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CONFIRMATION NO. 6672

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## FILING RECEIPT



Date Mailed: 08/07/2008

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**\*\* SMALL ENTITY \*\***

Title

Inductive feedback

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| INVENTOR(S)                            |                        |                                                         |
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| Alfred                                 | Leibovitz              | Petach Tikva, Israel                                    |

Additional inventors are being named on the \_\_\_\_\_ separately numbered sheets attached hereto

**TITLE OF THE INVENTION (500 characters max):**

Inductive Feedback

Direct all correspondence to: **CORRESPONDENCE ADDRESS**

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**OR**

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**ENCLOSED APPLICATION PARTS (check all that apply)**

☐ Application Data Sheet. See 37 CFR 1.76

☒ Drawing(s) Number of Sheets 4

☒ Specification (e.g. description of the invention) Number of Pages 14

☐ CD(s), Number of CDs \_\_\_\_\_

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**PROVISIONAL APPLICATION COVER SHEET**  
**Page 2 of 2**

PTO/SB/16 (07-07)

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SIGNATURE /Yossi Azancot/ /Amir Ben Shalom/ /Arik Rofe/ /Oola Greenwald/ /Alfred Leibovitz/

Date 24<sup>th</sup> July 2008

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Docket Number 1052-44

## **Inductive Feedback**

### **Field of the Invention**

The present invention is directed to providing a communications channel for the transfer of feedback signals in inductive power transfer systems. More specifically, the present invention relates to coil-to-coil signal transfer in inductive power couplings.

### **Background**

When providing power to electric devices it may be desirable to provide a channel for signal transfer. This may be useful for power regulation or load authentication for example. Thus a communication channel is often provided alongside the power input channel. Known methods for providing such a communication channel include wired connections to the device, which may be packaged within the same cable as the power lines.

Devices such as transformers and induction connectors transfer energy between primary and secondary coils by induction. In such systems, feedback from the device to the power source is necessary, in order to regulate the power provided to a load via the secondary coil. However in applications where the primary coil and secondary coil must remain galvanically isolated from one another, a wired connection is inherently unsuitable.

Systems for the transfer of signals between galvanically isolated elements of a circuit are known. For example, an optical signal may be transmitted from an optical transmitter, such as a light emitting diode, over a short optical path to a galvanically isolated receiver, such as a photo-transistor which may convert the optical signal into an electrical signal. Such system require an optical line-of-sight between transmitter and receiver which may be inappropriate.

United States Patent No. 5,455,466 titled, "Inductive coupling system for power and data transfer" to Terry J. Parks and David S. Register describes a system for inductively coupling power and data to a portable electronic device. The portable device, such as a personal digital assistant (PDA), is powered or recharged via an inductive link between the device and a support unit. The same inductive link is also used to transfer data signals between the device and a second electronic device, such as a conventional desktop computer. The support unit includes a primary winding of a

transformer, a power amplifier and a modulator. The portable device includes a secondary winding connected in parallel with the input of a rectifier, the output of which is connected to a battery charging circuit, and to a modem, which is further connected to the device microprocessor. Placement of the device on the support unit  
5 effects the inductive coupling when the primary and secondary windings are in proximity to one another. Parks' system is thus directed to providing a data channel for synchronizing two data storage devices for example a PDA and a computer.

In Parks' system data transfer from the primary winding to the secondary winding may be provided by modulating the power signal. This requires a separate  
10 data signal to be transmitted by the secondary winding which is induced in the primary winding. Power transmission must therefore be interrupted in order to transmit data signals from the secondary winding to the primary winding. As a result, Parks' system does not offer any solution to providing a feedback signal for the regulation of uninterrupted inductive power transfer to an electric load.

15 The need remains for a signal transfer system for transferring feedback signals between an electric load and an inductive power outlet, which does not require alignment of the signal transmitter and the signal receiver, and the present invention addresses this need.

20

## Summary of the Invention

It is an aim of the invention to provide a signal transfer system for an inductive power transfer system, the inductive power transfer system comprising at least one primary inductive coil for forming an inductive couple with at least one secondary inductive coil wired to an electric load. The primary inductive coil is wired to a power supply via a driver configured to provide a driving voltage across the primary inductive coil. The driving voltage oscillates at a transmission frequency higher than the resonant frequency of the inductive couple. The primary inductive coil is further wired to a reception circuit comprising a voltage monitor for monitoring the amplitude of a primary voltage across the primary coil. The secondary inductive coil is further wired to a transmission circuit for connecting at least one electric element to the secondary inductive coil thereby increasing the resonant frequency.

In preferred embodiments the secondary inductive coil is wired to two inputs of a bridge rectifier, the electric load is wired to two outputs of said bridge rectifier and the transmission circuit is wired to one input of said bridge rectifier and one output of said bridge rectifier.

The transmission circuit may further comprise a modulator for modulating a bit-rate signal with an input signal to create a modulated signal and a switch for intermittently connecting said electrical element to said secondary inductive coil according to said modulated signal.

Optionally, the voltage monitor further comprises a correlator for cross-correlating the amplitude of said primary voltage with said bit-rate signal for producing an output signal.

Variously, the signal transfer system may transfer data pertaining to at least one of the group comprising:

- presence of said electric load;
- location of said secondary inductive coil;
- required operating voltage for said electric load;
- required operating current for said electric load;
- required operating temperature for said electric load;

- required operating power for said electric load;
- measured operating voltage for said electric load;
- measured operating current for said electric load;
- measured operating temperature for said electric load;
- 5       ▪ measured operating power for said electric load;
- power delivered to said primary inductive coil;
- power received by said secondary inductive coil, and
- a user identification code.

10       Typically, the signal transfer system transfers a feedback signal from said secondary inductive coil to said primary inductive coil for regulating power transfer across an inductive power coupling. In some embodiments, the driver being configured to adjust said transmission frequency in response to said feedback signals.

Preferably, the system is adapted to transfer a first signal and a second signal, and said driver is configured to:

- 15       ▪ increase said transmission frequency when said first signal is received by the receiver, and
- decrease said transmission frequency when said second signal is received by the receiver.

20       Optionally, the system comprises a power converter selected from the group comprising: a transformer, a DC-to-DC converter, an AC-to-DC converter, an AC-to-AC converter, a flyback transformer, a flyback converter, a full-bridge converter, a half-bridge converter and a forward converter.

25       It is another aim of the invention to provide a method for transferring a signal, in an inductive power transfer system, from a secondary inductive coil wired to an electric load, to a primary inductive coil, wired to a power supply via a driver, said method comprising the following steps:

- Step (a) - providing a voltage monitor for monitoring the amplitude of a primary voltage across said primary coil;

- Step (b) - providing a transmission circuit for connecting an electric element to said secondary inductive coil thereby increasing the resonant frequency of said inductive power transfer system;
- 5 Step (c) - providing an oscillating voltage to said primary inductive coil at an initial transmission frequency higher than said resonant frequency thereby inducing a voltage in said secondary inductive coil;
- 10 Step (d) - said transmission circuit modulating a bit-rate signal with the input signal to create a modulated signal and connecting said electrical element to said secondary inductive coil intermittently according to said modulated signal;
- Step (e) - said voltage monitor cross-correlating the amplitude of said primary voltage with said bit-rate signal for producing an output signal.

It is still a further aim of the invention to provide a signal transfer system for transferring feedback signals for regulating power transfer in an inductive power transfer system, said inductive power transfer system comprising at least one primary inductive coil for forming an inductive couple with at least one secondary inductive coil wired to an electric load, wherein said feedback signals are transferred from said secondary inductive coil to said primary inductive coil concurrently with uninterrupted inductive power transfer from said primary inductive coil to said secondary inductive coil.

15

20

## Brief Description of the Figures

For a better understanding of the invention and to show how it may be carried into effect, reference will now be made, purely by way of example, to the accompanying drawings.

5        With specific reference now to the drawings in detail, it is stressed that the particulars shown are by way of example and for purposes of illustrative discussion of the preferred embodiments of the present invention only, and are presented in the cause of providing what is believed to be the most useful and readily understood description of the principles and conceptual aspects of the invention. In this regard, no  
10       attempt is made to show structural details of the invention in more detail than is necessary for a fundamental understanding of the invention; the description taken with the drawings making apparent to those skilled in the art how the several forms of the invention may be embodied in practice. In the accompanying drawings:

      Fig. 1 is a block diagram showing the main elements of an inductive power transfer system with an inductive feedback channel according to a first embodiment of  
15       the present invention.

      Fig. 2 is a graph showing how the amplitude of operational voltage of an inductive power transfer system varies according to the voltage transmission frequency and the resonant frequency of the system;

20       Fig. 3 is a circuit diagram of an inductive power transfer system including an inductive feedback channel for providing coil-to-coil signal transfer concurrently with uninterrupted inductive power transfer between the coils in accordance with another embodiment of the invention; and

      Fig. 4 is a flowchart showing a method for transferring a signal from the  
25       secondary inductive coil to a primary inductive coil of an inductive power transfer system according to still a further embodiment of the invention.

## Description of the Preferred Embodiments

      Reference is now made to Fig. 1 showing a block diagram of the main  
30       elements of an inductive power transfer system 100 consisting of an inductive power outlet 200 configured to provide power to a remote secondary unit 300. The inductive power transfer system 100 includes an inductive communication channel 120 according to a first embodiment of the present invention. The communication

channel 120 is configured to produce an output signal  $S_{out}$  in the power outlet 200 when an input signal  $S_{in}$  is provided by the secondary unit 300.

5 The inductive power outlet 200 includes a primary inductive coil 220 wired to a power source 240 via a driver 230. The driver 230 is configured to provide an oscillating driving voltage to the primary inductive coil 220, typically at a voltage transmission frequency  $f_t$  which is higher than the resonant frequency  $f_R$  of the system.

10 The secondary unit 300 includes a secondary inductive coil 320, wired to an electric load 340, which is inductively coupled to the primary inductive coil 220. The electric load 340 draws power from the power source 240. Where the electric load 340 requires a direct current supply, for example a charging device for an electrochemical cell or the like, a rectifier 330 may be provided to rectify the alternating current signal induced in the secondary coil 320.

15 An inductive communication channel 120 is provided for transferring signals from the secondary inductive coil 320 to the primary inductive coil 220 concurrently with uninterrupted inductive power transfer from the primary inductive coil 220 to the secondary inductive coil 320. The communication channel 120 may provide feedback signals to the driver 230.

20 The inductive communication channel 120 includes a transmission circuit 122 and a receiving circuit 124. The transmission circuit 122 is wired to the secondary coil 320, optionally via a rectifier 330, and the receiving circuit 124 is wired to the primary coil 220.

25 The signal transmission circuit 122 includes at least one electrical element 126, selected such that when it is connected to the secondary coil 320, the resonant frequency  $f_R$  of the system increases. The transmission circuit 122 is configured to selectively connect the electrical element 126 to the secondary coil 320.

As known, the resonant frequency  $f_R$  of an inductive couple is given by the formula  $f_R = \frac{1}{2\pi\sqrt{LC}}$ , where  $L$  is the inductance of the system and  $C$  is the capacitance of the system. Thus any decrease in either the inductance  $L$  or the capacitance  $C$  increases the resonant frequency of the system. The electrical element 126 may be a low resistance for example, typically the resistance of the electrical element 126 is under 50 ohms and preferably about 1 ohm.

30

The signal receiving circuit 124 may include a voltage peak detector 128 configured to detect large increases in the transmission voltage. In systems where the voltage transmission frequency  $f_t$  is higher than the resonant frequency  $f_R$  of the system, such large increases in transmission voltage may be caused by an increase in the resonant frequency  $f_R$  thereby indicating that the electrical element 126 has been connected to the secondary coil 320. Thus the transmission circuit 122 may be used to send a signal pulse to the receiving circuit 124 and a coded signal may be constructed from such pulses.

According to some embodiments, the transmission circuit 122 may also include a modulator (not shown) for modulating a bit-rate signal with the input signal  $S_{in}$ . The electrical element 126 may then be connected to the secondary inductive coil 320 according to the modulated signal. The receiving circuit 124 may include a demodulator (not shown) for demodulating the modulated signal. For example the voltage peak detector 128 may be connected to a correlator for cross-correlating the amplitude of the primary voltage with the bit-rate signal thereby producing the output signal  $S_{out}$ .

In other embodiments, a plurality of electrical elements 126 may be provided which may be selectively connected to induce a plurality of voltage peaks of varying sizes in the amplitude of the primary voltage. The size of the voltage peak detected by the peak detector 128 may be used to transfer multiple signals.

Fig. 2 is a graph showing how the amplitude of the operational voltage varies according to the transmission frequency. It is noted that the voltage is at its highest when the transmission frequency is equal to the resonant frequency  $f_R$  of the system, this maximum amplitude is known as the resonance peak 2. If the resonant frequency  $f_R$  of the system increases, a new resonance peak 2' is produced.

According to an exemplary embodiment of the invention, an inductive power transfer system 100 operates at a given transmission frequency  $f_t$  which is higher than the resonant frequency  $f_R$  of the system. The normal operating voltage  $V_t$  is monitored by the voltage peak detector 128. When the electric element 126 is connected to the secondary inductive coil 320 the resonant frequency of the system increases. Therefore, the operating voltage increases to a higher value  $V_t'$ . This increase is detected by the voltage peak detector 128.

The present invention allows data signals to be transferred from the secondary coil 320 to the primary coil 220 concurrently with inductive transfer of power from

the primary coil 220 to the secondary coil 320. Consequently, the signal transfer system may be used to provide feedback signals for real time power regulation. This is in contradistinction to prior art inductive signal transfer systems, such as the system described in the abovementioned United States Patent No. 5,455,466 titled, "Inductive  
5 coupling system for power and data transfer" to Terry J. Parks and David S. Register as referred to hereabove, in which a separate data signal is supplied to the secondary inductive coil such that a voltage is induced in the primary coil.

Fig. 3 shows an exemplary circuit diagram of an inductive power outlet 2200 and a secondary unit 2300, according to another embodiment of the invention. An  
10 inductive feedback channel 2120 is provided for transferring signals between the coils concurrently with uninterrupted inductive power transfer.

The inductive power outlet 2200 comprises a primary coil 2220 driven by a half-bridge converter 2230 connected to a power source 2240. The half-bridge converter 2230 is configured to drive the primary coil 2220 at a frequency higher than  
15 the resonant frequency of the system. The secondary unit 2300 comprises a secondary coil 2320 wired to the input terminals  $T_1$ ,  $T_2$  of a rectifier 2330, and an electric load 2340 wired to the output terminals  $T_3$ ,  $T_4$  of the rectifier 2330.

Although only a half-bridge converter 2230 is represented in the inductive power outlet 2200 of Fig. 3, it is noted that other driving circuits could be used. These  
20 include: a DC-to-DC converter, an AC-to-DC converter, an AC-to-AC converter, a flyback transformer, a full-bridge converter, a flyback converter or a forward converter for example.

The inductive feedback channel 2120 comprises a transmission circuit 2122, in the secondary unit 2300 and a receiving circuit 2124 in the inductive power outlet  
25 2200. The transmission circuit 2122 comprises an electrical resistor 2126 connected to the rectifier 2330 via a power MOSFET switch 2125. A modulator 2123 may provide an input signal  $S_{in}$  to the power MOSFET 2125.

It is noted that in this embodiment the transmission circuit 2122 is wired to one input terminal  $T_1$  and one output terminal  $T_3$  of the rectifier 2330. This  
30 configuration is particularly advantageous as, even when the transmission circuit 2122 is connected, the resistor 2126 only draws power from the system during one half of the AC cycle, thereby significantly reducing power loss.

The receiving circuit 2124 includes a voltage peak detector 2128 that is configured to detect increases in the transmission voltage, and a demodulator 2129 for producing an output signal  $S_{out}$ .

5 With reference now to Fig. 4, a flowchart is presented showing the main steps in a method for transferring a signal from the secondary inductive coil to a primary inductive coil of an inductive power transfer system. The method includes the following steps:

Step (a) – connecting the primary inductive coil to a voltage monitor for monitoring the amplitude of a primary voltage across the primary coil;

10 Step (b) – connecting the secondary inductive coil to a transmission circuit for connecting an electric element to the secondary inductive coil thereby increasing the resonant frequency of the inductive power transfer system;

Step (c) – providing an oscillating voltage to the primary inductive coil at an initial transmission frequency higher than the resonant frequency thereby inducing a voltage in the secondary inductive coil;

Step (d) – using the transmission circuit to modulate a bit-rate signal with the input signal to create a modulated signal and connecting the electrical element to the secondary inductive coil intermittently according to the modulated signal;

20 Step (e) – using the voltage monitor to cross-correlate the amplitude of the primary voltage with the bit-rate signal for producing an output signal.

The inductive feedback channel 2120 may be used for transferring data, such as data pertaining to any or all of the following:

- the required operating voltage, current, temperature or power for the electric load 240
- 25 ▪ the measured voltage, current, temperature or power supplied to the electric load 240 during operation
- the measured voltage, current, temperature or power received by the electric load 240 during operation and the like
- identification data for the user, electronic device and such like

30 Therefore, the inductive communication channel may be used to transfer a feedback signal from the secondary inductive coil to the primary inductive coil for regulating power transfer across an inductive power coupling.

For example the system may be configured to transfer two signals with the driver being configured to decrease the transmission power when a first signal is received, and to increase the transmission power when a second signal is received.

Power may be regulated by altering the duty cycle of the transmission voltage  
5 provided by the driver. Furthermore, when the transmission frequency is not equal to the resonance frequency of the system, the driver 230 may also be configured to adjust the transmission frequency in order to regulate the power transfer, as described in the inventors' copending application United States Serial No. 61/129,526. Accordingly, the driver may be configured to adjust the transmission frequency in  
10 response to feedback signals. The transmission frequency may be increased when the first signal is received thereby decreasing the operating voltage, and the transmission frequency may be decreased when the second signal is received, thereby increasing the operating voltage.

Thus the present invention provides a communication channel which may be  
15 used for regulating power transfer and/or for transmitting data signals from the secondary coil to the primary coil of an inductive couple while power is being transferred. The scope of the present invention is defined by the appended claims and includes both combinations and sub combinations of the various features described hereinabove as well as variations and modifications thereof, which would occur to  
20 persons skilled in the art upon reading the foregoing description.

In the claims, the word "comprise", and variations thereof such as "comprises", "comprising" and the like indicate that the components listed are included, but not generally to the exclusion of other components.

## Claims

1. A signal transfer system for an inductive power transfer system, said inductive power transfer system comprising at least one primary inductive coil for forming an inductive couple with at least one secondary inductive coil wired to an electric load,  
5 said primary inductive coil being wired to a power supply via a driver; said driver being configured to provide a driving voltage across said primary inductive coil, said driving voltage oscillating at a transmission frequency higher than the resonant frequency of said inductive couple; wherein
  - 10 a. said primary inductive coil is further wired to a reception circuit comprising a voltage monitor for monitoring the amplitude of a primary voltage across said primary coil, and
  - b. said secondary inductive coil is further wired to a transmission circuit for connecting at least one electric element to said secondary inductive coil  
15 thereby increasing said resonant frequency.
2. The signal transfer system of claim 1 said secondary inductive coil being wired to two inputs of a bridge rectifier and said electric load being wired to two outputs of said bridge rectifier wherein said transmission circuit is wired to one input of said bridge rectifier and one output of said bridge rectifier.
- 20 3. The signal transfer system of claim 1 wherein said transmission circuit further comprises a modulator for modulating a bit-rate signal with an input signal to create a modulated signal and a switch for intermittently connecting said electrical element to said secondary inductive coil according to said modulated signal.
4. The signal transfer system of claim 3 wherein said voltage monitor further  
25 comprises a correlator for cross-correlating the amplitude of said primary voltage with said bit-rate signal for producing an output signal.
5. The signal transfer system of claim 1 for transferring data pertaining to at least one of the group comprising:
  - a. presence of said electric load;
  - 30 b. location of said secondary inductive coil;

- c. required operating voltage for said electric load;
  - d. required operating current for said electric load;
  - e. required operating temperature for said electric load;
  - f. required operating power for said electric load;
  - 5 g. measured operating voltage for said electric load;
  - h. measured operating current for said electric load;
  - i. measured operating temperature for said electric load;
  - j. measured operating power for said electric load;
  - k. power delivered to said primary inductive coil;
  - 10 l. power received by said secondary inductive coil, and
  - m. a user identification code.
6. The signal transfer system of claim 1 for transferring a feedback signal from said secondary inductive coil to said primary inductive coil for regulating power transfer across an inductive power coupling.
- 15 7. The system of claim 6 said driver being configured to adjust said transmission frequency in response to said feedback signals.
8. The system of claim 6 adapted to transfer a first signal and a second signal, and said driver being configured to:
- i. increase said transmission frequency when said first signal is
  - 20 received by the receiver, and
  - ii. decrease said transmission frequency when said second signal is received by the receiver.
9. The system of claim 1 comprising a power converter selected from the group comprising: a transformer, a DC-to-DC converter, an AC-to-DC converter, an
- 25 AC-to-AC converter, a flyback transformer, a flyback converter, a full-bridge converter, a half-bridge converter and a forward converter.
10. A method for transferring a signal, in an inductive power transfer system, from a secondary inductive coil wired to an electric load, to a primary inductive coil, wired to a power supply via a driver, said method comprising the following steps:

- a. providing a voltage monitor for monitoring the amplitude of a primary voltage across said primary coil;
  - b. providing a transmission circuit for connecting an electric element to said secondary inductive coil thereby increasing the resonant frequency of said inductive power transfer system;
  - c. providing an oscillating voltage to said primary inductive coil at an initial transmission frequency higher than said resonant frequency thereby inducing a voltage in said secondary inductive coil;
  - d. said transmission circuit modulating a bit-rate signal with the input signal to create a modulated signal and connecting said electrical element to said secondary inductive coil intermittently according to said modulated signal;
  - e. said voltage monitor cross-correlating the amplitude of said primary voltage with said bit-rate signal for producing an output signal.
11. A signal transfer system for transferring feedback signals for regulating power transfer in an inductive power transfer system, said inductive power transfer system comprising at least one primary inductive coil for forming an inductive couple with at least one secondary inductive coil wired to an electric load, wherein said feedback signals are transferred from said secondary inductive coil to said primary inductive coil concurrently with uninterrupted inductive power transfer from said primary inductive coil to said secondary inductive coil.

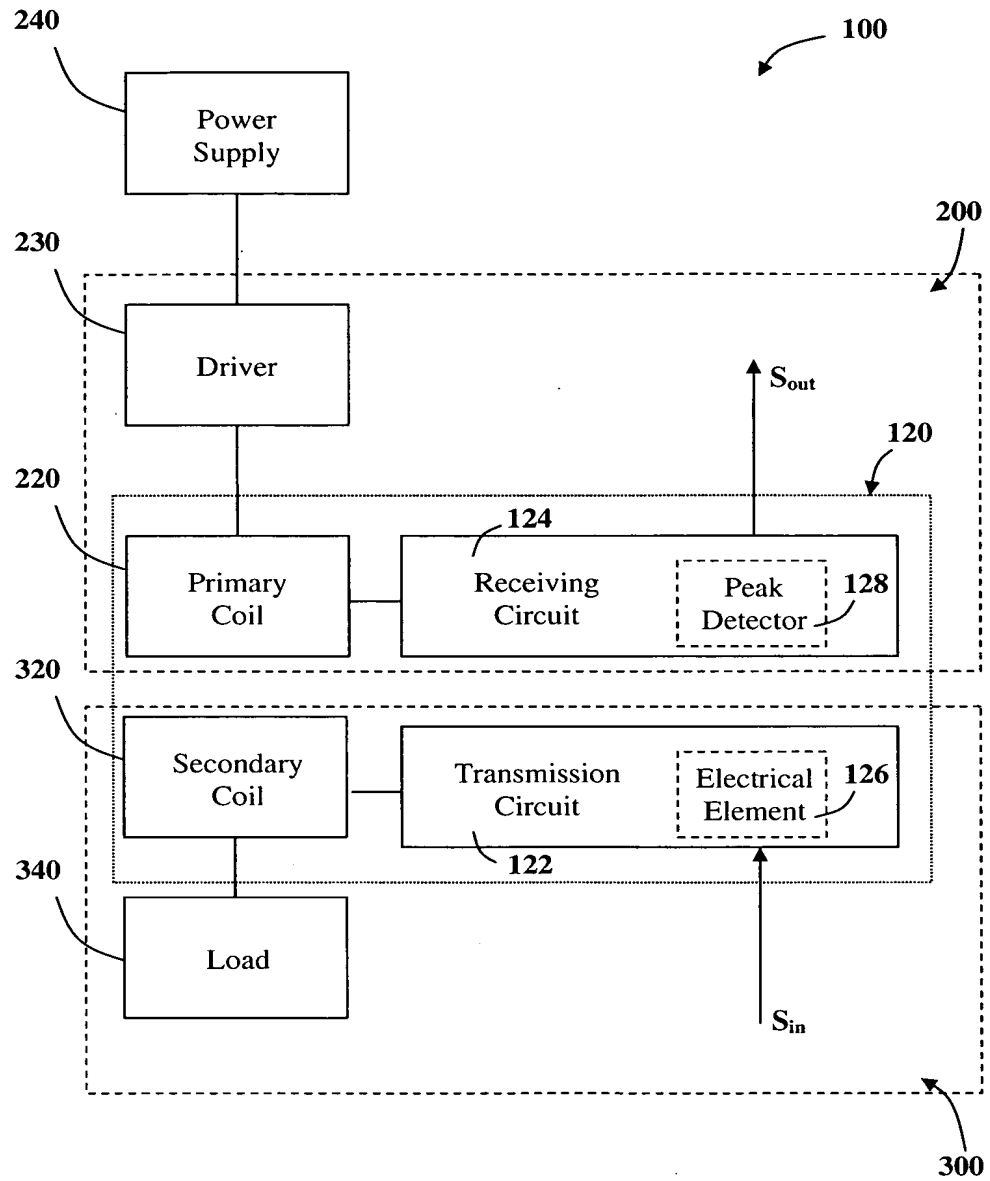


Fig. 1

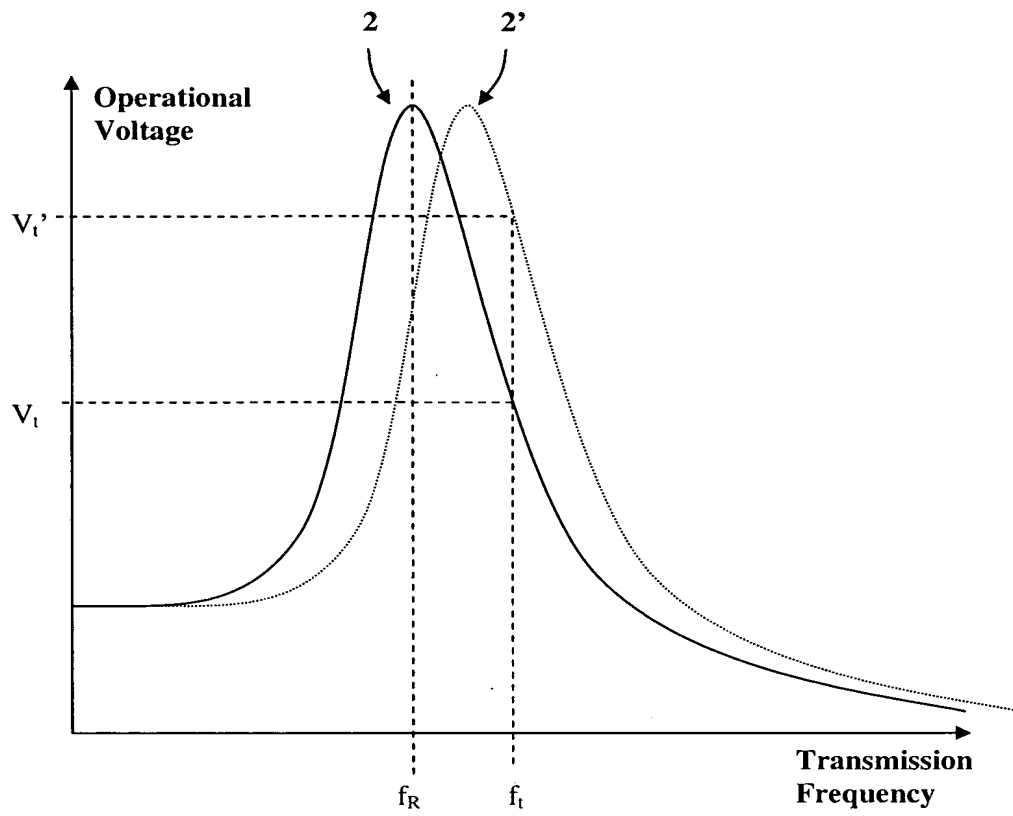


Fig. 2

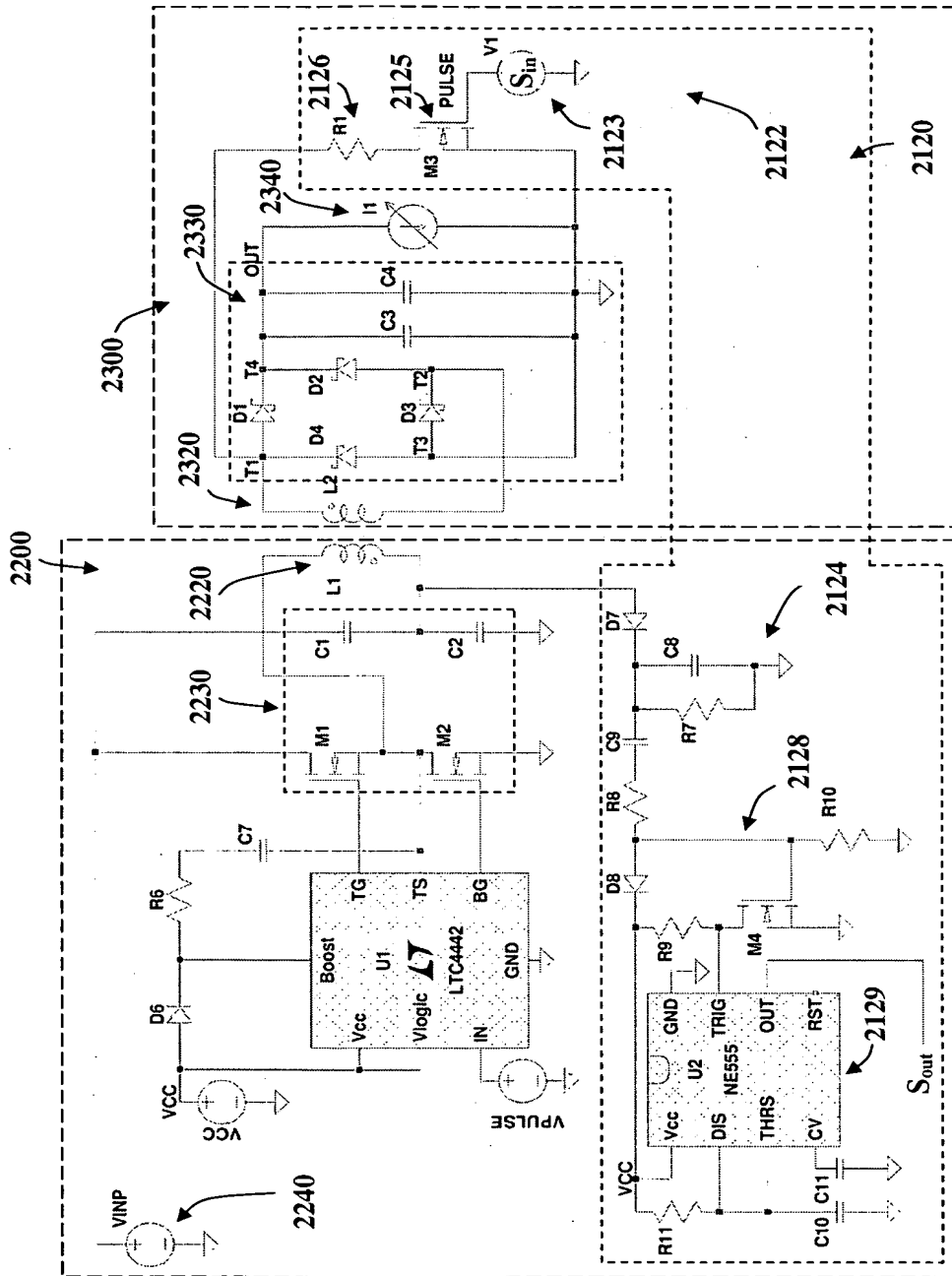


Fig. 3

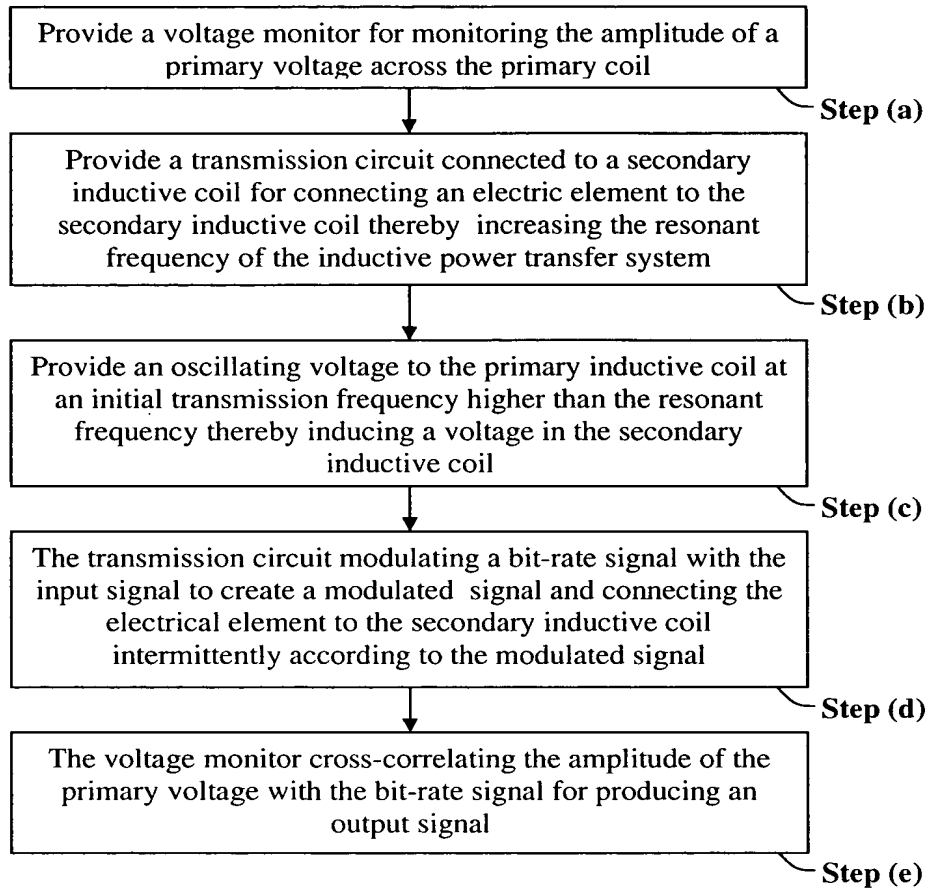


**Fig. 4**

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