which it is coupled, a usable power (para [0005]), wherein U1 is defined as kappa1/gamma1, if the power load is coupled to the first resonator structure and defined as kappa1/gamma2 if the power load is coupled to the second resonator structure (para [0024]).

Regarding claim 46, the combination of Joannopoulos, Qi and Richley discloses the apparatus of claim 45, and Joannopoulos further discloses wherein U1 is chosen to maximize the ratio of the energy-transfer efficiency to the radiation efficiency (para [0012]).

Regarding claim 47, the combination of Joannopoulos, Qi and Richley discloses the apparatus of claim 46, and Joannopoulos further discloses wherein the driving frequency is different from the resonance frequencies of the first and second resonator structures and is closer to a frequency corresponding to an odd normal mode of the system of the two resonator structures (para [0024]), wherein the detuning of the first resonator from the driving frequency is defined as D1 = (omega - omega1)/gamma1 and is approximately equal to UV, and the detuning of the second resonator structure from the driving frequency is defined as D2 = (omega - omega2)/gamma2 (para [0024]) and is approximately equal to UV, wherein U1 is approximately equal to sqrt((1 + U^2)(1 - V^2)) (para [0028]).

Regarding claim 57, the combination of Joannopoulos and Qi discloses the method of claim 55, and Joannopoulos further discloses wherein, during operation, a power generator is coupled to one of the first and second resonant structure (para [0005]), with a coupling rate kappag (para [0006]), wherein Ug is defined as kappag/gamma1, if the power generator is coupled to the first resonator structure and defined as kappag/gamma2 if the power generator is coupled to the second resonator structure (para [0024]). Neither specifically discloses wherein a power generator is configured to drive the resonator structure, to which it is coupled, at a driving frequency f, corresponding to a driving angular frequency omega = 2pif. However, Richley does disclose wherein a power generator is configured to drive the resonator structure, to which it is coupled, at a driving frequency f, corresponding to a driving angular frequency omega = 2pif (col 9, ln 6-18). It would have been obvious to one of ordinary skill in the art to combine the method of Joannopoulos and Qi with the element of Richley because Richley teaches that its element addresses an ongoing need in the art for driving the resonators (Richley col 9, ln 6-18).

Regarding claim 58, the combination of Joannopoulos, Qi and Richley discloses the method of claim 57, and Joannopoulos further discloses wherein, during operation, a power load is coupled to the resonant structure to which the power generator is not coupled, and is configured to receive from the resonator structure, to which it is coupled, a usable power (para [0005]).

Regarding claim 61, the combination of Joannopoulos and Qi discloses the method of claim 59, and Joannopoulos further discloses wherein, during operation, a power generator is coupled to one of the first and second resonant structure (para [0005]), with a coupling rate kappag (para [0006]), wherein Ug is defined as kappag/gamma1, if the power generator is coupled to the first resonator structure and defined as kappag/gamma2 if the power generator is coupled to the second resonator structure (para [0024]). Neither specifically discloses wherein a power generator is configured to drive the resonator structure, to which it is coupled, at a driving frequency f, corresponding to a driving angular frequency omega = 2pif. However, Richley does disclose wherein a power generator is configured to drive the resonator structure, to which it is coupled, at a driving frequency f, corresponding to a driving angular frequency omega = 2pif (col 9, ln 6-18). It would have been obvious to one of ordinary skill in the art to combine the method of Joannopoulos and Qi with the element of Richley because Richley teaches that its element addresses an ongoing need in the art for driving the resonators (Richley col 9, ln 6-18).

Regarding claim 62, the combination of Joannopoulos, Qi and Richley discloses the method of claim 61, and Joannopoulos further discloses wherein, during operation, a power load is coupled to the resonant structure to which the power generator is not coupled, and is configured to receive from the resonator structure, to which it is coupled, a usable power (para [0005]).

Claims 1 - 63 have industrial applicability as defined by PCT Article 33(4) because the subject matter can be made or used in industry.

(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) World Intellectual Property Organization
International Bureau

(43) International Publication Date
26 July 2007 (26.07.2007)

PCT

(10) International Publication Number
WO 2007/084717 A2

(51) International Patent Classification:
H04B 1/38 (2006.01) *H04M 1/00* (2006.01)

(21) International Application Number:
PCT/US2007/001529

(22) International Filing Date: 18 January 2007 (18.01.2007)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:

60/760,064	18 January 2006 (18.01.2006)	US
11/408,793	21 April 2006 (21.04.2006)	US
11/654,883	17 January 2007 (17.01.2007)	US

(71) Applicant *(for all designated States except US)*: **THIRD OPTION LLC** [US/US]; 11512 El Camino Real, Suite 100, San Diego, CA 92130 (US).

(72) Inventors; and

(75) Inventors/Applicants *(for US only)*: **COOK, Nigel, P.** [GB/US]; 1739 Vakas Drive, El Cajon, CA 92019 (US). **LEVINE, Richard, C.** [US/US]; 7950 Woodstone Lane, Dallas, TX 75248 (US).

(74) Agent: **GAZDZINSKI, Robert, F.**; GAZDZINSKI & ASSOCIATES, 11440 West Bernardo Court, Suite 375, San Diego, CA 92127 (US).

(81) Designated States *(unless otherwise indicated, for every kind of national protection available)*: AE, AG, AL, AM, AT, AU, AZ, BA, BB, BG, BR, BW, BY, BZ, CA, CH, CN, CO, CR, CU, CZ, DE, DK, DM, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IS, JP, KE, KG, KM, KN, KP, KR, KZ, LA, LC, LK, LR, LS, LT, LU, LV, LY, MA, MD, MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PG, PH, PL, PT, RO, RS, RU, SC, SD, SE, SG, SK, SL, SM, SV, SY, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, ZA, ZM, ZW.

(84) Designated States *(unless otherwise indicated, for every kind of regional protection available)*: ARIPO (BW, GH, GM, KE, LS, MW, MZ, NA, SD, SL, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European (AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HU, IE, IS, IT, LT, LU, LV, MC, NL, PL, PT, RO, SE, SI, SK, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, ML, MR, NE, SN, TD, TG).

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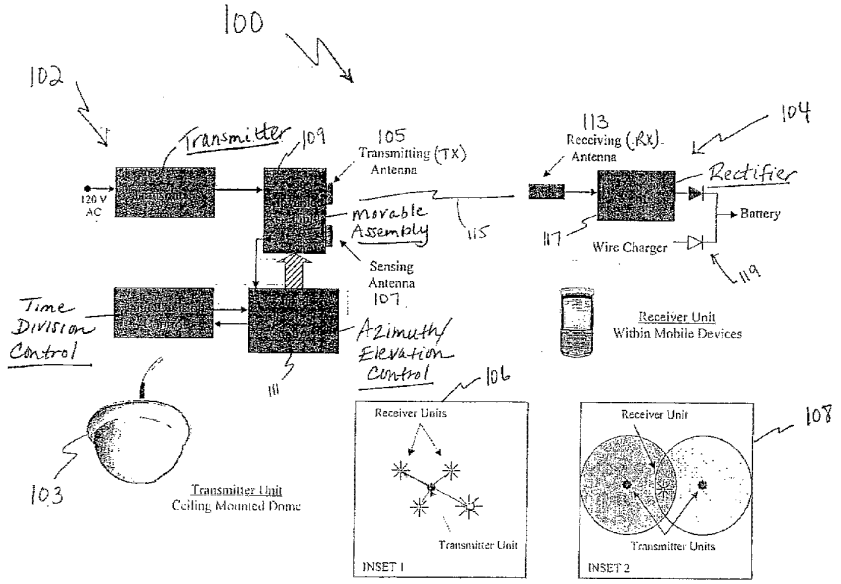
— *as to applicant's entitlement to apply for and be granted a patent (Rule 4.17(ii))*

Published:

— *without international search report and to be republished upon receipt of that report*

[Continued on next page]

(54) Title: METHOD AND APPARATUS FOR DELIVERING ENERGY TO AN ELECTRICAL OR ELECTRONIC DEVICE VIA A WIRELESS LINK



(57) Abstract: A method and apparatus for providing power to e.g., a chargeable device via a radio frequency link. In one aspect, a method of providing power to a chargeable device via radio frequency link comprises generating a substantially un-modulated signal. The method further comprises radiating a substantially un-modulated radio frequency (RF) signal to the chargeable device via a transmit antenna based on the substantially un-modulated signal. The method further comprises powering or charging the chargeable device with power delivered by the substantially un-modulated RF signal.

WO 2007/084717 A2

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METHOD AND APPARATUS FOR DELIVERING ENERGY TO AN ELECTRICAL OR ELECTRONIC DEVICE VIA A WIRELESS LINK

Priority and Related Applications

This application claims priority to co-owned and co-pending U.S. Utility Application Serial No. 11/_____ filed January 17, 2007 and entitled "Method And Apparatus For Delivering Energy To An Electrical Or Electronic Device Via A Wireless Link", which claims priority to U.S. Provisional Patent Application Serial No. 60/760,064 entitled "Method and System for Charging an Electronic Device via a Wireless Link" filed on January 18, 2006, each of the foregoing incorporated herein by reference in its entirety. This Application is also related to, and claims priority to, U.S. Patent Application Serial No. 11/408,793 entitled "Method and System for Powering an Electronic Device via a Wireless Link" filed on April 21, 2006, assigned to the Assignee hereof, and which is also incorporated herein by reference in its entirety.

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1. Field of the Invention

This invention relates generally to methods and apparatus for energy or power transfer, and in one aspect to wirelessly charging a portable power source, such as a battery, associated with an electronic device.

2. Description of Related Technology

Methods and systems for the wireless transmission of power are known in the prior art, for example, United States Patent No. 6,633,026 to Tuominen issued October 14, 2003 and entitled "Wireless power transmission" discloses a method for wireless power transmission in a system comprising a power transmitter which in turn comprises a first light source and means for directing the light emitted by the first light source to a desired direction, and at least one power

InductEV, Inc.
Exhibit 1002
Page 368

receiver comprising a first photo-detector for receiving the emitted light and for converting it into electric current. A second light source included in the power transmitter is used for transmitting light around the light emitted by the first light source and substantially parallel to it, the intensity of the light being lower than that of the light emitted by the first light source. A second photo-detector included in the power receiver is used for detecting the light emitted by the second light source and for transmitting a control signal to the power transmitter in response to a successful reception of the light emitted by the second light source. The first light source of the power transmitter is switched on in response to the reception of the control signal from the power receiver informing of the reception of the light emitted by the second light source.

United States Patent No. 6,664,770 to Bartels issued December 16, 2003 and entitled "Wireless power transmission system with increased output voltage" discloses a system for wireless power transmission, which makes it possible to generate an increased voltage on the receiver side using a radio signal that is optimized for this purpose and thereby permits operation particularly of digital semiconductor components in the receiver even if the receiver does not have a power supply of its own.

United States Patent No. 6,999,857 to Kasper, et al. issued February 14, 2006 and entitled "Data communication and power transmission system for sensing devices" discloses a wireless power transmission and communication network that provides interrogation and powering of sensors for use on undersea vehicles. The invention employs a wave-guide that allows the propagation of electromagnetic waves through a dielectric material that covers the exterior of an undersea vehicle's hull. Embedded within the dielectric material is an N dimensional array of Micro Electronic Mechanical Systems sensing devices coupled with radio frequency (RF) decoders and transceivers, and strips of conductive metal tape. Electromagnetic waves such as microwaves propagate through the dielectric material both powering the sensor network and addressing and interrogating individual sensing devices. The sensing devices take readings and then format and transmit the data results back across the wave-guide where they are received and processed by a digital processor within the hull of the undersea vehicle.

United States Patent No. 7,027,311 to Vanderelli, et al. issued April 11, 2006 and entitled "Method and apparatus for a wireless power supply" discloses an apparatus for a wireless power supply including a mechanism for receiving a range of RF radiation across a collection of frequencies. The apparatus includes a mechanism for converting the RF radiation across the collection of frequencies, preferably at a same time into DC. A method for a wireless power supply including the steps of receiving a range of RF radiation across a collection of frequencies.

InductEV, Inc.
Exhibit 1002
Page 369

There is the step of converting the RF radiation across the collection of frequencies, preferably at a same time into DC.

United States Patent No. 7,068,991 to Parise issued June 27, 2006 and entitled "Remote power recharge for electronic equipment" discloses a conductorless charging and power system for electronic appliances and a method for communicating power to a power receiver employing wireless energy transmission. The remote charging system includes a power transmission unit, which transmits energy as a directional power beam, and a power receiver system that receives the transmitted energy. The power receiver system is preferably incorporated in an appliance and includes an energy receptor capable of receiving the wireless power beam and transferring the energy from the beam to an energy storage device included in the appliance. The power transmission unit receives and tracks a power request signal from the power receiver system to track the power receiver system location during energy transmission. Data streams may be incorporated into the wireless signals of the remote charging system, allowing the remote charging system to function as a communications pathway as well as a power delivery system.

United States Patent Publication No. 20060097667 to Kang, et al. published on May 11, 2006 and entitled "Wireless power supply and method of supplying power" discloses a wireless power supply and method of wirelessly supplying power using light to directly supply power wirelessly to an electrical apparatus without a power cable. The wireless power supply includes: a plurality of pressure switches adapted to switch ON/OFF in response to an applied pressure; and a plurality of light emitting devices respectively connected to the plurality of pressure switches, the plurality of light emitting devices adapted to emit light to supply the power to a load in response to at least one of the pressure switches being switched ON.

United States Patent Publication No. 20060205381 to Beart, et al. published on September 14, 2006 and entitled "Adapting portable electrical devices to receive power wirelessly" discloses a wireless power receiving apparatus that is retrofitted to a portable electrical device to enable the device to receive power wirelessly. The apparatus comprises a power-receiving element adapted to be attached to the device, e.g. by adhesive, and also being adapted to receive power wirelessly from a transmitter of power when the element and transmitter are in proximity with one another. One or more power connectors are connected electrically to the power-receiving element and are adapted to be connected, when the apparatus is in use, to one or more corresponding power connectors of the portable electrical device to deliver power received by the element to the device. The power-receiving element may be in the form of a sticker or may be carried by or incorporated in a replacement cover portion for the portable electrical device.

InductEV, Inc.
Exhibit 1002
Page 370

United States Patent Publication No. 20060238365 to Vecchione, et al. published on October 26, 2006 and entitled "Short-range wireless power transmission and reception" discloses a short-range wireless power transmission and reception system and methods. Power is transmitted from the electrical utility mains power supply to electrically powered appliances via electromagnetic radiation. The appliances are capable of receiving the transmitted power, converting it into electricity and storing it for subsequent use, as well as using it directly to power the appliances.

United States Patent Publication No. 20060266917 to Baldis, et al. published on November 30, 2006 and entitled "Wireless Power Transmission System" discloses a method for wireless power transmission that comprises a transmitter and a receiver. The receiver does not require an independent power source and is comprised of an optical feedback to the transmitter, and therefore does not require a separate communication channel to the transmitter. The transmitter uses the optical feedback to locate and track the receiver. The transmitter can optionally employ a macro adjusters and micro adjusters that direct the beam onto the receiver for optimal power transmission. The system also optionally has a tight loop beam detector to enhance safety of the system. Either the receiver and/or the transmitter may also encode data on the energy transmission, resulting in one-way or two-way data transmission.

United States Patent Publication No. 20070010295 to Greene, et al. published on January 11, 2007 and entitled "Power transmission system, apparatus and method with communication" discloses a power transmission system with communication having a base station having a wireless power transmitter, a wireless data transmission component and a first wireless data reception component. The system includes a remote station having a power harvester for converting the power from the power transmitter into direct current and a power storage component in communication with the power harvester for storing the direct current. Alternatively, the system includes a base station having a wireless power transmitter which transmits power at a frequency at which any sidebands are at or below a desired level, and a first wireless data communication component.

Recent developments in technology enable electronic devices, such as without limitation laptop or notebook computers, cell phones and PDAs (personal digital assistant) to run various multimedia or other processing-intensive applications. However, despite the foregoing wireless power transmission systems, these new multimedia applications often require a large amount of power to run, and are unable to be charged via a wireless link. In addition to the convenience associated with a wireless power transmission system, there is also a significant benefit in convenience and safety when any of such devices, for example a cell phone, is kept adequately

InductEV, Inc.
Exhibit 1002
Page 371

charged without the need to connect to a powered wire. Therefore it is desired to provide an apparatus and/or system for the powering of certain electronic devices via a wireless link.

Moreover, delivery of power to electrical and electrical devices (e.g., appliances, lighting, etc.) also would allow a great degree of flexibility in terms of use and placement; e.g., a "wireless" lamp could be placed anywhere in a room without concern for tripping over wires, aesthetics, etc.

Summary of the Invention

In a first aspect of the invention, apparatus for providing power to a device via a wireless link is disclosed. In one embodiment, the apparatus comprises: a transmitting antenna operative to provide power to the device via the wireless link; a sensing antenna operative to sense signals transmitted by the device; and a control unit assembly operative to control the operation of the transmitting antenna. In one variant, at least a portion of the apparatus is mounted substantially within a ceiling-mounted dome. In another variant, the power transmitted is unmodulated.

In another variant, the control unit assembly is operative to control the movement of the transmitting antenna in at least two degrees of freedom. The at least two degrees of freedom comprise a substantially azimuthal degree of freedom and a substantially elevational degree of freedom.

In another variant, the control unit is operative to charge a plurality of devices via a wireless link according to a time-division multiple access (TDMA) scheme.

In a second aspect of the invention, a method for providing power to a device via a wireless link is disclosed. In one embodiment, the method comprises: detecting a first direction for the device using a sensing antenna; directing a transmission antenna so that it can transmit at least some power in the first direction based at least in part on the act of detecting; and transmitting power from the transmission antenna via the wireless link to the device.

In a third aspect of the invention, a method for providing power to a plurality of devices via a wireless link is disclosed. In one embodiment, the power is transmitted from a transmitting antenna, and the method comprises: disposing the transmitting antenna so that power can be transmitted to the plurality of devices substantially simultaneously; and transmitting power from the transmission antenna via the wireless link to the plurality of devices according to a multiple access scheme.

In one variant, the multiple access scheme comprises a substantially time-divided scheme. In another variant, the multiple access scheme comprises a substantially frequency-divided scheme. In yet another variant, the multiple access scheme comprises a substantially

InductEV, Inc.
Exhibit 1002
Page 372

frequency-hopped scheme. In still another variant, the multiple access scheme comprises a substantially code-divided scheme. As yet another alternative, the multiple access scheme comprises a sensing scheme wherein a channel is sampled before access is granted.

In a fourth aspect of the invention, apparatus for providing power to a plurality of devices via a wireless link is disclosed. In one embodiment, the apparatus comprises: a transmitting antenna configured to radiate power, the antenna further comprising apparatus allowing the antenna to selectively transmit power to the plurality of devices; a power source capable of generating the power for transmission; and a controller in signal communication with at least one of the antenna and source, the controller being adapted to cause the antenna to transmit the power to the plurality of devices according to a multiple access scheme.

In one variant, the antenna is substantially directional, and the multiple access scheme comprises a substantially time-divided scheme.

In a fifth aspect of the invention, apparatus for receiving power via a wireless link is disclosed. In one embodiment, the power is useful for providing electrical power to one or more components of the apparatus, and the apparatus comprises: a receiving antenna configured to receive power from a transmitting antenna; power source apparatus capable of storing at least a portion of the received power for subsequent use; and a controller in signal communication with at least one of the antenna and source apparatus, the controller being adapted to facilitate selective receipt of the power via the antenna. In one variant, the selective receipt comprises selective receipt according to a multiple access scheme, wherein devices other than the apparatus also receive power substantially simultaneously with the apparatus receiving power.

Brief Description of the Drawings

The features, objectives, and advantages of the invention will become more apparent from the detailed description set forth below when taken in conjunction with the drawings, wherein:

FIG. 1 illustrates at least one exemplary embodiment of a system for charging an electronic device via a wireless link.

FIG. 2 is a logical flow diagram that illustrates a first exemplary method of directing power from a transmission antenna.

FIG. 3 is a logical flow diagram that illustrates a first exemplary method of prioritizing time sharing between a plurality of mobile devices.

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InductEV, Inc.
Exhibit 1002
Page 373

Detailed Description of the Preferred Embodiment

Reference is now made to the drawings wherein like numerals refer to like parts throughout.

As used herein, the terms "mobile device" or "client device" include, but are not limited to, personal digital assistants (PDAs), handheld computers, personal communicators, J2ME equipped devices, cellular telephones, smartphones, "SIP" phones, personal computers (PCs) and minicomputers, whether desktop, laptop, or otherwise, or literally any other device capable of utilizing electrical or electromagnetic power.

As used herein, the term "application" refers generally to a unit of executable software that implements a certain functionality or theme. The themes of applications vary broadly across any number of disciplines and functions (such as communications, instant messaging, content management, e-commerce transactions, brokerage transactions, home entertainment, calculator etc.), and one application may have more than one theme. The unit of executable software generally runs in a predetermined environment; for example, the unit could comprise a downloadable Java Xlet™ that runs within the Java™ environment.

As used herein, the terms "microprocessor" and "digital processor" are meant generally to include all types of digital processing devices including, without limitation, digital signal processors (DSPs), reduced instruction set computers (RISC), general-purpose (CISC) processors, microprocessors, gate arrays (e.g., FPGAs), PLDs, reconfigurable compute fabrics (RCFs), array processors, and application-specific integrated circuits (ASICs). Such digital processors may be contained on a single unitary IC die, or distributed across multiple components.

As used herein, the term "integrated circuit (IC)" refers to any type of device having any level of integration (including without limitation ULSI, VLSI, and LSI) and irrespective of process or base materials (including, without limitation Si, SiGe, CMOS and GaAs). ICs may include, for example, memory devices (e.g., DRAM, SRAM, DDRAM, EEPROM/Flash, ROM), digital processors, SoC devices, FPGAs, ASICs, ADCs, DACs, transceivers, memory controllers, and other devices, as well as any combinations thereof.

As used herein, the term "memory" includes any type of integrated circuit or other storage device adapted for storing digital data including, without limitation, ROM. PROM, EEPROM, DRAM, SDRAM, DDR/2 SDRAM, EDO/FPMS, RLDRAM, SRAM, "flash" memory (e.g., NAND/NOR), and PSRAM.

As used herein, the term "cellular" includes any form of cell-based mobile communications system including cellular telephones, "walkie-talkie" devices (such as those marketed by Nextel

InductEV, Inc.
Exhibit 1002
Page 374

and Motorola Corporations, and so-called PTx ("push-to-anything") devices such as the exemplary PTT (push-to-talk over cellular) devices which establish and tear down SIP or other communications sessions as part of their protocol.

It will be appreciated that while the exemplary embodiments of the invention are described primarily in the context of mobile or client electronic devices, the various aspects of the present invention are in no way so limited, and in fact may be applied to other (e.g., non-mobile and/or non-electronic) devices, whether they include an electrical storage device or otherwise, including without limitation appliances, substantially fixed computer systems, televisions, lighting, and so forth.

Referring now to Fig. 1, one exemplary embodiment of a power transfer system according to the invention is described. In one embodiment, the transmitter 102 of the system may reside within, e.g., a ceiling mounted dome 103 or other such fixture, although mobile applications (e.g., in a car, truck, aircraft, etc.) are also contemplated. The receiver 104 may reside within a device that is capable of using electrical or electromagnetic power and/or wireless charging. The device may comprise, without limitation, at least one of a mobile or cellular telephone, personal data assistant (PDA), portable computer (e.g., a notebook PC), media player, a clock, an electronic display, or any other device that utilizes electric or electromagnetic power; e.g., from a portable source, such as a rechargeable battery.

Mobile devices that are turned on are considered to be active. In the example of a mobile telephone, the mobile telephone is active because it continuously or periodically communicates with its service-provider's local cell tower by, for example, exchanging a handshaking signal. It is this handshaking signal that enables the charging system's transmitter 102 to locate an exact or approximate position of the mobile device and target a concentrated charging beam at its receiver 104 to charge its battery.

In one embodiment, as shown in Inset 1 (106) of Figure 1, multiple mobile devices within the coverage of a single transmitter 102 may be charged concurrently. In another embodiment, as shown in Inset2 (108) of Figure 1, a single mobile device having a built-in receiver 104 may be located within the coverage of and be charged by multiple transmitters 102.

As noted above, the transmitter 102 of the exemplary embodiment is located within, for example, a ceiling dome 103 and powered by, for example, a standard 120 volts AC supply. The transmitter 102 generates signals that carry the charging energy. Signals of various waveforms including, for example, a continuous-wave (CW) single-frequency signal, a sinusoidal wave signal (no harmonics) may be used to carry and deliver the electric power to the receiver 104. In another embodiment, multiple frequency signals may be used. Also, the signal may be of any

InductEV, Inc.
Exhibit 1002
Page 375

frequency and power level suitable for carrying and delivering power sufficient to charge a battery of a mobile device within a range of about 0 – 40 feet, and preferably within a range of 0 – 20 feet. One example of the signal may be a single frequency selected in the microwave band. In one embodiment, the signal may be selected with a frequency between 1 GHz – 40 GHz, and preferably between 12 GHz – 36 GHz. It is desirable to select the transmitter 102 to generate signals of sufficient power to charge the mobile devices wirelessly, while at the same time avoiding undesired results, such as interference with other wireless systems in the vicinity of the transmitter 102. In one embodiment, the transmitter 102 is selected to generate signals at a power level of about 1 to 50 watts. For example, the power of the transmitter 102 may be selected to communicate to a transmitting antenna 105 a signal at a power level of about 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25, 26, 27, 28, 29, 30, 31, 32, 33, 34, 35, 36, 37, 38, 39, 40, 41, 42, 43, 44, 45, 46, 47, 48, 49, or 50 Watts. In another embodiment, signals of lower or higher power may also be used to achieve the delivery of power.

The signal from the transmitter 102 may be fed to the transmitting (TX) antenna 105, which may be omni-directional or directional. In one embodiment, it is desirable to select the TX antenna 105 as a directional antenna, e.g., with a beam-width angle between 0.1 – 20 degrees. For example, the beam-width angle may be selected at about 0.1, 0.2, 0.25, 0.5, 0.75, 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, or 20 degrees. In one embodiment, the TX antenna 105 is configured to emit a signal of about 1 degree in beam width angle, suitable for transmitting signals of frequencies within the 12 GHz to 36 GHz band. The power gain of the TX antenna 105 may be about 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15 or 16 decibels (dB). When using a 12 decibel power gain, the TX antenna 105 may amplify the transmit signal by about 16 times.

In one embodiment, the transmitter 102 also comprises a sensing antenna 107, which is selected to be substantially equally directional as the TX antenna 105. In one embodiment, the sensing antenna 107 is configured to be suitable for sensing signals already transmitted by a mobile device, e.g., signals of frequencies within the 800 to 1900 MHz band. It is however recognized that the sensing antenna 107 may be sensitive to receive and detect a signal in any desired frequency band. The TX antenna 105 and the sensing antenna 107 will, in one embodiment, advantageously point in substantially the same direction and be mounted on a movable assembly 109 that is configured to be adjustable in azimuth (bearing) and elevation (altitude). By pointing in substantially the same direction, the TX antenna 105 can be directed in a direction of a receiver 104 sensed by the sensing antenna 107 thereby emitting the wireless

InductEV, Inc.
Exhibit 1002
Page 376

power signal in a way that optimizes power transfer efficiency between the TX antenna 105 and the RX antenna 113.

In another embodiment, the TX antenna 105 and the sensing antenna 107 can be mounted so as to operate in independent directions. The advantage of such an embodiment is that the TX antenna 105 can, for example, operate independently of the sensing antenna 107. For example, the sensing antenna 107 can advantageously operate in a scanning mode which constantly attempts to reacquire an optimized direction in which the signal emitted by the receiver 104 is maximized thereby providing updated information of e.g. the location of the receiver 104 to a control unit 111. The control unit includes in one exemplary embodiment integrated circuit components (e.g., digital processor, memory, microcontroller, etc.) used to effect control of the apparatus, e.g., according to the principles and methods described herein, such as via control logic or a computer program of the type well known in the art. The TX antenna 105 can therefore maintain a fixed position on the desired direction, while the sensing antenna 107 scans the field, until the control unit 111 informs the TX antenna 105 that the desired transmission direction has changed (e.g. due to movement of the receiver 104, etc.). In this way, the transmission direction of the TX antenna 105 can remain static while the sensing antenna 107 continues to optimize transmission direction.

As previously alluded to, an azimuth/elevation control unit 111 is configured to move the assembly 109 through a search pattern, such as e.g., via the exemplary method 200 illustrated in FIG. 2. Upon detecting an active mobile device by the sensing antenna 107 (e.g., by receiving signals in the 800 - 1900 MHz range), the movable assembly's 109 position may be fine tuned until the sensing antenna 107 receives signals of maximum or close to a maximum received power from the mobile device in step 202. One goal that is achieved with this targeting procedure is to accurately align the TX antenna 105 to ensure that it is pointing directly at the mobile device (e.g., its receiving (RX) antenna 113), thereby achieving maximum transmit-to-receive power capture in step 204. In one embodiment, the procedure 200 may then be optionally repeated after a preset timer value has expired. In another embodiment, the procedure 200 may optionally be repeated once the received power from the mobile device detected in step 202 decreases beyond a predetermined threshold value. In yet another embodiment, the procedure 200 may optionally be repeated continuously so as to continuously reassess the proper direction for the TX antenna 105.

In one embodiment, the azimuth/elevation control unit 111 may be selected to operate in a manner similar to an infrared tracking security camera, except that the control unit 111 is configured to move the assembly 109 in response to a monitored signal (e.g., handshaking

InductEV, Inc.
Exhibit 1002
Page 377

signal) received by the sensing antenna 107 instead of an infrared signal. More particularly, the control unit 111 may be configured to scan for a radio frequency signal within a desired range of frequencies (and power levels) to identify a target device for activating a charging of power via a wireless link 115. The TX antenna 105 and sensing antenna 107 can then move in tandem or move in an independent manner as described previously.

In certain embodiments, the transmitter 102 may also comprise a control unit 111 for charging multiple receivers 104 concurrently. In one embodiment, the transmitter 102 comprises a multiple access scheme (e.g., time division multiple access (TDMA)) control unit 111. The TDMA control unit 111 determines how many active mobile devices lock with the transmitter 102, and coordinates time sharing the power charging among all of the locked mobile devices. It will be appreciated, however, that other multiple access/power transfer schemes may be used consistent with the invention. For example, in one variant, a frequency-divided (e.g., FDMA) system is used, wherein different devices are provided power using different frequencies (which may be narrowband or broadband in nature). Similarly, a frequency-hopped approach can be used, wherein each device to be powered is assigned a hopping code for access to power transmitted over a plurality of frequencies.

In another variant, an approach analogous to "carrier" sense (e.g., CSMA) can be used to effectively "grab" the power delivery channel when not in use by other device, recognizing, however, that in the strict sense, there is no "carrier" *per se* (unless a modulation is optionally applied). In still another variant, a code-divided approach (e.g., CDMA) can be used, so that power is transmitted across a range of frequencies to multiple devices, each of the devices being configured to receive the power transmitted according to their particular spreading code. This selective reception can be accomplished by, e.g., using selective filtering, a receiver which is only sensitive to certain frequencies, or any other techniques well known in the digital communication and multiple access fields. It will be appreciated, however, that unlike the digital communications arts, the apparatus of the present invention can be utilized without modulation if desired; i.e., no data or other modulations need be encoded onto the transferred power unless desired.

Moreover, combinations of the foregoing can be used. For example, in one such possible combination, the time-divided and frequency-divided approaches are combined, such

Referring now to FIG. 3, information may be detected by the sensing antenna 107 that provides information useful in prioritizing time sharing among all of the locked mobile devices using a predetermined algorithm 300. In step 302, the sensing antenna 107 may detect the direction of each of the mobile devices based on e.g. the power level of the respective signals

InductEV, Inc.
Exhibit 1002
Page 378

transmitted by the mobile devices. In step 304, the control unit 111 will parse prioritization information from the signals received from each of the plurality of mobile devices. For example, the sensing antenna 107 may, in one embodiment, receive information indicative a charge level for each of the locked mobile devices. The control unit 111 may then prioritize time sharing amongst the locked mobile devices with the lowest relative charge level in step 306. In another embodiment, the sensing antenna 107 may receive information which is indicative of rate of current power consumption by each of the locked mobile devices. Hence, the control unit 111 may then prioritize time sharing amongst the locked mobile devices so that those mobile devices currently consuming the largest amount of relative power are prioritized first in the time sharing scheme. Any number of other schemes may be utilized individually or in conjunction with one another, based on available information so as to provide an efficient time sharing scheme.

The receiver 104 is configured to receive the signal from the transmitter 102 and supply the same to charge the mobile device. In certain-embodiments, the receiver 104 is built into mobile devices. The receiver 104 comprises a wireless charging receiving antenna 113 which may or may not be the same antenna that mobile devices use to communicate with the cell tower. The wireless charging receiving antenna 113 gathers as much of the beamed radio frequency energy from the transmitter 102 and delivers it to a rectifier 117. The rectifier 117 may be a Germanium-based rectifier characterized by a low barrier or threshold voltage (i.e., low on-power rectifier), to allow activation of the rectifier 117 in the event of receiving a low level signal. The rectifier 117 may also be characterized as a passive RF power sensor to minimize the use of power by the rectifier 117 from the mobile device. In one embodiment, the receiver 104 also comprises a plurality of diodes 119 (e.g., two diodes) which allow the mobile device's battery to be charged by either the wireless charging link 115 or a wired charging path.

The rectifier 117 is configured to convert the AC electrical energy from the antenna to a voltage signal, e.g., a DC voltage signal, suitable for charging the mobile device's battery. In one embodiment, a voltage regulator may be integrated with or in addition to the rectifier to regulate or limit the power supplied to the mobile device at a desired level. The voltage regulator may operate particularly when the physical movement of the mobile device causes the power of the signal received by the RX antenna 113 to vary. This variation may be due to variation in the path of the signal transmitted by the transmitter 102.

The exemplary wireless charging system 100 is configured such that sufficient energy is transmitted and delivered at the receiving antenna 113 for charging. As an illustration, a typical cell phone charger may have a maximum rating of about 4.9 volts and 450 milliamperes (mA). The power rating therefore is about 2.2 watts maximum with 1 watts optimum. For this

InductEV, Inc.
Exhibit 1002
Page 379

illustration, the transmitter 102 may provide an effective charging area of, for example, 1000 square feet. In one embodiment, the transmitter 102 sends out signals of 25 watts power. The transmitting antenna 105 may be designed to be of a 12 decibel power gain amplifies the signal to be of 400 watts power (i.e., equivalent to 16 x 25 watts). Considering that a signal may be subject to a maximum of 20 dB loss over a 20 feet transmission path, a mobile device located 20 feet from the transmitting 102 may receive signals of at least 4 watts, sufficient to charge a typical mobile device. Therefore, this embodiment provides a coverage area of more than 1000 square feet.

It will be recognized that while certain aspects of the invention are described in terms of a specific sequence of steps of a method, these descriptions are only illustrative of the broader methods of the invention, and may be modified as required by the particular application. Certain steps may be rendered unnecessary or optional under certain circumstances. Additionally, certain steps or functionality may be added to the disclosed embodiments, or the order of performance of two or more steps permuted. All such variations are considered to be encompassed within the invention disclosed and claimed herein.

While the above detailed description has shown, described, and pointed out novel features of the invention as applied to various embodiments, it will be understood that various omissions, substitutions, and changes in the form and details of the device or process illustrated may be made by those skilled in the art without departing from the invention. The foregoing description is of the best mode presently contemplated of carrying out the invention. This description is in no way meant to be limiting, but rather should be taken as illustrative of the general principles of the invention. The scope of the invention should be determined with reference to the claims.

InductEV, Inc.
Exhibit 1002
Page 380

WHAT IS CLAIMED IS:

1. Apparatus for providing power to a device via a wireless link, comprising:
a transmitting antenna operative to provide power to said device via said wireless link;
a sensing antenna operative to sense signals transmitted by said device; and
a control unit assembly operative to control the operation of said transmitting antenna.

2. The apparatus of Claim 1, wherein said apparatus is mounted substantially within a ceiling-mounted dome.

3. The apparatus of Claim 1, wherein said control unit assembly is operative to control the movement of said transmitting antenna in at least two degrees of freedom, wherein said at least two degrees of freedom comprise a substantially azimuthal degree of freedom and a substantially elevational degree of freedom.

4. The apparatus of Claim 1, wherein said control unit is operative to charge a plurality of devices via a wireless link according to a time-division multiple access (TDMA) scheme.

5. A method for providing power to a device via a wireless link, comprising:
detecting a first direction for said device using a sensing antenna;
directing a transmission antenna so that it can transmit at least some power in said first direction based at least in part on said act of detecting; and
transmitting substantially unmodulated power from said transmission antenna via said wireless link to said device.

6. A method for providing power to a plurality of devices via a wireless link, said power being transmitted from a transmitting antenna, the method comprising:
disposing said transmitting antenna so that power can be transmitted to said plurality of devices substantially simultaneously; and
transmitting substantially power from said transmission antenna via said wireless link to said plurality of devices according to a multiple access scheme.

7. The method of Claim 6, wherein said multiple access scheme comprises a substantially time-divided scheme.

8. The method of Claim 6, wherein said multiple access scheme comprises a substantially frequency-divided scheme.

9. The method of Claim 6, wherein said multiple access scheme comprises a substantially frequency-hopped scheme.

InductEV, Inc.
Exhibit 1002
Page 381

10. The method of Claim 6, wherein said multiple access scheme comprises a substantially code-divided scheme.

11. The method of Claim 6, wherein said multiple access scheme comprises a sensing scheme wherein a channel is sampled before access is granted.

12. Apparatus for providing power to a plurality of devices via a wireless link, comprising:

a transmitting antenna configured to radiate power, said antenna further comprising apparatus allowing said antenna to selectively transmit power to said plurality of devices;

a power source capable of generating said power for transmission; and

a controller in signal communication with at least one of said antenna and source, said controller being adapted to cause said antenna to transmit said power to said plurality of devices according to a multiple access scheme.

13. The apparatus of Claim 12, wherein said antenna is substantially directional.

14. The apparatus of Claim 13, wherein said multiple access scheme comprises a substantially time-divided scheme.

15. Apparatus for receiving power via a wireless link, said power being useful for providing electrical power to one or more components of said apparatus, comprising:

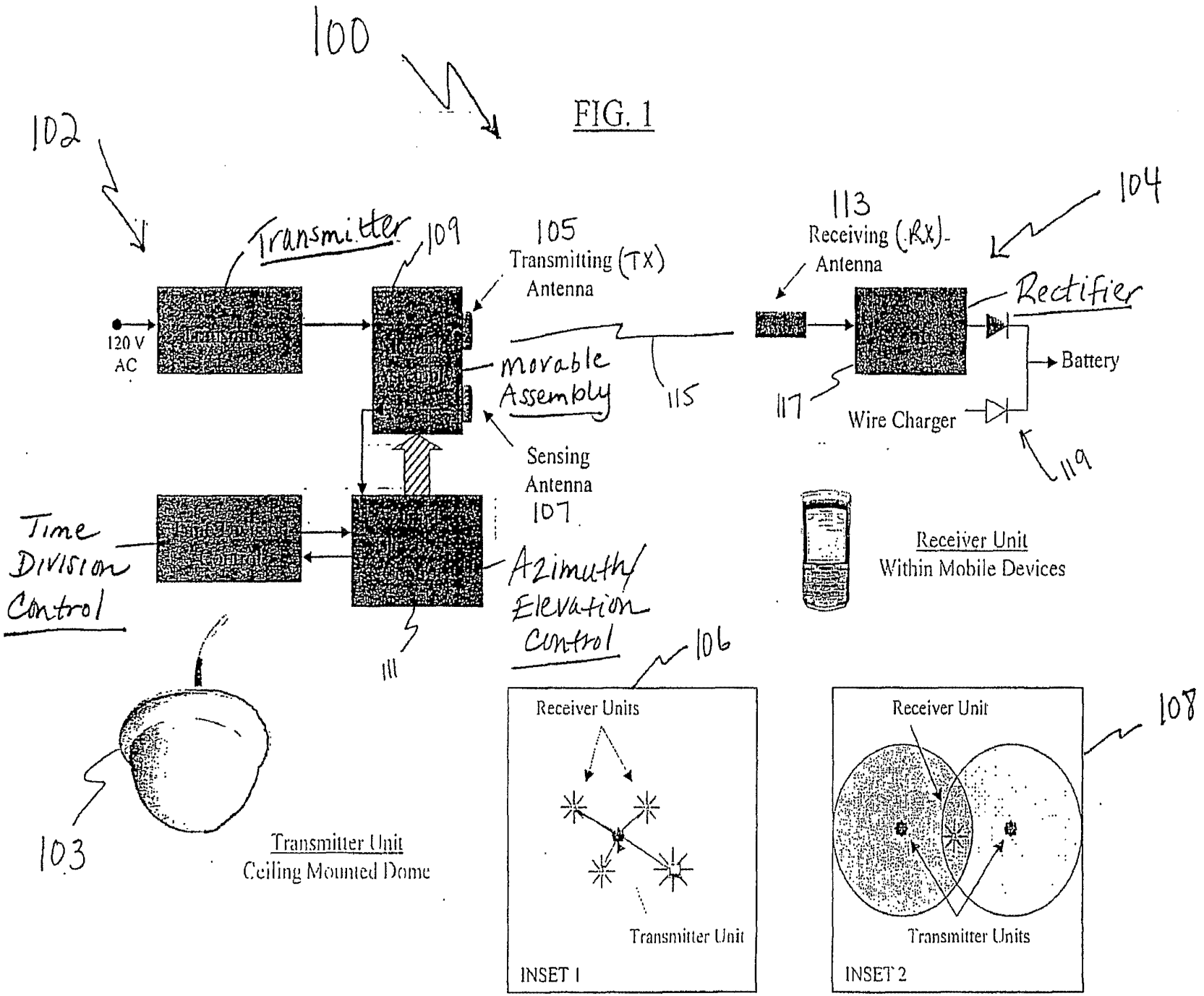
a receiving antenna configured to receive power from a transmitting antenna;

power source apparatus capable of storing at least a portion of said received power for subsequent use; and

a controller in signal communication with at least one of said antenna and source apparatus, said controller being adapted to facilitate selective receipt of said power via said antenna.

16. The apparatus of Claim 15, wherein said selective receipt comprises selective receipt according to a multiple access scheme, wherein devices other than said apparatus also receive power substantially simultaneously with said apparatus receiving power.

InductEV, Inc.
Exhibit 1002
Page 382


100
FIG. 1
102
Transmitter
109
105
Transmitting (TX) Antenna
113
Receiving (Rx) Antenna
104
Rectifier
120 V AC
Movable Assembly
115
Battery
117
Wire Charger
119
Sensing Antenna
107
Time Division Control
Azimuth/ Elevation Control
111
Receiver Unit
Within Mobile Devices
106
Receiver Units
Transmitter Unit
INSET 1
108
Receiver Unit
Transmitter Units
INSET 2
103
Transmitter Unit
Ceiling Mounted Dome

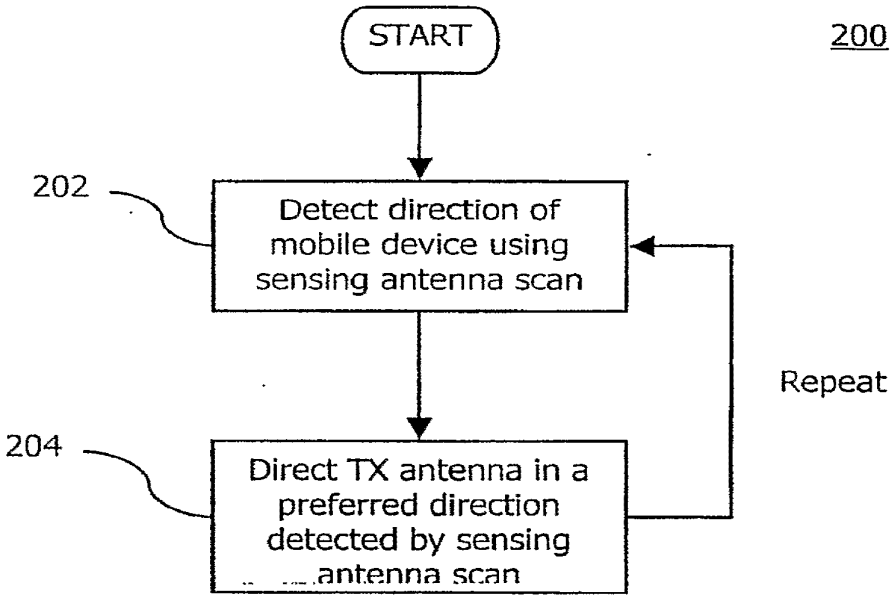

START
200
202
Detect direction of mobile device using sensing antenna scan
Repeat
204
Direct TX antenna in a preferred direction detected by sensing antenna scan

FIG. 2

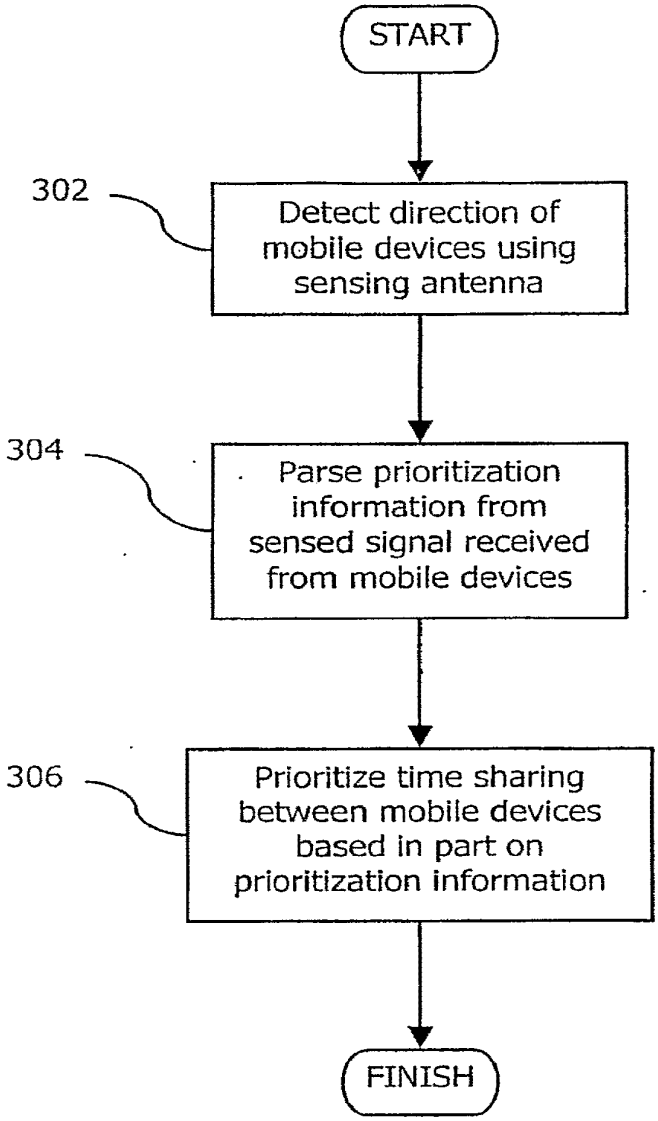

START
300
302
Detect direction of mobile devices using sensing antenna
304
Parse prioritization information from sensed signal received from mobile devices
306
Prioritize time sharing between mobile devices based in part on prioritization information
FINISH

FIG. 3

(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) World Intellectual Property Organization
International Bureau

(43) International Publication Date
26 July 2007 (26.07.2007)

PCT

(10) International Publication Number
WO 2007/084717 A3

(51) International Patent Classification:
H04B 1/38 (2006.01) *H04M 1/00* (2006.01)

(21) International Application Number:
PCT/US2007/001529

(22) International Filing Date: 18 January 2007 (18.01.2007)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:

60/760,064	18 January 2006 (18.01.2006)	US
11/408,793	21 April 2006 (21.04.2006)	US
11/654,883	17 January 2007 (17.01.2007)	US

(71) Applicant *(for all designated States except US)*: **NIGEL POWER LLC.** [US/US]; 11512 El Camino Real, Suite 100, San Diego, CA 92130 (US).

(72) Inventors; and

(75) Inventors/Applicants *(for US only)*: **COOK, Nigel, P.** [GB/US]; 1739 Vakas Drive, El Cajon, CA 92019 (US). **LEVINE, Richard, C.** [US/US]; 7950 Woodstone Lane, Dallas, TX 75248 (US).

(74) Agent: **HARRIS, Scott, C.**; Fish & Richardson P.C., P.O. Box 1022, Minneapolis, MN 55440-1022 (US).

(81) Designated States *(unless otherwise indicated, for every kind of national protection available)*: AE, AG, AL, AM, AT, AU, AZ, BA, BB, BG, BR, BW, BY, BZ, CA, CH, CN, CO, CR, CU, CZ, DE, DK, DM, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IS, JP, KE, KG, KM, KN, KP, KR, KZ, LA, LC, LK, LR, LS, LT, LU, LV, LY, MA, MD, MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PG, PH, PL, PT, RO, RS, RU, SC, SD, SE, SG, SK, SL, SM, SV, SY, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, ZA, ZM, ZW.

(84) Designated States *(unless otherwise indicated, for every kind of regional protection available)*: ARIPO (BW, GH, GM, KE, LS, MW, MZ, NA, SD, SL, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European (AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HU, IE, IS, IT, LT, LU, LV, MC, NL, PL, PT, RO, SE, SI, SK, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, ML, MR, NE, SN, TD, TG).

Declaration under Rule 4.17:

— *as to applicant's entitlement to apply for and be granted a patent (Rule 4.17(ii))*

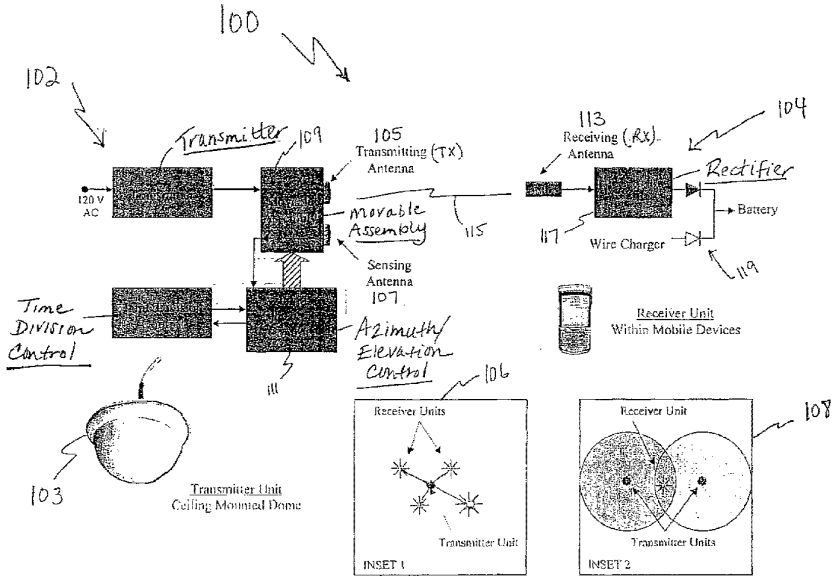
Published:

— *with international search report*

— *before the expiration of the time limit for amending the claims and to be republished in the event of receipt of amendments*

[Continued on next page]

(54) Title: METHOD AND APPARATUS FOR DELIVERING ENERGY TO AN ELECTRICAL OR ELECTRONIC DEVICE VIA A WIRELESS LINK



(57) Abstract: A method and apparatus for providing power to e.g., a chargeable device via a radio frequency link. In one aspect, a method of providing power to a chargeable device via radio frequency link comprises generating a substantially un-modulated signal. The method further comprises radiating a substantially un-modulated radio frequency (RF) signal to the chargeable device via a transmit antenna based on the substantially un-modulated signal. The method further comprises powering or charging the chargeable device with power delivered by the substantially un-modulated RF signal.

WO 2007/084717 A3

(88) Date of publication of the international search report:
13 December 2007

For two-letter codes and other abbreviations, refer to the "Guidance Notes on Codes and Abbreviations" appearing at the beginning of each regular issue of the PCT Gazette.

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US 07/01529

A. CLASSIFICATION OF SUBJECT MATTER
IPC(8) - H04B 1/38; H04M 1/00 (2007.01)
USPC - 455/572
According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
USPC: 455/572

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched
USPC: 455/572

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
PubWEST(USPT,PGPB,EPAB,JPAB); Google Scholar
Search Terms: deliver, transmit, transfer, power, energy, wireless, dome, ceiling, charging, azimuthal, TDMA, frequency, time, divided, code, multiple access scheme, hop, antenna

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X --- Y	US 6,437,685 B2 (HANAKI) 20 August 2002 (20.08.2002), Fig. 3, col 1, ln 41-44, col 2, ln 8-10, col 4, ln 21-28, ln 48-49, col 5, ln 21-23, col 6, ln 49-50, col 7, ln 14-16,ln 40-44, ln 50-52	1-3, 5, 15 --- 4, 6-14, 16
Y	US 2005/0220057 A1 (MONSEN) 06 October 2005 (06.10.2005), [0021], [0022], [0035], [0037]	4, 6-14, 16
A	US 2005/0194926 A1 (DI STEFANO) 08 September 2005 (08.09.2005), entire document	1-16

☐ Further documents are listed in the continuation of Box C. ☐

* Special categories of cited documents:
"A" document defining the general state of the art which is not considered to be of particular relevance
"E" earlier application or patent but published on or after the international filing date
"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)
"O" document referring to an oral disclosure, use, exhibition or other means
"P" document published prior to the international filing date but later than the priority date claimed
"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
24 September 2007 (24.09.2007)	25 OCT 2007
Name and mailing address of the ISA/US Mail Stop PCT, Attn: ISA/US, Commissioner for Patents P.O. Box 1450, Alexandria, Virginia 22313-1450 Facsimile No. 571-273-3201	Authorized officer: Lee W. Young PCT Helpdesk: 571-272-4300 PCT OSP: 571-272-7774

Form PCT/ISA/210 (second sheet) (April 2007)

PATENT COOPERATION TREATY

From the INTERNATIONAL SEARCHING AUTHORITY

To:
ROBERT A. MAZZARESE
STRATEGIC PATENTS, P.C.
C/O INTELLEVATE
P.O. BOX 52050
MINNEAPOLIS, MN 55402

PCT

NOTIFICATION OF TRANSMITTAL OF THE INTERNATIONAL SEARCH REPORT AND THE WRITTEN OPINION OF THE INTERNATIONAL SEARCHING AUTHORITY, OR THE DECLARATION

(PCT Rule 44.1)

	Date of mailing *(day/month/year)*
Applicant's or agent's file reference WTCY0026PWO	**FOR FURTHER ACTION** See paragraphs 1 and 4 below
International application No. PCT/US 09/58499	International filing date *(day/month/year)* 25 September 2009 (25.09.2009)
Applicant WITRICITY CORPORATION	

80157.E92W01

1. ☒ The applicant is hereby notified that the international search report and the written opinion of the International Searching Authority have been established and are transmitted herewith.

   Filing of amendments and statement under Article 19:
   The applicant is entitled, if he so wishes, to amend the claims of the international application (see Rule 46):

   When? The time limit for filing such amendments is normally two months from the date of transmittal of the international search report.

   Where? Directly to the International Bureau of WIPO, 34 chemin des Colombettes 1211 Geneva 20, Switzerland, Facsimile No.: +41 22 338 8270

   For more detailed instructions, see the notes on the accompanying sheet.

2. ☐ The applicant is hereby notified that no international search report will be established and that the declaration under Article 17(2)(a) to that effect and the written opinion of the International Searching Authority are transmitted herewith.

3. ☐ **With regard to the protest** against payment of (an) additional fee(s) under Rule 40.2, the applicant is notified that:

   ☐ the protest together with the decision thereon has been transmitted to the International Bureau together with the applicant's request to forward the texts of both the protest and the decision thereon to the designated Offices.

   ☐ no decision has been made yet on the protest; the applicant will be notified as soon as a decision is made.

4. **Reminders**

   Shortly after the expiration of **18 months** from the priority date, the international application will be published by the International Bureau. If the applicant wishes to avoid or postpone publication, a notice of withdrawal of the international application, or of the priority claim, must reach the International Bureau as provided in Rules 90*bis*.1 and 90*bis*.3, respectively, before the completion of the technical preparations for international publication.

   The applicant may submit comments on an informal basis on the written opinion of the International Searching Authority to the International Bureau. The International Bureau will send a copy of such comments to all designated Offices unless an international preliminary examination report has been or is to be established. These comments would also be made available to the public but not before the expiration of 30 months from the priority date.

   Within **19 months** from the priority date, but only in respect of some designated Offices, a demand for international preliminary examination must be filed if the applicant wishes to postpone the entry into the national phase **until 30 months** from the priority date (in some Offices even later); otherwise, the applicant must, **within 20 months** from the priority date, perform the prescribed acts for entry into the national phase before those designated Offices.

   In respect of other designated Offices, the time limit of **30 months** (or later) will apply even if no demand is filed within 19 months.

   See the Annex to Form PCT/IB/301 and, for details about the applicable time limits, Office by Office, see the *PCT Applicant's Guide*, Volume II, National Chapters and the WIPO Internet site.

Name and mailing address of the ISA/US Mail Stop PCT, Attn: ISA/US Commissioner for Patents P.O. Box 1450, Alexandria, Virginia 22313-1450 Facsimile No. 571-273-3201	Authorized officer: Lee W. Young PCT Helpdesk: 571-272-4300 PCT OSP: 571-272-7774

Form PCT/ISA/220 (January 2004) *(See notes on accompanying sheet)*

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PATENT COOPERATION TREATY

From the INTERNATIONAL SEARCHING AUTHORITY

To:
ROBERT A. MAZZARESE
STRATEGIC PATENTS, P.C.
C/O INTELLEVATE
P.O. BOX 52050
MINNEAPOLIS, MN 55402

PCT

NOTIFICATION OF TRANSMITTAL OF THE INTERNATIONAL SEARCH REPORT AND THE WRITTEN OPINION OF THE INTERNATIONAL SEARCHING AUTHORITY, OR THE DECLARATION

(PCT Rule 44.1)

	Date of mailing *(day/month/year)* 10 DEC 2009
Applicant's or agent's file reference WTCY0026PWO	**FOR FURTHER ACTION** See paragraphs 1 and 4 below
International application No. PCT/US 09/58499	International filing date *(day/month/year)* 25 September 2009 (25.09.2009)
Applicant WITRICITY CORPORATION	

1. ☒ The applicant is hereby notified that the international search report and the written opinion of the International Searching Authority have been established and are transmitted herewith.

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   The applicant is entitled, if he so wishes, to amend the claims of the international application (see Rule 46):

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   Where? Directly to the International Bureau of WIPO, 34 chemin des Colombettes 1211 Geneva 20, Switzerland, Facsimile No.: +41 22 338 8270

   For more detailed instructions, see the notes on the accompanying sheet.

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   ☐ the protest together with the decision thereon has been transmitted to the International Bureau together with the applicant's request to forward the texts of both the protest and the decision thereon to the designated Offices.

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   Within **19 months** from the priority date, but only in respect of some designated Offices, a demand for international preliminary examination must be filed if the applicant wishes to postpone the entry into the national phase **until 30 months** from the priority date (in some Offices even later); otherwise, the applicant must, **within 20 months** from the priority date, perform the prescribed acts for entry into the national phase before those designated Offices.

   In respect of other designated Offices, the time limit of **30 months** (or later) will apply even if no demand is filed within 19 months.

   See the Annex to Form PCT/IB/301 and, for details about the applicable time limits, Office by Office, see the *PCT Applicant's Guide*, Volume II, National Chapters and the WIPO Internet site.

Name and mailing address of the ISA/US Mail Stop PCT, Attn: ISA/US Commissioner for Patents P.O. Box 1450, Alexandria, Virginia 22313-1450 Facsimile No. 571-273-3201	Authorized officer: Lee W. Young PCT Helpdesk: 571-272-4300 PCT OSP: 571-272-7774

Form PCT/ISA/220 (January 2004) *(See notes on accompanying sheet)*

PATENT COOPERATION TREATY

PCT

INTERNATIONAL SEARCH REPORT

(PCT Article 18 and Rules 43 and 44)

Applicant's or agent's file reference WTCY0026PWO	**FOR FURTHER ACTION**	see Form PCT/ISA/220 as well as, where applicable, item 5 below.
International application No. PCT/US 09/58499	International filing date *(day/month/year)* 25 September 2009 (25.09.2009)	(Earliest) Priority Date *(day/month/year)* 27 September 2008 (27.09.2008)
Applicant WITRICITY CORPORATION		

This international search report has been prepared by this International Searching Authority and is transmitted to the applicant according to Article 18. A copy is being transmitted to the International Bureau.

This international search report consists of a total of 2 sheets.

☐ It is also accompanied by a copy of each prior art document cited in this report.

1. **Basis of the report**

   a. With regard to the **language**, the international search was carried out on the basis of:

   ☒ the international application in the language in which it was filed.

   ☐ a translation of the international application into _____ which is the language of a translation furnished for the purposes of international search (Rules 12.3(a) and 23.1(b)).

   b. ☐ This international search report has been established taking into account the **rectification of an obvious mistake** authorized by or notified to this Authority under Rule 91 (Rule 43.6*bis*(a)).

   c. ☐ With regard to any **nucleotide and/or amino acid sequence** disclosed in the international application, see Box No. I.

2. ☐ **Certain claims were found unsearchable** (see Box No. II).

3. ☐ **Unity of invention is lacking** (see Box No. III).

4. With regard to the **title**,

   ☒ the text is approved as submitted by the applicant.

   ☐ the text has been established by this Authority to read as follows:

5. With regard to the **abstract**,

   ☒ the text is approved as submitted by the applicant.

   ☐ the text has been established, according to Rule 38.2, by this Authority as it appears in Box No. IV. The applicant may, within one month from the date of mailing of this international search report, submit comments to this Authority.

6. With regard to the **drawings**,

   a. the figure of the **drawings** to be published with the abstract is Figure No. 1

   ☒ as suggested by the applicant.

   ☐ as selected by this Authority, because the applicant failed to suggest a figure.

   ☐ as selected by this Authority, because this figure better characterizes the invention.

   b. ☐ none of the figures is to be published with the abstract.

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US 09/58499

A. CLASSIFICATION OF SUBJECT MATTER
IPC(8) - H03B 19/00 (2009.01)
USPC - 327/113
According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
USPC: 327/113

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched
USPC: 327/113, 306, 530, 555; 375/323; 307/134 (keyword limited - see terms below)

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
PubWEST (PGPB, USPT, USOC, EPAB, JPAB); GOOGLE
Search Terms: energy, power, power generator, generator, wireless, resonator, first resonator, second resonator, third resonator, Q-factor, distance, tunable, oscillating, impedance, capacitance, load

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	US 2007/0222542 A1 (Joannopoulos et al.) 27 September 2007 (27.09.2007), entire document, especially; abstract, para. [0004], [0005], [0013], [0014], [0019], [0023], [0025], [0029], [0033]	1 - 26
Y	US 6,452,465 B1 (Brown et al.) 17 September 2002 (17.09.2002), entire document, especially; abstract, col. 2, ln 4-6, col. 3, ln 7-12, 66-67	1 - 26

☐ Further documents are listed in the continuation of Box C. ☐

* Special categories of cited documents:
"A" document defining the general state of the art which is not considered to be of particular relevance
"E" earlier application or patent but published on or after the international filing date
"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)
"O" document referring to an oral disclosure, use, exhibition or other means
"P" document published prior to the international filing date but later than the priority date claimed
"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
24 November 2009 (24.11.2009)	10 DEC 2009
Name and mailing address of the ISA/US Mail Stop PCT, Attn: ISA/US, Commissioner for Patents P.O. Box 1450, Alexandria, Virginia 22313-1450 Facsimile No. 571-273-3201	Authorized officer: Lee W. Young PCT Helpdesk: 571-272-4300 PCT OSP: 571-272-7774

Form PCT/ISA/210 (second sheet) (July 2009)

PATENT COOPERATION TREATY

From the
INTERNATIONAL SEARCHING AUTHORITY

To: ROBERT A. MAZZARESE
STRATEGIC PATENTS, P.C.
C/O INTELLEVATE
P.O. BOX 52050
MINNEAPOLIS, MN 55402

PCT

WRITTEN OPINION OF THE
INTERNATIONAL SEARCHING AUTHORITY

(PCT Rule 43*bis*.1)

Date of mailing *(day/month/year)*	10 DEC 2009

Applicant's or agent's file reference	FOR FURTHER ACTION
WTCY0026PWO	See paragraph 2 below

International application No.	International filing date *(day/month/year)*	Priority date *(day/month/year)*
PCT/US 09/58499	25 September 2009 (25.09.2009)	27 September 2008 (27.09.2008)

International Patent Classification (IPC) or both national classification and IPC
IPC(8) - H03B 19/00 (2009.01)
USPC - 327/113

Applicant WITRICITY CORPORATION

1. This opinion contains indications relating to the following items:

- [X] Box No. I Basis of the opinion
- [ ] Box No. II Priority
- [ ] Box No. III Non-establishment of opinion with regard to novelty, inventive step and industrial applicability
- [ ] Box No. IV Lack of unity of invention
- [X] Box No. V Reasoned statement under Rule 43*bis*.1(a)(i) with regard to novelty, inventive step or industrial applicability; citations and explanations supporting such statement
- [ ] Box No. VI Certain documents cited
- [ ] Box No. VII Certain defects in the international application
- [ ] Box No. VIII Certain observations on the international application

2. **FURTHER ACTION**

If a demand for international preliminary examination is made, this opinion will be considered to be a written opinion of the International Preliminary Examining Authority ("IPEA") except that this does not apply where the applicant chooses an Authority other than this one to be the IPEA and the chosen IPEA has notified the International Bureau under Rule 66.1*bis*(b) that written opinions of this International Searching Authority will not be so considered.

If this opinion is, as provided above, considered to be a written opinion of the IPEA, the applicant is invited to submit to the IPEA a written reply together, where appropriate, with amendments, before the expiration of 3 months from the date of mailing of Form PCT/ISA/220 or before the expiration of 22 months from the priority date, whichever expires later.

For further options, see Form PCT/ISA/220.

3. For further details, see notes to Form PCT/ISA/220.

Name and mailing address of the ISA/US	Date of completion of this opinion	Authorized officer:
Mail Stop PCT, Attn: ISA/US Commissioner for Patents P.O. Box 1450, Alexandria, Virginia 22313-1450 Facsimile No. 571-273-3201	27 November 2009 (27.11.2009)	Lee W. Young PCT Helpdesk: 571-272-4300 PCT OSP: 571-272-7774

Form PCT/ISA/237 (cover sheet) (July 2009)

WRITTEN OPINION OF THE INTERNATIONAL SEARCHING AUTHORITY

International application No.
PCT/US 09/58499

Box No. I Basis of this opinion

1. With regard to the **language**, this opinion has been established on the basis of:

   ☒ the international application in the language in which it was filed.

   ☐ a translation of the international application into _____ which is the language of a translation furnished for the purposes of international search (Rules 12.3(a) and 23.1(b)).

2. ☐ This opinion has been established taking into account the **rectification of an obvious mistake** authorized by or notified to this Authority under Rule 91 (Rule 43*bis*.1(a))

3. With regard to any **nucleotide and/or amino acid sequence** disclosed in the international application, this opinion has been established on the basis of a sequence listing filed or furnished:

   a. (means)

      ☐ on paper

      ☐ in electronic form

   b. (time)

      ☐ in the international application as filed

      ☐ together with the international application in electronic form

      ☐ subsequently to this Authority for the purposes of search

4. ☐ In addition, in the case that more than one version or copy of a sequence listing has been filed or furnished, the required statements that the information in the subsequent or additional copies is identical to that in the application as filed or does not go beyond the application as filed, as appropriate, were furnished.

5. Additional comments:

InductEV, Inc.
Exhibit 1002
Page 394

WRITTEN OPINION OF THE INTERNATIONAL SEARCHING AUTHORITY

International application No.
PCT/US 09/58499

Box No. V **Reasoned statement under Rule 43*bis*.1(a)(i) with regard to novelty, inventive step or industrial applicability; citations and explanations supporting such statement**

1. Statement

Novelty (N)	Claims	1 - 26	YES
	Claims	None.	NO
Inventive step (IS)	Claims	None.	YES
	Claims	1 - 26	NO
Industrial applicability (IA)	Claims	1 - 26	YES
	Claims	None.	NO

2. Citations and explanations:

Claims 1 - 26 lack an inventive step under PCT Article 33(3) as being obvious over US 2007/0222542 A1 to Joannopoulos et al. (hereinafter 'Joannopoulos'), in view of US 6,452,465 B1 to Brown et al. (hereinafter 'Brown').

Regarding claim 1, Joannopoulos teaches a system, comprising: a source resonator having a Q-factor Q1 and a characteristic size X1 (abstract, para. [0005]), coupled to a power generator (external power supply, para. [0005]), and a second resonator having a Q-factor Q2 and a characteristic size X2 (para. [0005]), coupled to a load located a distance D from the source resonator (distance between the two resonators can be larger than the characteristic size of each resonator, para. [0005]), wherein the source resonator and the second resonator are coupled to exchange energy wirelessly among the source resonator and the second resonator (abstract, para. [0004], [0013]). Joannopoulos does not teach that the square root of Q1Q2 > 100. However, Brown teaches multiple resonators that are tunable (abstract), and that filters may be fabricated with low quality factor resonators (col. 2, ln 4-6). It would have been obvious to one skilled in the art to combine the teachings of Joannopoulos with those of Brown in order to provide an inexpensive resonator structure. Neither Joannopoulos nor Brown specifically teach that the square root of Q1Q2 > 100. However, this configuration could have been determined via routine experimentation, and provided based on the specific application of the system.

Regarding claims 2 and 3, neither Joannopoulos nor Brown teaches that Q1 (or Q2 - claim 3) < 100. However, it was well known it the art at the time of the invention that resonator materials were available with low quality factors, e.g. Q1 (or Q2 - claim 3) < 100. It would have been obvious to one skilled in the art to provide Q1 (or Q2 - claim 3) < 100, in order to provide an inexpensive resonator structure.

Regarding claims 4 and 5, neither Joannopoulos nor Brown specifically teaches a third resonator having a Q-factor Q3 configured to transfer energy non-raditively with the source and second resonators, wherein the square root of Q1Q3 > 100 and the square root of Q2Q3 > 100, wherein Q3 < 100 (claim - 5). However, this configuration could have been determined via routine experimentation, and provided based on the specific application of the system.

Regarding claim 6, Joannopoulos teaches that the source resonator is coupled to the power generator with direct electrical connections (para. [0014]).

Regarding claim 7, Joannopoulos teaches that the source resonator is coupled and impedance matched to the power generator with direct electrical connections (para. [0014]).

Regarding claim 8, Brown teaches a tunable circuit wherein the source resonator is coupled to the power generator through the tunable circuit with direct electrical connections (abstract, col. 3, ln 7-12).

Regarding claim 9, Joannopoulos teaches that at least one of the direct electrical connections is configured to substantially preserve a resonant mode of the source resonator (resonant cavity, para. [0033]).

Regarding claim 10, neither Joannopoulos nor Brown specifically teaches that the source resonator has a first terminal, a second terminal, and a center terminal, and wherein an impedance between the first terminal and the center terminal and between the second terminal and the center terminal are substantially equal. However, this configuration could have been determined via routine experimentation and provided to maximize power transfer.

Regarding claim 11, Joannopoulos teaches that the source resonator includes a capacitive loaded loop having a first terminal, a second terminal, and a center terminal (para. [0019]), and wherein an impedance between the first terminal and the center terminal and between the second terminal and the center terminal are substantially equal (para. [0019]).

Regarding claim 12, neither Joannopoulos nor Brown specifically teaches that the source resonator is coupled to an impedance matching network and the impedance matching network further comprises a first terminal, a second terminal, and a center terminal, and wherein an impedance between the first terminal and the center terminal and between the second terminal and the center terminal are substantially equal. However, this configuration could have been determined via routine experimentation and provided to maximize power transfer.

---(continued in Supplemental Box)---

Supplemental Box

In case **the space in any of the preceding boxes is not sufficient.**
Continuation of:

V.2 Citations and explanations:

Regarding claim 13, neither Joannopoulos nor Brown teaches that the first terminal and the second terminal are directly coupled to the power generator and driven with oscillating signals that are near 180 degrees out of phase. However, this configuration was well known in the art at the time of the invention, and could have been provided based on the specific application.

Regarding claim 14, Joannopoulos teaches that the source resonator has a resonant frequency WI and the first terminal and the second terminal are directly coupled to the power generator and driven with oscillating signals that are substantially equal to the resonant frequency omega sub 1 (para. [0023], [0025]).

Regarding claim 15, neither Joannopoulos nor Brown specifically that the center terminal is connected to an electrical ground. However, this configuration was well known in the art at the time of the invention, and could have been provided in order to provide a voltage reference point.

Regarding claim 16, neither Joannopoulos nor Brown teach that the source resonator has a resonant frequency omega sub 1 and the first terminal and the second terminal are directly coupled to the power generator and driven with a frequency substantially equal to the resonant frequency omega sub 1. However, this configuration could have been determined via routine experimentation and provided to maximize power transfer.

Regarding claim 17, Brown teaches a plurality of capacitors coupled to the power generator and the load (col., 3, ln 66-67).

Regarding claim 18, Joannopoulos that the source resonator and the second resonator are each enclosed in a low loss tangent material (para. [0023]).

Regarding claim 19, Joannopoulos teaches a power conversion circuit wherein the second resonator is coupled to the power conversion circuit to deliver DC power to the load (abstract).

Regarding claim 20, Joannopoulos teaches a power conversion circuit wherein the second resonator is coupled to the power conversion circuit to deliver AC power to the load (power, abstract, para. [0029]).

Regarding claim 21, Joannopoulos teaches a power conversion circuit, wherein the second resonator is coupled to the power conversion circuit to deliver both AC and DC power to the load (power, abstract, para. [0029]).

Regarding claim 22, Joannopoulos teaches a power conversion circuit and a plurality of loads, wherein the second resonator is coupled to the power conversion circuit (abstract), and the power conversion circuit is coupled to the plurality of loads (abstract).

Regarding claim 23, Brown teaches the system, wherein the impedance matching network comprises capacitors (col., 3, ln 66-67).

Regarding claim 24, Joannopoulos teaches that the impedance matching network comprises inductors (coils, para. [0025]).

Regarding claim 25, Brown teaches that the tunable circuit comprises variable capacitors (col., 3, ln 66-67).

Regarding claim 26, Joannopoulos teaches that the tunable circuit comprises variable inductors (para. [0025]).

Claims 1 - 26 have industrial applicability as defined by PCT Article 33(4) because the subject matter can be made or used in industry.

NOTES TO FORM PCT/ISA/220

These Notes are intended to give the basic instructions concerning the filing of amendments under Article 19. The Notes are based on the requirements of the Patent Cooperation Treaty, the Regulations and the Administrative Instructions under that Treaty. In case of discrepancy between these Notes and those requirements, the latter are applicable. For more detailed information, see also the *PCT Applicant's Guide*.

In these Notes, "Article," "Rule" and "Section" refer to the provisions of the PCT, the PCT Regulations and the PCT Administrative Instructions, respectively.

INSTRUCTIONS CONCERNING AMENDMENTS UNDER ARTICLE 19

The applicant has, after having received the international search report and the written opinion of the International Searching Authority, one opportunity to amend the claims of the international application. It should however be emphasized that, since all parts of the international application (claims, description and drawings) may be amended during the international preliminary examination procedure, there is usually no need to file amendments of the claims under Article 19 except where, e.g. the applicant wants the latter to be published for the purposes of provisional protection or has another reason for amending the claims before international publication. Furthermore, it should be emphasized that provisional protection is available in some States only (see *PCT Applicant's Guide*, Annex B).

The attention of the applicant is drawn to the fact that amendments to the claims under Article 19 are not allowed where the International Searching Authority has declared, under Article 17(2), that no international search report would be established (see *PCT Applicant's Guide*, International Phase, paragraph 296).

What parts of the international application may be amended?

Under Article 19, only the claims may be amended.

During the international phase, the claims may also be amended (or further amended) under Article 34 before the International Preliminary Examining Authority. The description and drawings may only be amended under Article 34 before the International Preliminary Examining Authority.

Upon entry into the national phase, all parts of the international application may be amended under Article 28 or, where applicable, Article 41.

When? Within 2 months from the date of transmittal of the international search report or 16 months from the priority date, whichever time limit expires later. It should be noted, however, that the amendments will be considered as having been received on time if they are received by the International Bureau after the expiration of the applicable time limit but before the completion of the technical preparations for international publication (Rule 46.1).

Where not to file the amendments?

The amendments may only be filed with the International Bureau and not with the receiving Office or the International Searching Authority (Rule 46.2).

Where a demand for international preliminary examination has been/is filed, see below.

How? Either by cancelling one or more entire claims, by adding one or more new claims or by amending the text of one or more of the claims as filed.

A replacement sheet or sheets containing a complete set of claims in replacement of all the claims previously filed must be submitted.

Where a claim is cancelled, no renumbering of the other claims is required. In all cases where claims are renumbered, they must be renumbered consecutively in Arabic numerals (Section 205(a)).

The amendments must be made in the language in which the international application is to be published.

What documents must/may accompany the amendments?

Letter (Section 205(b)):

The amendments must be submitted with a letter.

The letter will not be published with the international application and the amended claims. It should not be confused with the "Statement under Article 19(1)" (see below, under "Statement under Article 19(1)").

The letter must be in English or French, at the choice of the applicant. However, if the language of the international application is English, the letter must be in English; if the language of the international application is French, the letter must be in French.

InductEV, Inc.
Exhibit 1002
Page 397

ons concerning several claims may be grouped), whether

he claim is unchanged;

he claim is cancelled;

he claim is new;

he claim replaces one or more claims as filed;

ne claim is the result of the division of a claim as filed.

)les illustrate the manner in which amendments must be explained in the accompanying

there were 48 claims and after amendment of some claims there are 51]:
31, 32, 34, 35, 37 to 48 replaced by amended claims bearing the same numbers;
36 unchanged; new claims 49 to 51 added."

there were 15 claims and after amendment of all claims there are 11]:
:placed by amended claims 1 to 11."

there were 14 claims and the amendments consist in cancelling some claims and in adding

1 14 unchanged; claims 7 to 13 cancelled; new claims 15, 16 and 17 added." or
ncelled; new claims 15, 16 and 17 added; all other claims unchanged."

nds of amendments are made]:
anged; claims 11 to 13, 18 and 19 cancelled; claims 14, 15 and 16 replaced by amended
7 subdivided into amended claims 15, 16 and 17; new claims 20 and 21 added."

-ticle 19(1)" (Rule 46.4)

be accompanied by a statement explaining the amendments and indicating any impact that
ht have on the description and the drawings (which cannot be amended under Article 19(1)).

published with the international application and the amended claims.

guage in which the international application is to be published.

ceeding 500 words if in English or if translated into English.

ed with and does not replace the letter indicating the differences between the claims as filed
ust be filed on a separate sheet and must be identified as such by a heading, preferably by
ment under Article 19(1)."

y disparaging comments on the international search report or the relevance of citations
t. Reference to citations, relevant to a given claim, contained in the international search
ly in connection with an amendment of that claim.

ternational preliminary examination has already been filed

g any amendments and any accompanying statement, under Article 19, a demand for
ry examination has already been submitted, the applicant must preferably, at the time of
(and any statement) with the International Bureau, also file with the International
Authority a copy of such amendments (and of any statement) and, where required, a
endments for the procedure before that Authority (see Rules 55.3(a) and 62.2, first
information, see the Notes to the demand form (PCT/IPEA/401).

ional preliminary examination is made, the written opinion of the International Searching
in certain cases where the International Preliminary Examining Authority did not act as
Authority and where it has notified the International Bureau under Rule 66.1*bis*(b), be
n opinion of the International Preliminary Examining Authority. If a demand is made, the
the International Preliminary Examining Authority a reply to the written opinion together,
h amendments before the expiration of 3 months from the date of mailing of Form
he expiration of 22 months from the priority date, whichever expires later (Rule 43*bis*.1(c)).

slation of the international application for entry into the national phase

n is drawn to the fact that, upon entry into the national phase, a translation of the claims as
19 may have to be furnished to the designated/elected Offices, instead of, or in addition to,
ims as filed.

the requirements of each designated/elected Office, see the *PCT Applicant's Guide*.

InductEV, Inc.
Exhibit 1002
Page 398

SEQUENCE LISTINGS AND TABLES RELATED THERETO IN INTERNATIONAL APPLICATIONS FILED IN THE U.S. RECEIVING OFFICE

The Administrative Instructions (AIs) under the Patent Cooperation Treaty (PCT), in force as of **July 1, 2009**, contain important changes relating to the manner of filing, and applicable fees for, sequence listings and/or tables related thereto (sequence-related tables) in international applications. The complete text may be accessed at http://www.wipo.int/pct/en/texts/index.htm.

Effective **July 1, 2009**, Part 8 and Annex C-*bis* will no longer form part of the AIs. Part 8 was introduced in 2001 as a temporary solution to problems arising from the filing of very large sequence listings on paper and provided for a *sequence listing forming part of the international application* to be filed in electronic form on physical medium (*e.g.*, CD), together with the remainder of the application on paper. In 2002, Part 8 was expanded to include sequence-related tables and Annex C-*bis* was added to provide technical requirements. All applicants may now file complete international applications in electronic form, eliminating the need for these temporary provisions.

I. AIS PART 8 AND ANNEX C-*BIS DELETED AS OF JULY 1, 2009*

A) **Sequence-related tables cannot be filed as a separate part of the description or in text format.** They must be provided as an integral part of the international application either:
- in PDF format as part of an international application filed in electronic form via EFS-Web; or
- on paper as part of an international application filed on paper.

B) A ***sequence listing forming part of an international application*** may be provided either:
- in electronic form, as part of an international application filed in electronic form via EFS-Web, in
  - Annex C/ST.25 text format (preferred), or
  - PDF format; or
- on paper as part of an international application filed on paper.

C) **A *sequence listing not forming part of the international application* (for search under PCT Rule 13*ter*) in Annex C/ST.25 text format**
- is not required where the *sequence listing forming part of the international application* was filed in Annex C/ST.25 text format as part of an international application filed in electronic form via EFS-Web
- is required for search where the *sequence listing forming part of the international application* was filed in PDF
- is required for search on physical medium (*e.g.*, CD) where the *sequence listing forming part of the international application* was filed on paper as part of an international application filed on paper.

II. CALCULATION OF THE INTERNATIONAL FILING FEE AND FEE REDUCTION UNDER AI § 707

A) A **sequence-related table** must form an integral part of the international application and will incur FULL page fees with no upper limit.

B) A ***sequence listing forming part of an international application*** filed:
- via EFS-Web in Annex C/ST.25 text format will incur NO page fees;
- on paper or in PDF format will incur FULL page fees with no upper limit.

III. AVAILABILITY OF SEQUENCE LISTINGS SUBMITTED FOR SEARCH UNDER PCT RULE *13TER*

International Searching Authorities will be required to transmit to the International Bureau a copy of an Annex C/ST.25 text format sequence listing provided for search under PCT Rule 13*ter*. Any such sequence listing will be made available on PATENTSCOPE® (*sequence listings forming part of the international application* are already available).

IV. JULY 2009 REQUEST (PCT/RO/101)

The Request now has two options for the last sheet: one for paper filings; and one for EFS-Web filings. The July 2009 Request may be accessed at http://www.wipo.int/pct/en/forms/index.htm