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FILING RECEIPT



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Title

Power System

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Power System

BACKGROUND OF THE INVENTION

It is more convenient to be able to power portable devices without the need to plug in a traditional power cable into the device. For example patent GB2399225 describes a wireless power system in which a portable device placed on the unit can receive power without the need for a direct electrical contact. However, when there is no device on the unit (or when the only devices on the unit are fully charged) it is desirable to keep the power consumption at a minimum to reduce the impact on the environment.

In patent GB2414121 the wireless power unit has a standby mode, whereby it periodically transmits power for a short period to look for devices. If the unit detects a valid device that is requesting power and determines that there are no foreign objects that would get hot or hinder power transfer in the vicinity then the unit may come out of standby. The power level of the pulses in standby mode are sufficiently high to transfer enough power to the portable device so that it can communicate back, because it is possible that the device's batteries may be fully depleted. The length of the pulses are long enough to determine that the device is a valid device and that there are no foreign objects present that may get hot or otherwise interfere with the system. The time between the pulses is short enough that the user gets quick feedback that the unit is operational. There is therefore a limit to how low the power consumption can be during standby.

In addition to the power needed to determine the presence of devices requiring power, there are practical limitations which increase the power consumption further. For instance, in some inductive power supplies a DC power source is required even between the transmitted pulses. This means that mains rectification losses are always present and can be considerable. In some scenarios, multiple DC voltages are required and it would not be practical to start these up within the pulse duration, so DC conversion losses might always be present. The microprocessor in the unit that drives the pulse width modulation for the inverter typically is relatively high performance and consumes a certain amount of power continuously.

These and other factors make it challenging for a wireless power system to have low standby power. One attempted solution is to have a switch, so that the user switches the unit on before placing a device on it. However, this considerably detracts from the main benefit the system provides – the convenience of just putting the device on the wireless power supply. With careful design it is possible to achieve standby powers as low as 0.5W. However, there is a desire for these figures to be reduced further. A typical mobile phone charger may only be used for 3 hours a week and spend the rest of the time in standby. Assuming an average of 4W consumption during charging and 0.5W during standby, the annual energy consumption would be 0.624kWH to charge the phone and 4.38kWH whilst in standby. This means that seven times as much energy is wasted in standby compared to the energy used. The impact of shipping 100M units (10% of annual cell phone sales in 2007) would mean approximately 50MW of power generation

capacity just to service the standby. There is increasing awareness that energy wastage through electronic devices left on standby may contribute to climate change. As a result there are initiatives to reduce the power consumption of electronic devices whilst in standby.

There have been several devices aimed at reducing the standby power of televisions and other appliances using remote controls (US6330175, WO2006106310). However, these are not applicable to wireless power systems.

In addition to wireless power systems, other systems for example contactless card systems also suffer from power wastage in standby.

SUMMARY OF THE INVENTION

According to a first aspect of the invention there is provided a method for reducing the power drawn by a primary unit capable of interacting with a secondary device, separable from the primary unit, the method having the following modes:

the first mode comprising the steps of:

- preventing or restricting the supply of power to the primary unit;
- detecting changes in the number, type, position or distance of objects or object, in proximity to the primary unit;
- upon detecting said changes, entering a second mode;

the second mode comprising the steps of:

- supplying power to the primary unit at a higher level than the first mode;
- identifying if there is a secondary device in proximity;
- remaining in the second mode or entering the first mode in dependence upon the identification.

The first mode may take power from a different source to the second mode.

The first mode may take power from an energy storage element.

The second mode may enter the first mode if there is no secondary device present.

The second mode may also comprise the step of determining if the primary unit should interact with the secondary device and if not enter the first mode.

The second mode may also determine if there are objects in addition to the secondary device and in consequence enter the first mode.

According to a second aspect of the invention there is provided a method for reducing the power drawn by a primary unit used to transfer power and/or information wirelessly to/from a secondary device, the secondary device being separable from the primary unit, the method having the following modes:

the first mode comprising the steps of:

- preventing or restricting the supply of power to the primary unit;

- detecting changes in the number, type, or position of objects or object, in proximity to the primary unit;
- upon detecting said changes, entering a second mode;
- the second mode comprising the steps of:
 - supplying power to the primary unit at a higher level than the first mode;
 - identifying if there is a secondary device in proximity;
 - upon identifying that there us a secondary device entering a third mode;
- the third mode comprising the steps of:
 - supplying power to the primary unit at a higher level than the first mode;
 - transferring power and/or information between the primary unit and the secondary device.

The first mode may take power from a different source to the second mode and/or third mode.

The first and/or second mode may take power from an energy storage element.

The third mode may supply power to the primary unit at a higher level than the second mode.

The second mode may enter the first mode if there is no secondary device present and the third mode if there is a secondary device present.

The second mode may also comprise the step of determining if the primary unit should interact with the secondary device before entering the third mode.

The second mode may also determine if there are objects in addition to the secondary device and in consequence enter the first mode.

The third mode may also determine that the primary unit and secondary device have finished transferring power and/or information and enter the first or second mode.

According to a third aspect of the invention there is provided a method for reducing the power drawn by a primary unit capable of interacting with a secondary device, separable from the primary unit, the method having the following modes:

- the first mode comprising the steps of:
 - preventing or restricting the supply of power from the power supply to the primary unit;
 - taking power from an energy storage element, separate from said power supply;
 - identifying if there is a secondary device in proximity;
 - upon determining that there us a secondary device entering a second mode;
- the second mode comprising the steps of:
 - supplying power to the primary unit from the power supply;

The first mode may detect that an object is in proximity before identifying whether or not it is a secondary device.

The second mode may additionally supply power to the energy storage element to recharge it.

There may also be a third mode which is entered from the second mode if the energy storage unit goes below a predetermined threshold, the mode comprising the steps of: supplying power to the energy storage element to recharge it; detecting or identifying if there is a secondary device in proximity; upon determining that there us a secondary device entering said second mode; entering said first mode if the energy storage unit becomes fully charged.

According to a fourth aspect of the invention there is provided a method for reducing the power drawn by a primary unit used to transfer power and/or information wirelessly to/from a secondary device, the secondary device being separable from the primary unit, the method comprising the following modes:

- the first mode comprising the steps of:

- preventing or restricting the supply of power from the power supply to the primary unit;

- taking power from an energy storage element;

- detecting or identifying if there is a secondary device in proximity;

- upon determining that there us a secondary device entering a second mode;

- the second mode comprising the steps of:

- supplying power to the primary unit at a higher level than the first mode;

- transferring power and/or information between the primary unit and the secondary device.

The first mode may detect that an object is in proximity before identifying whether or not it is a secondary device.

The second mode may additionally supply power to the energy storage element to recharge it.

There may also be a third mode which is entered from the second mode if the energy storage unit goes below a predetermined threshold, the mode comprising the steps of: supplying power to the energy storage element to recharge it; detecting or identifying if there is a secondary device in proximity; upon determining that there us a secondary device entering said second mode; entering said first mode if the energy storage unit becomes fully charged.

According to a fifth aspect of the invention there is provided a primary unit for interacting with a secondary device, separable from the primary unit, with reduced power, the primary unit comprising:

a detection unit for detecting the presence of an object in proximity to the primary unit;
an identification unit for identifying a secondary device detected by said detection unit,
at least one switch operable for stopping or restricting the supply of power to at least part of the primary unit.
wherein the at least one switch is operated in dependence of the detection unit and/or the identification unit.

The detection unit may be the same as the identification unit.

The detection unit may be separate from the identification unit.

The identification unit may require more power than the detection unit to operate.

The identification unit may take its power from a different source to the detection unit.

The detection unit and/or identification unit may take power from an energy storage element.

There may be first and second switches operable to supply power or increase the supply of power to the primary unit, the first switch activated by the detection unit and the second switch activated by the identification unit.

According to a sixth aspect of the invention there is provided a primary unit for transferring power and/or information wirelessly to/from a secondary device separable from the primary unit, with reduced power, the primary unit comprising:

a detection unit for detecting the presence of an object in proximity to the primary unit;
an identification unit for identifying a secondary device detected by said detection unit;
at least one switch operable for stopping or restricting the supply of power to at least part of the primary unit;
an antenna for transferring power and/or information between the primary unit and the secondary device;
wherein the at least one switch is operated in dependence of the detection unit and/or the identification unit such that power is reduced when no secondary devices require power and/or information transfer.

The antenna may be coupled to the detection unit and/or the identification unit.

The detection unit may be the same as the identification unit.

The detection unit may be separate from the identification unit.

The identification unit may require more power than the detection unit to operate.

The identification unit may take its power from a different source to the detection unit.

The detection unit and/or identification unit may take power from an energy storage element.

The identification unit may take its power from a different source to the detection unit.

There may be first and second switches operable to supply power to the primary unit at different levels, the first switch activated by the detection unit and the second switch activated by the identification unit.

According to a seventh aspect of the invention there is provided a primary unit for interacting with a secondary device, separable from the primary unit, with reduced power, the primary unit comprising:

- a power input for receiving power from an external source;
- an energy storage unit;
- an identification unit for detecting and/or identifying a secondary device;
- a switch operable for stopping or restricting the supply of power from the power input to at least part of the primary unit;
- wherein in the absence of secondary devices in proximity to the primary unit, said switch is operated to stop or restrict power and the identification unit is powered from the energy storage unit;
- wherein upon the identification unit establishing a secondary device requiring interaction, the switch is operated to allow the supply of power from the power input.

The energy storage element may be recharged from the power input.

According to an eighth aspect of the invention there is provided a primary unit for transferring power and/or information wirelessly to/from a secondary device separable from the primary unit, with reduced power, the primary unit comprising:

- a power input for receiving power from an external source;
- an energy storage unit;
- an identification unit for detecting and/or identifying a secondary device;
- a switch operable for stopping or restricting the supply of power from the power input to at least part of the primary unit;
- an antenna for transferring power and/or information between the primary unit and the secondary device;
- wherein in the absence of secondary devices in proximity to the primary unit, said switch is operated to stop or restrict power and the identification unit is powered from the energy storage unit;
- wherein upon the identification unit establishing a secondary device requiring power and/or information, the switch is operated to allow the supply of power from the power input to the antenna.

The energy storage element may be recharged from the power input.

According to a ninth aspect of the invention there is provided a system for transferring power and/or information between a primary unit and a secondary device, separable from the primary unit, the system comprising:

- a primary unit, the primary unit comprising:

- a detection unit for detecting the presence of an object in proximity to the primary unit;

- a transceiver for transmitting and/or receiving information or power
 - at least one switch operable for stopping or restricting the supply of power to at least part of the primary unit.

- a secondary device, the secondary device comprising:

- a transceiver for transmitting and/or receiving information or power;

- wherein when there are no secondary devices requiring power and/or information in proximity to the primary unit, the switch is operated to stop or restrict power;

- wherein upon the detection unit detecting the presence of an object, the primary unit receives information from any secondary devices that may be present;

- wherein upon the primary unit determining that there is a secondary device present, power and/or information is exchanged between the primary unit and the secondary device.

According to a tenth aspect of the invention there is provided a system for transferring power and/or information between a primary unit and a secondary device, separable from the primary unit, the system comprising:

- a primary unit, the primary unit comprising:

- a power input for receiving power from an external source;

- an energy storage unit;

- an identification unit for detecting and/or identifying a secondary device;

- a switch operable for stopping or restricting the supply of power from the power input to at least part of the primary unit;

- an antenna for transferring power and/or information between the primary unit and the secondary device;

- a secondary device, the secondary device comprising:

- an antenna for transferring power and/or information between the primary unit and the secondary device;

- wherein in the absence of secondary devices in proximity to the primary unit, said switch is operated to stop or restrict power and the identification unit is powered from the energy storage unit;

- wherein upon the identification unit establishing a secondary device requiring power and/or information, the switch is operated to allow the supply of power from the power input to the antenna.

According to an eleventh aspect of the invention there is provided a power supply for converting alternating current (AC) mains electricity to direct current (DC) and supplying an external device, with reduced power dissipation, the power supply comprising:

- a power input for receiving an AC voltage from the mains;
- a rectifier for converting said AC voltage to a DC voltage.
- a switch coupled to the power input and said rectifier;
- a power output to supplying said DC voltage to the external device;
- a signal input for operating the switch so as to prevent said AC voltage being delivered to said rectifier;
- wherein an external device is able to receive DC power via the power output;
- wherein an external device is able to operate the switch via the signal input to prevent power being dissipated in the rectifier.

The power supply may additionally comprise a DC to DC converter to convert the DC voltage from the rectifier to a different DC voltage at the power supply output.

According to a twelfth aspect of the invention there is provided a system for supplying power to a unit, the system comprising:

- a power supply, the power supply comprising:
 - a power input for receiving an AC voltage from the mains;
 - a rectifier for converting said AC voltage to a DC voltage.
 - a switch coupled to the power input and said rectifier;
 - a power output to supplying said DC voltage to the external device;
 - a signal input for operating the switch so as to prevent said AC voltage being delivered to said rectifier
- a unit, the unit comprising:
 - an energy storage element;
 - a signal output;
- wherein said unit is able to receive DC power via the power output;
- wherein said external device is able to operate the switch via the signal output and signal input to prevent power being dissipated in the rectifier.
- wherein said external device may be powered by said energy storage element when said switch has been operated to prevent said AC voltage being delivered to said rectifier.

All these aspects have the advantage that the overall power consumption is reduced. This and other objects, advantages, and features of the invention will be more fully understood and appreciated by reference to the description of the current embodiment and the drawings.

DESCRIPTION OF THE CURRENT EMBODIMENT

Figure 1 shows an example of a wireless power system, which uses electromagnetic induction. There is a wireless power supply which takes electrical power and transmits this power to a portable device. The charger takes an AC electrical input from the mains. This is rectified (Mains Rectification) to produce DC power. This DC power is down-

converted to a lower voltage using a DC-DC Converter. The down-converted voltage is used to drive an Inverter. The Inverter generates an AC voltage which is applied to the primary coil. The portable device has a secondary coil which couples to the primary coil, thereby producing a voltage. This voltage is down-converted to a lower voltage using a DC/DC converter to supply the Load. The Load is representative of the power requiring parts of the portable device, and includes for example the battery and charging circuit. There is a Control element in the Wireless power supply. This is used to adjust the DC/DC converter to regulate the coil voltage and generate the pulse width modulated signals for the inverter. It may also used for device detection and to detect the presence of foreign objects which could adversely affect operation.

Figure 2 shows a wireless power supply of one embodiment of the invention. This embodiment includes a switch, SW1, an Energy Storage unit and a Sense Circuit. When the Wireless power supply is in standby, SW1 is open, so that no power is drawn from the mains. In the standby mode, the only power drawing element is the Sense Circuit. The Sense Circuit detects when an object is placed in (or removed from) the proximity of the Wireless power supply, but does not determine whether or not the object is a legitimate object nor whether or not it desires power. If the Sense Circuit detects that an object has been placed on the wireless power supply, then SW1 is closed allowing all the circuits in the wireless power supply to receive power. The Control element in the Wireless power supply then determines i) whether there is a valid device present, ii) if there is a valid device whether it desires power; iii) whether there is a foreign object present. If there is a valid device requiring power and no foreign objects present, then the control unit will activate the Inverter to supply current to the primary coil to deliver power to the portable device.

Foreign objects may be detected using a method disclosed in GB2414121 (incorporated by reference). If a valid device is detected, then it communicates its power requirement to the Wireless Power Supply. The wireless power supply measures the power being drawn from the primary coil and compares it to the power requirement communicated by the device. In the current embodiment, if there is no significant difference between the two values then the wireless power supply determines that there is a valid device and no foreign objects present and therefore enables full power delivery to the device.

Figure 3 shows one implementation of the Energy Storage Unit. The Energy Storage unit is used to power the Sense Circuit. The Energy Storage unit takes DC power as its input. This is coupled to a charge controller which supplies power to an energy storage element. The energy storage element is optionally a supercapacitor, but other elements may be used such as a battery or other form of electrical energy storage. One form of charge controller that may be used is a Buck regulator in which the output capacitor is replaced by the supercapacitor. Feedback is used to drive the Buck regulator such that constant current is delivered to the supercapacitor. The energy storage element is coupled to the Energy Storage Unit output. There may also be protection circuits and/or and/or voltage/current regulation/limitation. In one embodiment there is also an output which is indicative of the energy level of the energy storage element.

Figure 4 shows an Energy Storage unit in which there is additionally a diode to prevent back feed of current into the charging circuitry. There is also a switch in this embodiment. The switch may be opened when the Sense Circuit is being powered from the Energy Storage Unit to prevent reverse leakage current from depleting the capacitor or cell.

Figure 5 shows one implementation of the Sense Circuit. In this arrangement, the Sense Circuit uses the same coil for detection as used for the transfer of power, L_p . The Sense Circuit has an additional inductor L_{sen} , which forms a bridge with the primary coil, L_p . (Although an inductor is used any impedance: resistive, reactive or a combination of other elements may be used), This bridge may be driven with an Oscillator. In the current embodiment, the oscillator output voltage and frequency is such that there is minimal power dissipation across the inductance bridge formed between L_{sen} and L_p . If the inductance seen across L_p changes, then this will result in a change in the peak voltage at the midpoint of the bridge, M. This inductance would change if a portable device, such as that shown in Figure 1 was placed on the wireless power supply, such that the secondary coil coupled to the primary coil. This would be true whether or not there was a load in the portable device. The inductance would also change if a metal object or an object containing magnetic material was placed in proximity to the primary coil, L_p . Likewise the inductance would change if a device or metal object was removed from the wireless power supply.

In the current embodiment, the Sense Circuit detects the peak voltage at point M using a Peak Detector. The output of the Peak Detector is fed into a microprocessor unit (MPU). The MPU periodically reads the value of the peak detector. If this value changes, between two consecutive readings then the Sense Circuit determines that an inductance change has occurred, and the Wireless power supply checks if there is a valid device requiring power or whether this is due to a foreign object. It may be desirable to perform a running average on the measurements to reduce the effect of noise.

The sense circuit may use two switches controlled by the MPU, SW3 and SW4. In the illustrated embodiment, SW3 is used to isolate the Sense Circuit from the primary coil, L_p when wireless power supply is delivering power to the portable device. Switch SW3 is closed during standby mode and open during power delivery. Switch SW4 is used to reduce the power consumption of the Sense Circuit still further. Rather than have the Oscillator and Peak Detector powered continuously, the MPU only closes SW4 for the duration of each inductance measurement. Although SW3 is controlled by the MPU within the Sense Circuit in this example, it may instead be controlled by the Control Unit within the main Wireless Power Supply.

In the current embodiment, the Energy Storage element is monitored so that it does not deplete fully, preventing operation of the Sense Circuit. This may be charged from the power input when the Wireless power supply is delivering power to the load. In addition, the Sense Circuit periodically monitors the energy in the Energy Storage element via the Energy Level Output from the Energy storage unit. If this gets below a certain threshold, the Sense Circuit activates SW1 so that the Energy Storage element can be recharged.

One advantage of this arrangement is that the Sense Circuit can be made to consume very low power, because it does not need to do anything more complicated than determine if a change in inductance has taken place. The inductance change threshold can be set to be relatively low to get high sensitivity. A false trigger will not have a dramatic effect on power consumption, as the Control Unit in the wireless power supply will optionally make sure that there is a valid device before delivering full power. The current to sense an inductance change is far lower than the current to transfer power to the portable device and hence a significant power saving is possible. It should be noted that these switches can be configured to isolate the sense circuit and minimize losses. It should also be noted that alternatives using blocking diodes and various switch circuits may provide an alternative solution with minimal losses.

Figure 6 shows an example flow diagram illustrating the operation of the system. The system first checks the energy level in the Energy Storage element. If it is low then the mains is connected and power supplied to it to recharge it. If the Energy is not low then the mains is disconnected to reduce power consumption. The Sense Circuit then sees if there has been an inductance change. If there has not, then after a period of waiting, the system goes back to the start. If there has been an inductance change, the system connects the mains and sees if there is a device requiring power. If there is not it goes back to the start. If there is, the system checks to see if there is a foreign object present (this may have been placed at the same time as the device). If there is then the system goes back to the start. If there is not, then the system delivers power to the primary coil to supply power to the portable device. It continues to check that the device is still requiring power and only goes back to the start when the device no longer requires power or if a foreign object is placed on the wireless power supply.

Figure 7 shows a more detailed flow diagram illustrating one implementation of the system. This flow chart illustrates the separate measurements made to determine the inductance change. In this variation, if the Energy Storage element is depleted then the system temporarily does not use the Sense Circuit, but only uses the device validation system until the Energy Storage element is charged. In Figure 5, X1 is the threshold below which the Energy Storage element is recharged, X2 is the threshold above which it is fully charged. Y is the difference in inductance measurements need to trigger the Sense Circuit. In this example, the memory containing the inductance reading is updated after each measurement. This means that the circuit will follow drifts over time, e.g. due to fluctuation in the coil inductance with ambient temperature. Alternatively, the memory is not updated. This will mean that there will be more false triggers due to fluctuation in ambient conditions. However, it will also prevent the system from being fooled if a device is brought very slowly into proximity with the system.

Figure 8 shows example timing diagrams of the power delivered to the primary coil (not to scale). Figure 8(a) shows an example when a foreign object is placed on the wireless power supply at time A. Periodically, the sense circuit powers up to see if an inductance change has occurred since the previous measurement. After the foreign object has been placed on the wireless power supply, an inductance change will be detected at the next

sense point, B. This will then trigger the system to connect the mains. At point C, the system will look to see if it is a valid device, whether it requires power and whether there are foreign objects present. As the object is foreign, the system will not power up, but will remain in standby. At the next sense point D, the inductance will be the same as that at point B because the foreign object is still there. Accordingly no inductance change will be observed and the system will remain in standby. It will remain in standby until the next inductance change. When the object is removed, this will cause another inductance change and the system will again look for valid devices.

Figure 8(b) shows an example timing diagram when a valid device is placed on the wireless power supply at time E. At the next sense point (time F), the wireless power supply will detect the inductance change, connect the mains and at point G look for valid devices. It will determine that a valid device is present. As a result at point H the system will deliver full power to the portable device. When the device is fully charged, the control unit will determine that no further power is required and place the system in standby (providing there are no other valid devices requiring power). Removing the device will trigger The Sense Circuit, but full power will only be delivered when a valid device requiring power is placed on the wireless power supply. It should be noted that the system is able to work if both a foreign object and a valid device are placed at the same time. It is also able to work if multiple foreign objects are placed at the same time but removed at different times and vice versa.

Figure 9 shows one implementation of the system using a microcontroller unit (MCU). The MCU includes a digital oscillator output and an analogue to digital (A/D) input. In this implementation, the inductance of the primary coil, L_p is used to form a bandpass filter. This filter is used to selectively filter the fundamental frequency component of the square-wave signal to generate a sinusoidal one. However, as the inductance of L_p changes, the passband frequency also changes, thereby altering both the amplitude and phase of the resultant signal. One advantage of this embodiment is that the filtering and inductance detection are performed in the same step using only passive components.

In the current embodiment, the digital squarewave output is AC coupled via C2 to the parallel combination of L_p and C1. L_p and C1 are resonant in the vicinity of the oscillator frequency. This combination is then AC coupled via C3 to a level shifter formed by R1 and R2. R1 and R2 add a DC component to the signal to prevent negative voltages entering the MCU. The top of R1 is fed with the rail voltage of the oscillator. This is provided from an output pin of the MCU. This means that when a measurement is not taking place that the MCU can remove this voltage and prevent power dissipation through R1 and R2. The output from the level shifter is applied to the analogue to digital converter input of the MCU.

Some MCUs have a facility to put them into a 'sleep mode' whereby all of the circuit elements are turned off apart from the watchdog timer. This may enable further power saving. It is desirable for the MCU only to wake up every time a measurement is required by setting the time interval on the watchdog timer appropriately. One example MCU is a PIC10F220. With a 2V supply and a 4MHz internal clock, this device requires only

175 μ A current when operating and only 100nA in sleep mode (350 μ W and 200nW power consumption respectively).

Generally, greater sensitivity can be obtained at the expense of higher power consumption, so there is a trade-off to be made. This could be for example, using amplifiers, using phase sensitive detection rather than peak detection, using higher voltage levels, or having longer acquisition times and hence less time when the Sense Circuit is in sleep mode. It is possible to make this trade-off software configurable, so that depending on where the system is located, the sensitivity and power consumption can be optimised.

It may be desirable to dynamically adapt the frequency of the oscillator signal in the Sense Circuit. This could be to position the frequency on the most sensitive part of the inductance versus output amplitude curve, or to position it in a region of low power dissipation or to position it in an optimised trade-off between the two. The frequency could be adapted at power up, periodically or whenever the Sense Circuit is reset. For instance when a device or metal object is placed on the wireless power supply it might take the Sense Circuit close to the limit of its dynamic range. The Sense circuit could adjust the oscillator to bring it back to near the centre of the range when sensing for the next event. An alternative way of implementing the system is to always adjust the frequency to the position of maximum amplitude. Any reduction in amplitude would then indicate that a change had taken place.

Figure 10 shows an exemplary operation of the circuit of Figure 9. Figure 10(a) shows a signal within the MCU (divided down from its internal oscillator clock). Figure 10(b) shows the oscillator output from the MCU which is applied to the impedance bridge. Figure 10(c) shows the signal at the midpoint of the bridge under one set of conditions. This signal differs in amplitude and/or phase. Figure 10(d) shows the signal at the midpoint of the bridge under a different set of conditions (for example if a device or metal object is placed on the wireless power supply). In general figure 10(d) differs from Figure 10(c) in amplitude and/or phase. The microprocessor first allows the oscillator signal to settle. For each inductance measurement, a number of readings from the A/D converter are taken at a specific number of clock cycles from a given reference point, 0. These three reading points are labelled i, ii, iii in Figure 10(a). The values read by the A/D converter at these reading points are illustrated in Figures 10(c) and 10(d). It can be seen that in this example the values obtained in the case of Figure 10(d) differ to those of Figure 10(c) indicating that some change has occurred. One advantage of sampling the signal at different points, rather than simply measuring the peak signal is that the sense circuit can be made more sensitive because the circuit responds to changes in phase as well as amplitude. It is desirable to ensure that the measurement points do not coincide with the same points in the cycle of the sense frequency. In particular it is desirable to obtain at least one reading which is of significant amplitude as comparing two values close to zero is prone to errors induced by noise. One way to ensure this is to make sure that the time interval is not constant (e.g. the time interval between reading i and reading ii is different to that between reading ii and reading iii).

In one embodiment, it is desirable for the Sense Circuit to be sensitive to phase, because it is possible that there is a change in impedance caused by the addition of ferrite in the secondary coil which exactly balances the impedance of the load. An alternative to making the Sense Circuit phase sensitive is to make two peak amplitude measurements at different frequencies as the inductive impedance has a different frequency dependence to the AC resistance losses.

Figure 11 shows an alternative embodiment of the Figure 10 implementation where a peak detector is used. Some MPUs do not have fast analogue to digital converters, making a phase sensitive technique impractical. In this example, the peak detector is formed by a diode, D1 and capacitor C4.

Figure 12 shows an embodiment in which the Sense Circuit uses a variable frequency oscillator to detect the inductance change. The Sense circuit has an Oscillator, the frequency of which is determined in part by an external inductance. This oscillator could by way of example be a Colpitts or Hartley oscillator and use a transistor, logic gate or operational amplifier as the gain element. It is advantageous to use a topology in which the inductor is ground connected, so that a single switch can be used to connect the inductor. In the example, the coil, L_p is coupled to the Oscillator via SW3. The output of the Oscillator is coupled to the digital input of the MPU. The Oscillator may have a digital, sinusoidal or other output. A sinusoidal output is less likely to cause electromagnetic interference as the current in the inductor will have lower harmonic content. However, if a non-digital output is used, it may be necessary to convert this signal to a digital one prior to the MPU. The MPU makes a relative measurement of the inductance by measuring the frequency of the signal. This is achieved by using internal counters within the MPU and counting the number of pulses within a defined time interval.

Figure 13 shows one embodiment of a method for implementing the system in which there are two power states. In the first state, A, the system is in the equivalent to the stand-by mode described above. In this state the Sense Circuit is powered from the Energy Storage Unit. If the Energy Storage Unit gets low, then the system powers up the mains to recharge it. The Sense Circuit periodically looks for a change indicating a device or object may have been placed on or removed from the charger. If the Sense Circuit detects that a change has taken place then the System enters state B.

In state B, the system is connected to the mains. The system periodically 'pings' the system by modulating the primary coil, L_p . If there is a portable device present then it replies (e.g. by modulating its load). If the system detects that there is a valid device then after checking that there are no foreign objects present, the system will deliver full power to the primary coil. The system will keep sending a 'ping' for a predetermined number of 'pings' or a predetermined amount of time. These predetermined numbers may be software configurable. If no device is detected during this time then the system will go back into state A.

One advantage of this arrangement is that it gives more opportunity to check if there is a valid device present. This prevents the system remaining in standby indefinitely if there is a valid device on it that was not detected on the first 'ping'. Some portable devices take time to 'wake up'. The first 'ping' may deliver sufficient power to start-up the microprocessor. However it may take longer to 'boot up' than the 'ping' duration. Such a device should then authenticate on the second 'ping'.

Figure 14 shows an exemplary timing diagram to illustrate the method of Figure 13. Figure 14(a) shows the system when a foreign object is placed on the system. The system starts in state A. It sees an inductance change and then goes into state B for three 'pings'. These 'pings' can be of a different time interval to the polling of the Sense Circuit. As no device is detected, the system goes back to state A. Figure 14(b) shows the system when a valid device is placed on the system. In this example, the device does not authenticate on the first 'ping', but it is able to on the second 'ping'.

Figure 15 shows a variation on the embodiment of Figure 2. Instead of the Sense Circuit having a separate impedance (L_{sen} in Figure 2), the Sense Circuit uses the resonant capacitor in series with the primary coil. [In Figure 2 Sense Circuit' refers to the sub-circuit Sense Circuit' referenced in Figure 3]. The Oscillator is applied to the point at which the capacitor is connected to the inverter output. The midpoint of the capacitor and inductor is connected to the peak detector. When a device is placed in proximity to the primary coil, the effective inductance seen across the primary coil will change, thereby changing the resonant frequency of the capacitor-inductor combination. This will in turn change the amplitude and/or phase of the signal at the peak detector. An advantage of this embodiment is that it is unnecessary to have an extra impedance element for the Sense Circuit'. However, it may mean that two switches are required to isolate the Sense Circuit' from the primary coil.

Figure 16 shows an example of the invention when the wireless power supply has a DC input rather than a mains input. In this example, the DC Power Supply is located at the mains electricity outlet and a cable delivers DC power to the wireless power supply. The DC Power supply includes the Mains Rectification and a DC/DC converter. However, it also includes a switch prior to the Mains Rectification. The cable between the DC Power Supply and the Wireless power supply includes another line so that the switch in the DC Power Supply can be controlled by the Sense circuit.

The DC supply may also be used without the Wireless power supply, to power different equipment. Other equipment that has a DC power input may benefit from the DC Power supply of Figure 16. Such equipment would have an Energy Storage Unit which powers a small MPU when it is in its standby state. Upon receiving a trigger signal from a stimulus, the equipment could signal via the cable to close switch SW2. Such stimulus may come from a remote control signal (e.g. optical, wireless, RF, ultrasonic), or from a proximity sensor or from another piece of equipment, or from a timer etc.). Alternatively the equipment may have a push button switch which activates SW2 without the need for a separate energy storage unit or microprocessor.

Figure 17 shows one embodiment of a smart power supply with logic controlling a similar process at the power supply. This same power supply may control voltage levels and the sleep cycle of the power supply. Such power supplies are used to power newer laptops. A simple command or logic level can control various aspects of the power supply along with starting and ending a sleep cycle of much lower power drain.

Figure 18 shows an embodiment where a separate energy storage element is not used. In this configuration it is not possible to have the switch before the Mains Rectification as there is no secondary power source. Instead, the Mains Rectification operates throughout. The Sense Circuit is powered off the output of the Mains Rectification unit. The switch is then placed between the Mains Rectification unit and all the other units (or as many as practically possible). This configuration is less optimal as there will be losses associated with the mains rectification. The switch may also be placed at other points in the system to selectively keep different parts of the system running during standby.

Figure 19 shows an embodiment where the power input is direct current. One application for this embodiment is in automotive applications. The operation is very similar to the Figure 18 embodiment.

Figure 20 shows an embodiment where a separate Sense Circuit is not used. Instead the devices are detected by periodically applying power to the primary coil using a method similar to that disclosed in GB2414121 (incorporated by reference). However, this embodiment differs from GB2414121 in that there is an Energy Storage unit present and a switch to switch off the supply of electricity from the mains. During standby, the control unit is powered from the Energy Storage element. The control unit is also able to deliver power to the primary coil via the Inverter from the Energy Storage element. Every so often power is applied to the primary coil for a short time to see if the device communicates back to acknowledge its presence. However, the level of power required for the device to communicate is less than the power required to transfer full power to the device. The control unit is therefore able to activate the inverter to deliver a lower level of power and therefore the amount of energy taken from the Energy Source is less. If the control unit receives a signal that a device is present, then it can switch on the Mains Rectification so that the system is powered from the Mains rather than the Energy Storage unit. If there is a valid device present, then it can also communicate its power requirement. The wireless power supply measures the power being drawn from the primary coil and compares it to the power requirement of the device. If there is no significant difference between the two then the wireless power supply determines that there is a valid device and no foreign objects and therefore enables full power delivery to the device.

Instead of receiving a communication from the device that it is present, the wireless power supply may simply detect that something is present merely by monitoring the power drawn from the primary coil. If the power drawn changes between successive measurements (or it is greater than a threshold value), then either there is a device drawing the power or alternatively a foreign object. In the current embodiment, the wireless power supply determines whether there is a foreign object present before

applying full power. This method is similar to the Sense Circuit, except that the inverter is being used as the Oscillator. In order to reduce the power consumption, it may be desirable to shift the frequency so that it is away from resonance and there is a large reactance to reduce power dissipation. It may also be desirable to reduce the rail voltage applied to the Inverter.

Figure 21 shows an embodiment in which there are a number of primary coils present. These individual primary coils may each be used to supply power to a portable device. This allows multiple devices to be powered simultaneously. Alternatively the primary coils may differ from one another, so that different types of device may be powered, for example as provided in WO2004038888. Alternatively some configurations of wireless power supply have an array of coils, to allow a device to be positioned anywhere over a continuous area and still receive power. An example of such a system is described in WO03105308. In a wireless power supply with multiple coils, the Sense Circuit may be shared across some or all the coils, saving the need for multiple Sense Circuits. Every time a device (or other object) is placed onto the wireless power supply or removed from the wireless power supply, the sense circuit is triggered. The wireless power supply unit would then poll each inactive coil to see which coils had a valid device in proximity. The wireless power supply would then apply power to the coils requiring power after first checking for the presence of foreign objects.

In Figure 21 a multipole switch is used to connect all the coils in the wireless power supply in parallel. The Sense Circuit will trigger when a device (or object) is placed in proximity to any of the coils, because any individual inductance change will alter the overall inductance of the parallel combination. In the current embodiment, the main control circuit polls each coil to determine which should be powered. As an alternative, rather than gang all the switches together in Figure 21, the switches may be individually controlled by the MPU. In such a system, the MPU has to perform separate measurement for each coil. Although this means that the overall detection time is longer (and hence standby power greater) it does mean that the sensitivity to inductance changes will be greater.

Figure 22 shows one embodiment of a system for minimising the power to multiple channels for power conservation. This configuration allows any combination of active primaries to charge or power as needed. It also allows the system to time out each channel or primary separately allowing each to have independent ultra low power modes. Once all are powered down it can even then turn off the main power and also control auxiliary devices and power.

Figure 23 shows one embodiment of the use of an ultra low power system in a multichannel system. Each channel or primary controller can shut down secondary systems first and then primary for even lower power consumption. This system allows a DC power supply to be controlled remotely via a logic communications link.

Figure 24 shows one embodiment of a power supply with direct power shut off using SW2 controlled by the Sense Circuit.

In the embodiment illustrated in Figure 25 a Proximity Detector is used to initially detect that a device or foreign object has been placed in the vicinity of the wireless power supply. It also detects if a device or foreign object is removed from the wireless power supply. This Proximity Detector is completely separate from the primary coil and therefore not connected to it. The Proximity Detector only needs to know that a change in the devices or objects present has occurred.

Optionally, an inductive proximity sensor could be formed using another coil in the wireless power supply which is independent of the coil used to transfer power. Another type of proximity detector that could be used is a capacitive proximity detector. The presence of the object causes a change in the dielectric constant between two metal electrodes. Alternatively the capacitance may change because of a change in mutual capacitance between the sensor and an object. Another type of proximity detector is a Hall Effect sensor, in which there is a change in voltage in response to a change in magnetic field. The presence of a ferrite core within the portable device may result in altering the magnetic field.

In some alternative embodiments an optical detector could be used, for example a photocell device. When a device is placed on the wireless power supply, less ambient light enters the photocell, thereby indicating the presence of the device. False triggers generated by fluctuating light conditions would not have a dramatic impact. Alternatively an LED or Laser could be used to generate light at visible or invisible frequencies and the reflected light could be detected. Another option would be an ultrasonic proximity detector. It is also possible to use a contact-based detector, such as a pressure switch. When a device is placed on the wireless power supply, the pressure applied is sufficient to make an electrical contact thus providing the same signal that the sense circuit would provide. It is possible to have an element in the portable device which facilitates its detection. For instance the device may contain a permanent magnet. When this magnet is in proximity to the wireless power supply it activates a switch within the wireless power supply by magnetic attraction.

There are a number of possible configurations of Sense Circuit that could be used. Instead of using an inductance bridge, other reactive and/or resistive elements could be used to form the bridge. The reactive elements may be capacitive or inductive. A resonance may be formed in order to increase the sensitivity of the bridge to inductance changes.

Instead of using a separate energy source, the Sense Circuit or Proximity Detector could be powered by other external means. These external means could include energy harvesting (whereby stray RF energy in the atmosphere from RF emitting devices is extracted), solar, thermal, wind, motion energy, hydroelectric etc. Instead of using a rechargeable energy source a non-rechargeable source could be used such as a primary cell. Other forms of energy storage which could be used include fuel cells.

In the current embodiment, the Mains Rectifier may include a transformer to step down the AC voltage, a diode bridge to convert the AC voltage to a DC voltage and a smoothing capacitor. There may also be other components such as inductors or filters to reduce ripple or for electromagnetic compliance. There may also be a DC to DC converter (which may be a switched mode DC to DC converter) to convert the DC voltage to a different DC voltage. Instead of a full diode bridge (consisting of 4 diodes) a half bridge may be used (2 diodes) or alternatively a centre-tapped transformer in conjunction with two diodes. The diodes may be Schottky diodes. Instead of diodes, transistors (which may be MOSFET transistors) may be used to reduce the voltage drop. It may be desirable to use techniques to avoid transient surges when the mains switch is operated. These may employ filters. Alternatively the load may be switched on gradually using a MOSFET with variable on-resistance. Series connected switches may also be used.

In the embodiments described both the magnetic field and the inductive coils could take a variety of forms. The field generated may be perpendicular or parallel or any other orientation with respect to the power transfer surface. The coils could be flat spiral wound coils, with or without a magnetic core; they could be PCB coils. The coils could be wound around a ferrite rod or rectangular rod. The coils may or may not have shielding. The coil axes may be parallel or perpendicular to the power transfer surface. The current and/or voltage during the standby sensing would typically be much lower than during power transfer. The frequency applied during the sensing standby may be different to or the same as the frequency applied during power transfer. Some or all of the voltage, current and frequency may vary or be static during operation and/or standby sensing.

The switches could be electromagnetic relays, MOSFET transistors, solid state relays, or other components. Latching relays are optional, they do not rely on a control voltage to be present continually and therefore the leakage current and hence power loss will be less. However latching relays can be considerably more costly than non latching ones. As an alternative it is possible to use non latching relays, configured so that SW1 is open and SW4 is closed in the absence of a control voltage. An electronic latch can then be made such that when the main Control Logic powers up, it supplies its own power to the relays to keep them in position.

Although the operation of this invention has been illustrated in the context of an inductive wireless power system, it may also be applicable to other types of wireless power systems. For instance it would be used where the energy is transmitted via RF radiation (including but not limited to microwave frequencies). The wireless power may also be transmitted by evanescent wave coupling (e.g. Witricity). The power may also be transferred by capacitive coupling. The power may also be transmitted optically. Other forms of inductive, capacitive, magnetic, electrostatic or electromagnetic power transfer may be used. There is no need for the portable device to have an energy storage device. It is unnecessary for the wireless power transmitter to have a connection to mains electricity. The transmitter may be powered by an internal or external power source such as a battery, supercapacitor, fuel cell or fuel powered generator or other. Alternatively it may

derive its power by other means (e.g. energy harvesting, solar, wind, motion, thermal, hydroelectric etc.)

Figure 26 shows the addition of controlling an auxiliary circuit using one embodiment of the method. This could be additional equipment that would be affected by this control. When SW1 is closed to allow mains electricity through to the Wireless Power Supply, it also allows the mains electricity through to the auxiliary output socket. Any equipment connected to this socket will also be switched on.

Figure 27 shows one embodiment of a remote controlled auxiliary unit. The main circuit controls a signal that is sent to a second device that controls additional power and or functions as needed. The signal may be transmitted by conventional wired connection, optical fibre, wireless, free space optical, ultrasound etc. It should also be noted that this wireless control can be any type of transceiver. Some examples of communication formats include Zigbee, ZWave, (mesh networks) current line carrier, X10, or others. These control technologies make controlling other system easier as they are designed to control appliances, thermostats, lighting and other powered devices. This can be a simple command set with commands being sent to control external devices.

Figure 28 shows an alternative embodiment, similar to the Figure 27 embodiment, except that the Sense Circuit transmits the signal directly.

Figures 29 and 30 show alternative embodiments whereby the wireless power supply is integrated with another piece of electronic equipment. The control circuit within the wireless power system is able to control the supply of power to the rest of the electronics circuitry.

Although the system has been illustrated in the context of a wireless power system, it is also applicable to other systems, where the system comes out of standby in response to an object, person or animal coming in proximity to it.

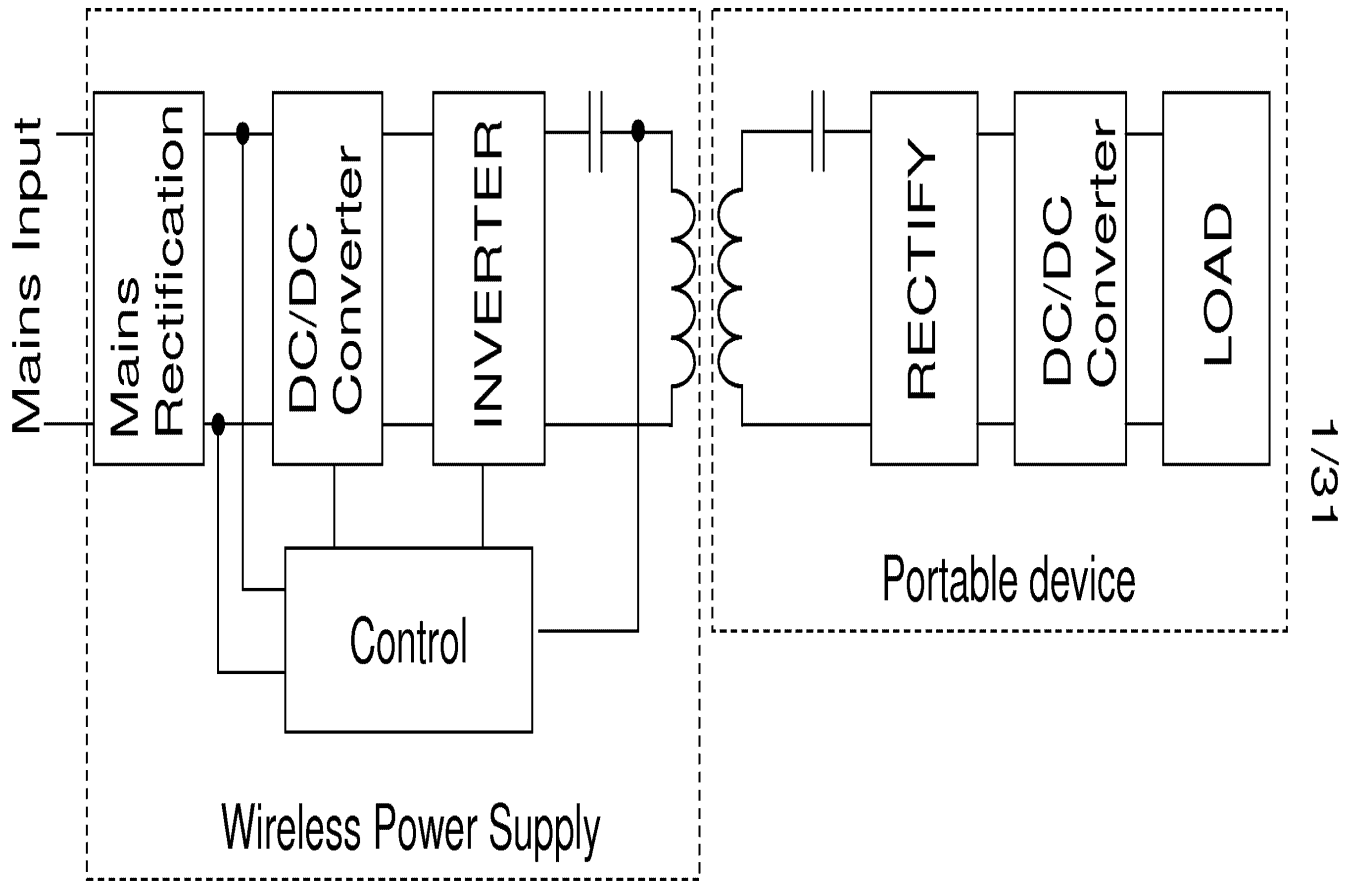
One possible class of system is radio frequency identification (RFID) and associated technologies such as Near Field Communications (NFC) and contactless smart cards. In these systems information is exchanged between a reader and a tag or device by a radio frequency or inductive means. The tag/device may be passive, in which it takes its power from the received electromagnetic power, avoiding the need for an internal battery. Alternatively the tag/device may be active and have internal batteries for power. The devices typically have an antenna consisting of a coil, transmit/receive circuitry and a microprocessor or other logic for control. A simple tag may be passive and simply transmit back a serial number to give its identity. More complex NFC devices being embedded into mobile phones can transmit and receive information between the reader and the phone. The readers are used for a variety of purposes, for example cashless payment systems, advertising, local information. It is undesirable to for such systems to be permanently on, as they may not be visited frequently.

Figure 31 shows an example of the invention being used in an RFID system (applicable to NFC and other contactless payment systems). When the RFID tag is placed in proximity to the reader, the Sense Circuit determines that there is tag/device in proximity. The system therefore connects the mains supply and powers up the reader. The reader then looks for tags/devices in proximity and communicates with them. It is unnecessary for the reader to transfer power to the tag/device. After the reader has finished communicating with all the tags/devices in proximity, it can re-enter the standby state. The system remains in this state until the next change occurs (either tags/devices are removed or placed).

The above description is that of the current embodiment of the invention. Various alterations and changes can be made without departing from the spirit and broader aspects of the invention as defined in the appended claims, which are to be interpreted in accordance with the principles of patent law including the doctrine of equivalents. Any reference to claim elements in the singular, for example, using the articles “a,” “an,” “the” or “said,” is not to be construed as limiting the element to the singular.

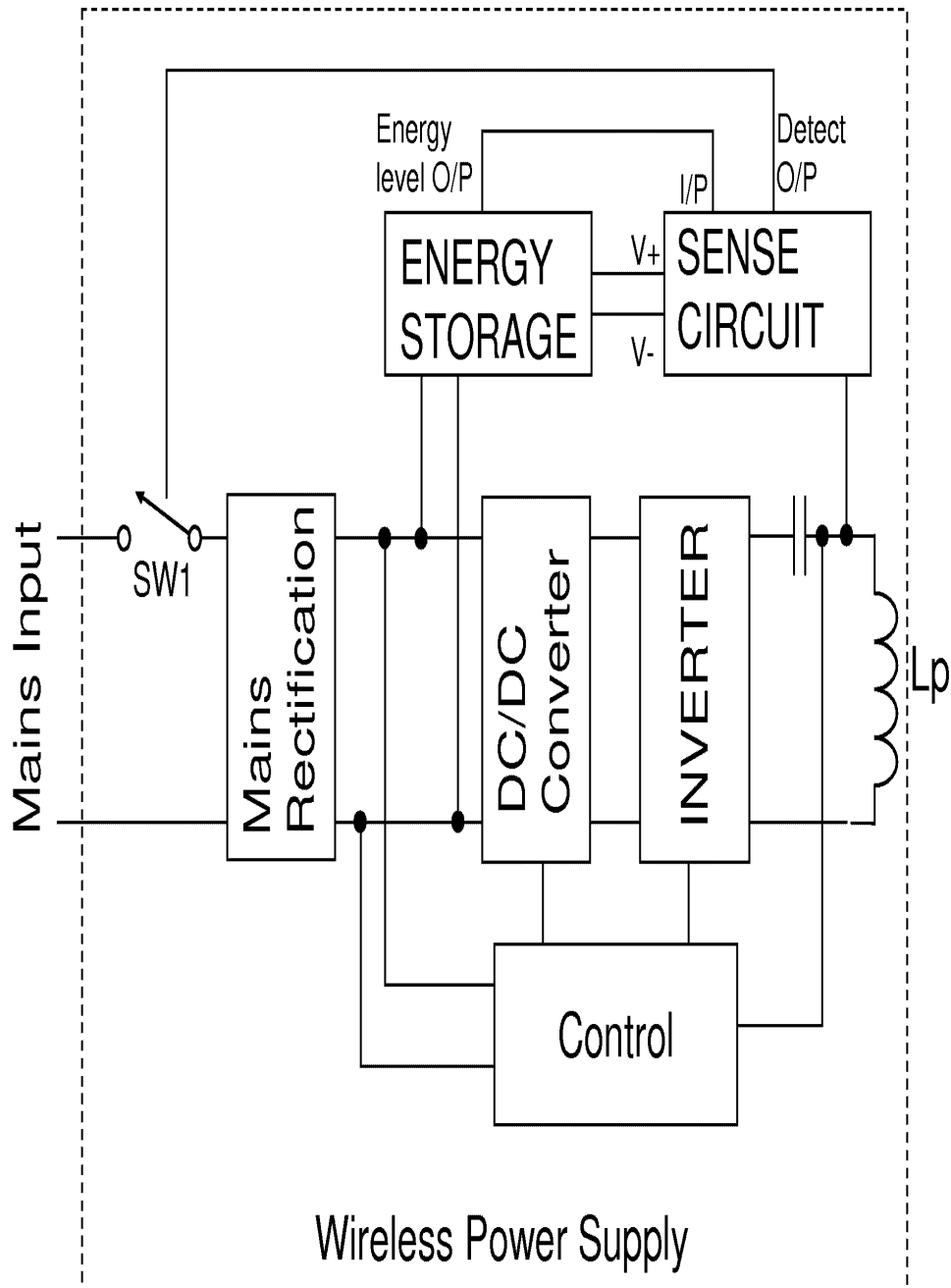
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Fig. 1



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Fig. 2



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Fig. 3

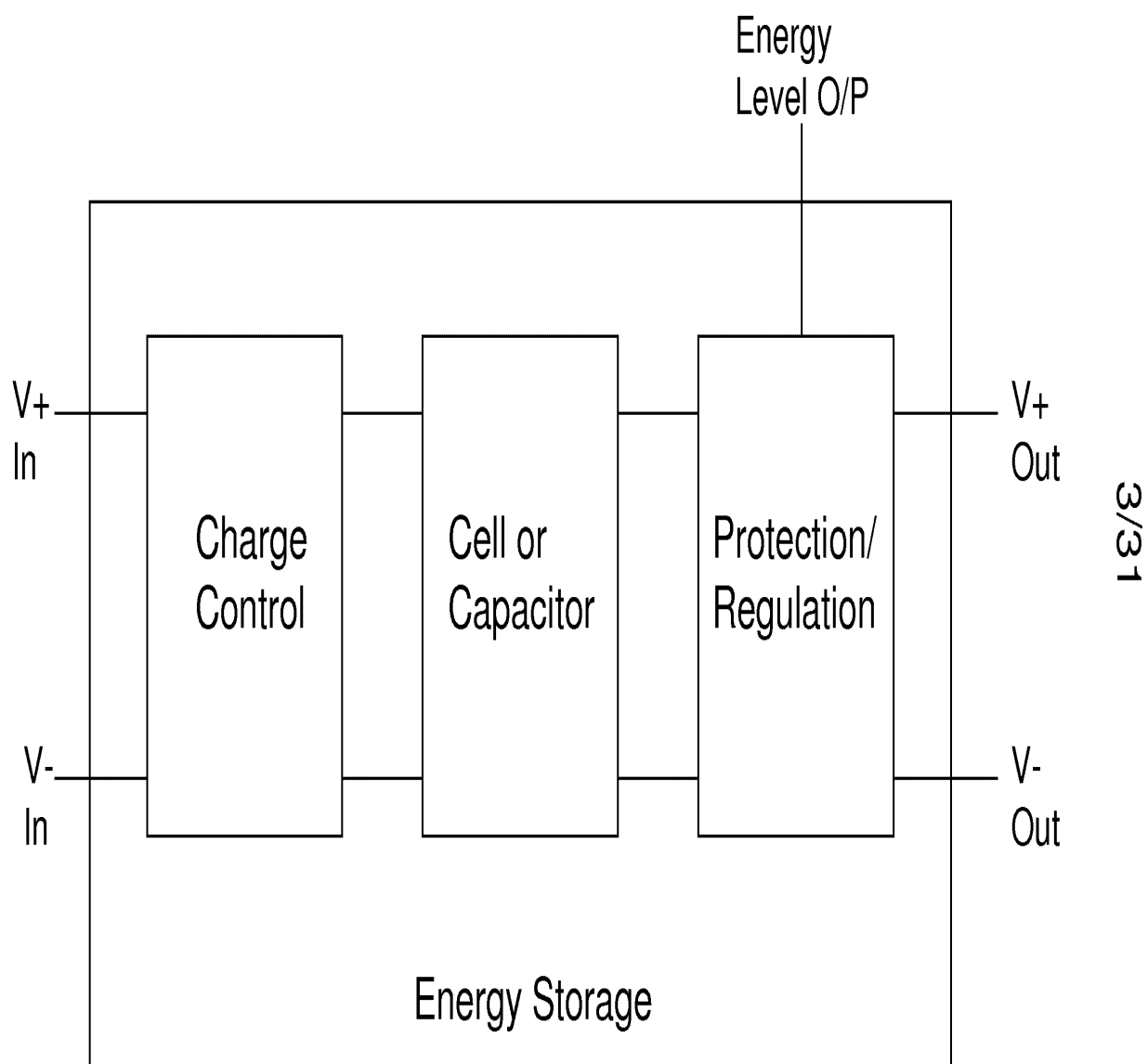
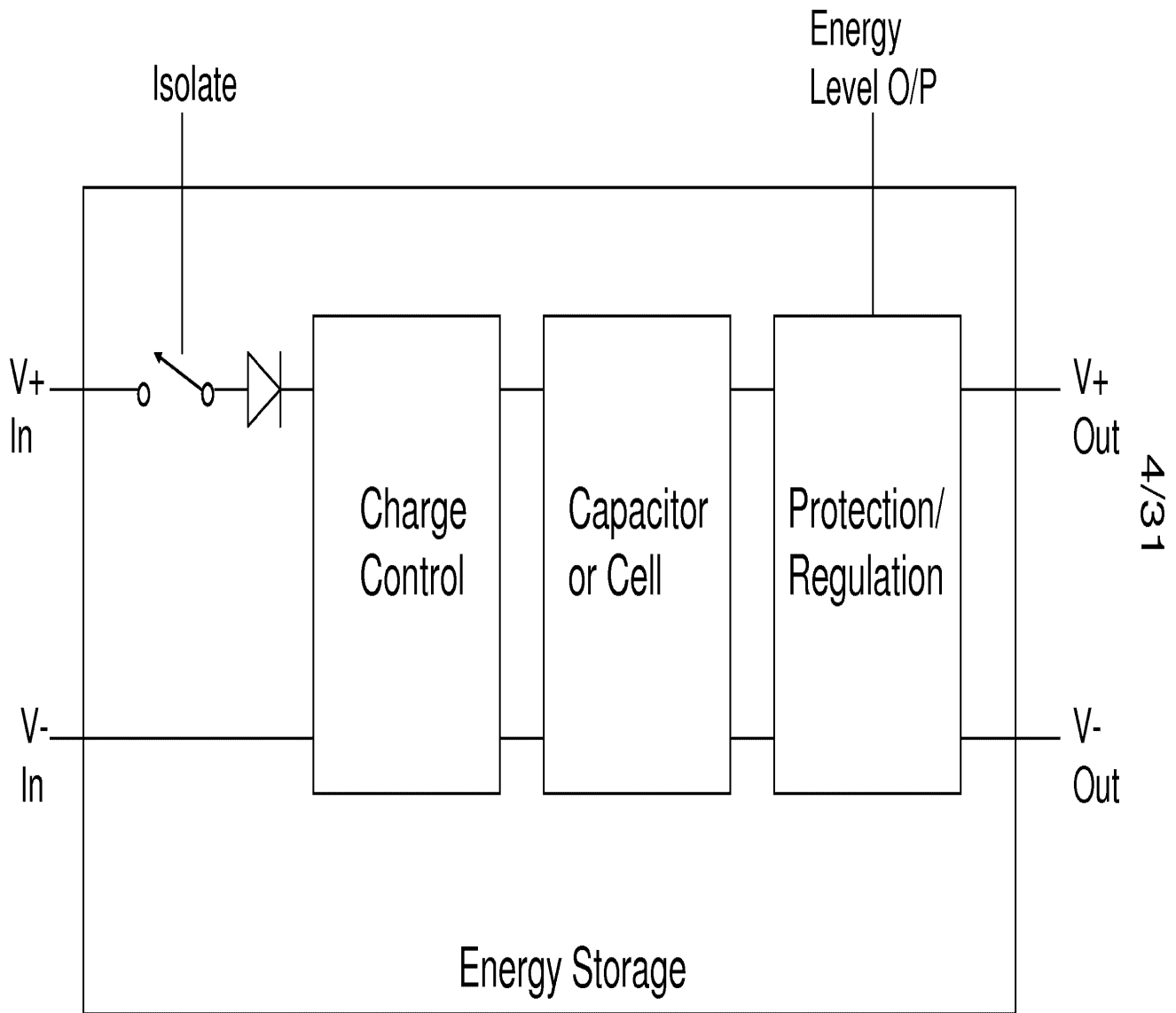
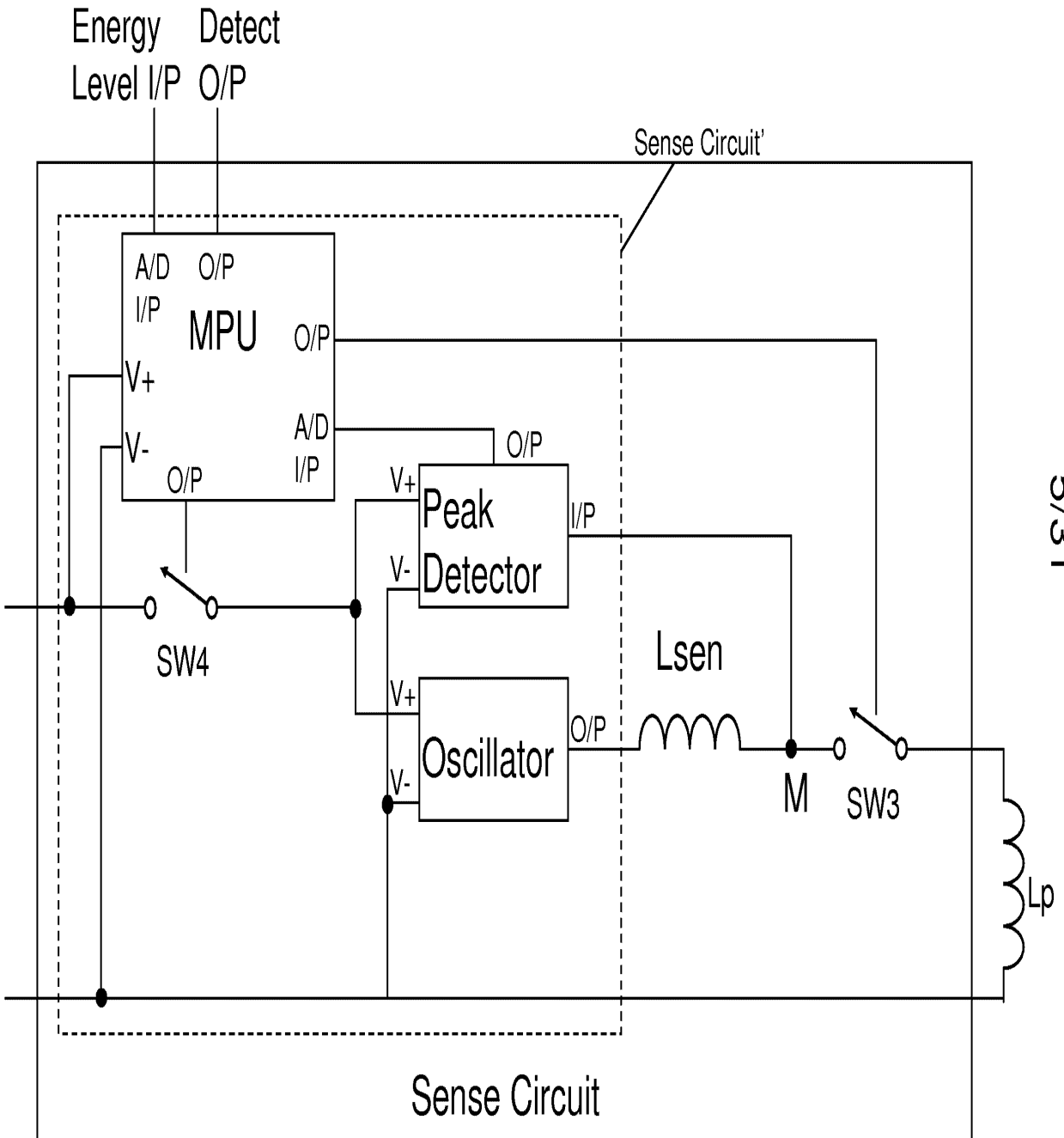


Fig. 4



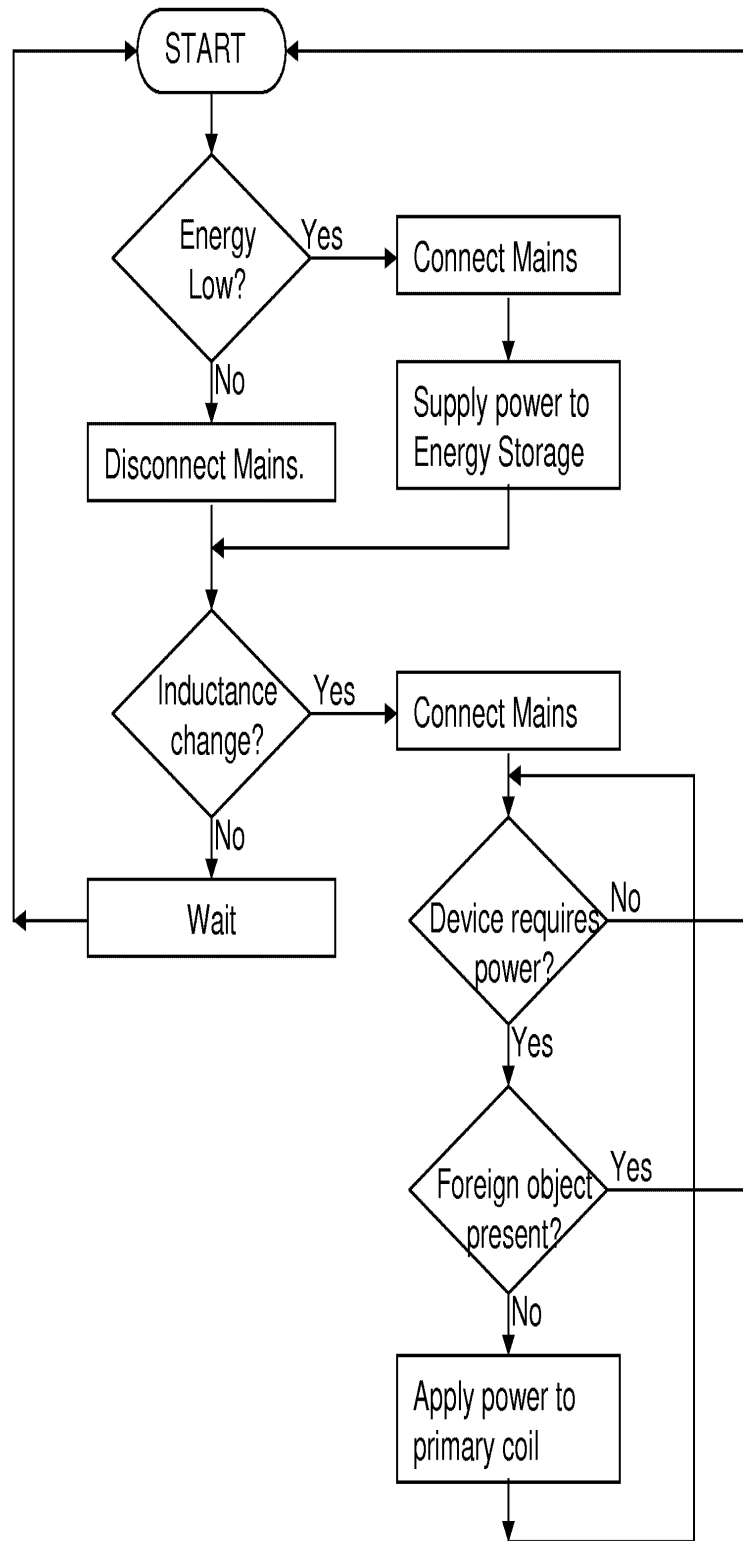
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Fig. 5



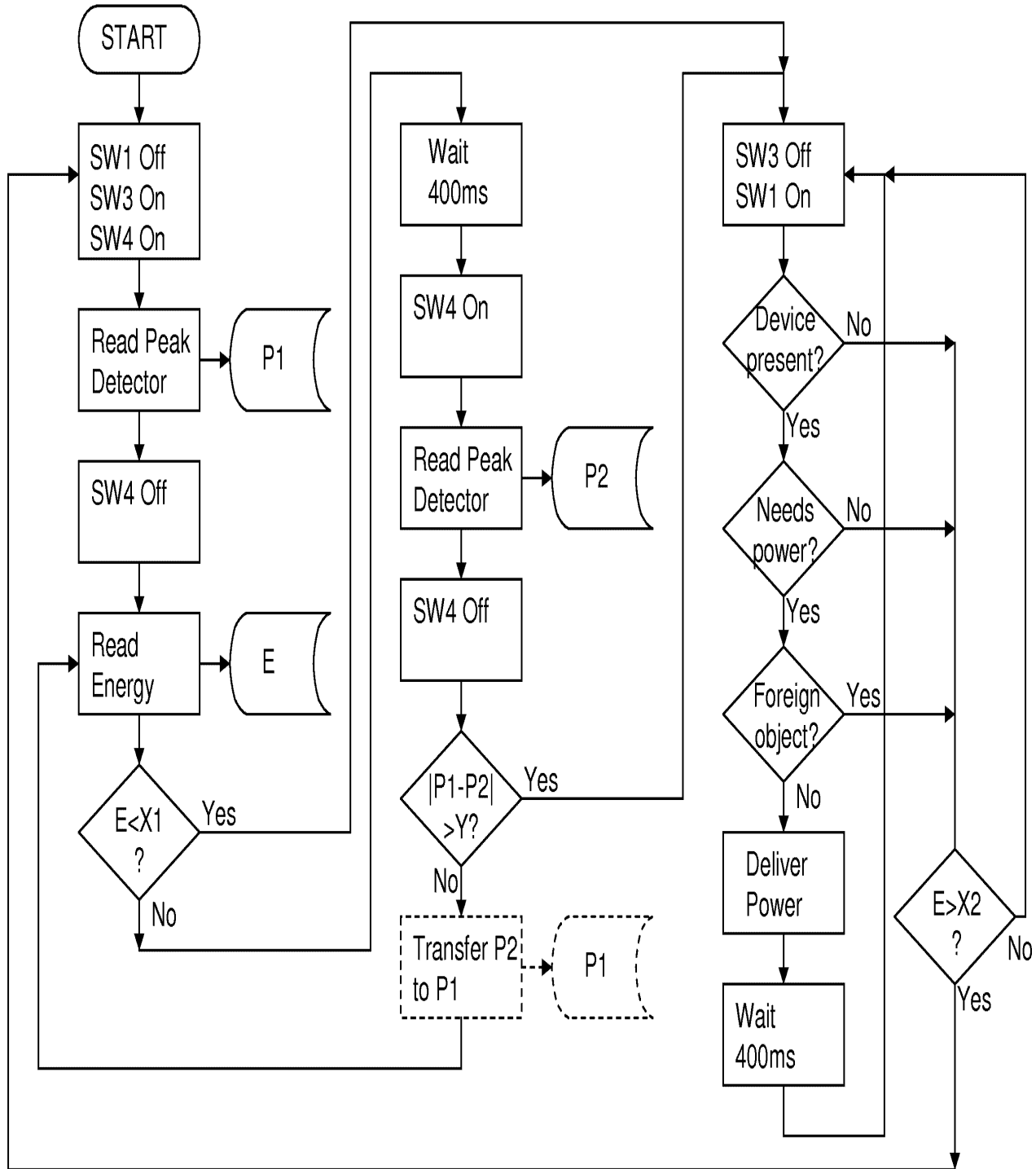
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Fig. 6



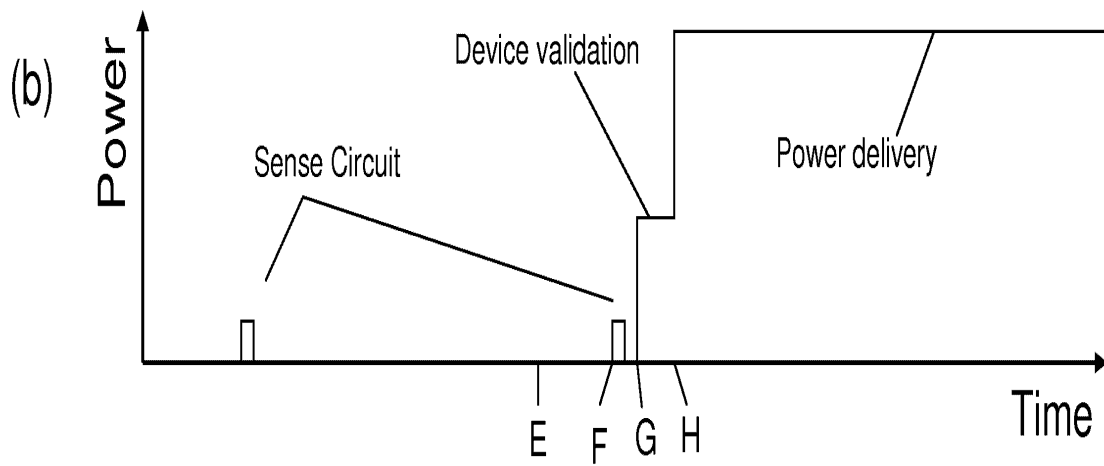
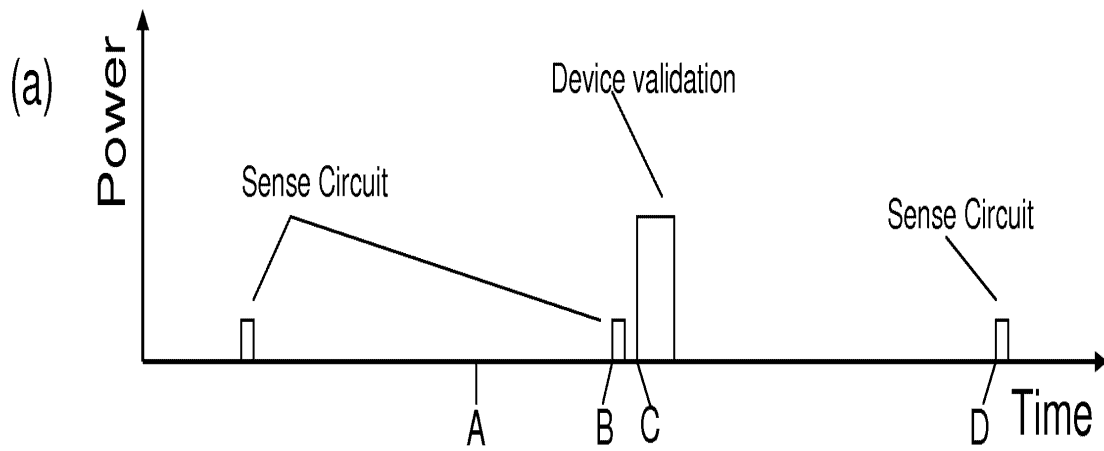
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Fig. 7



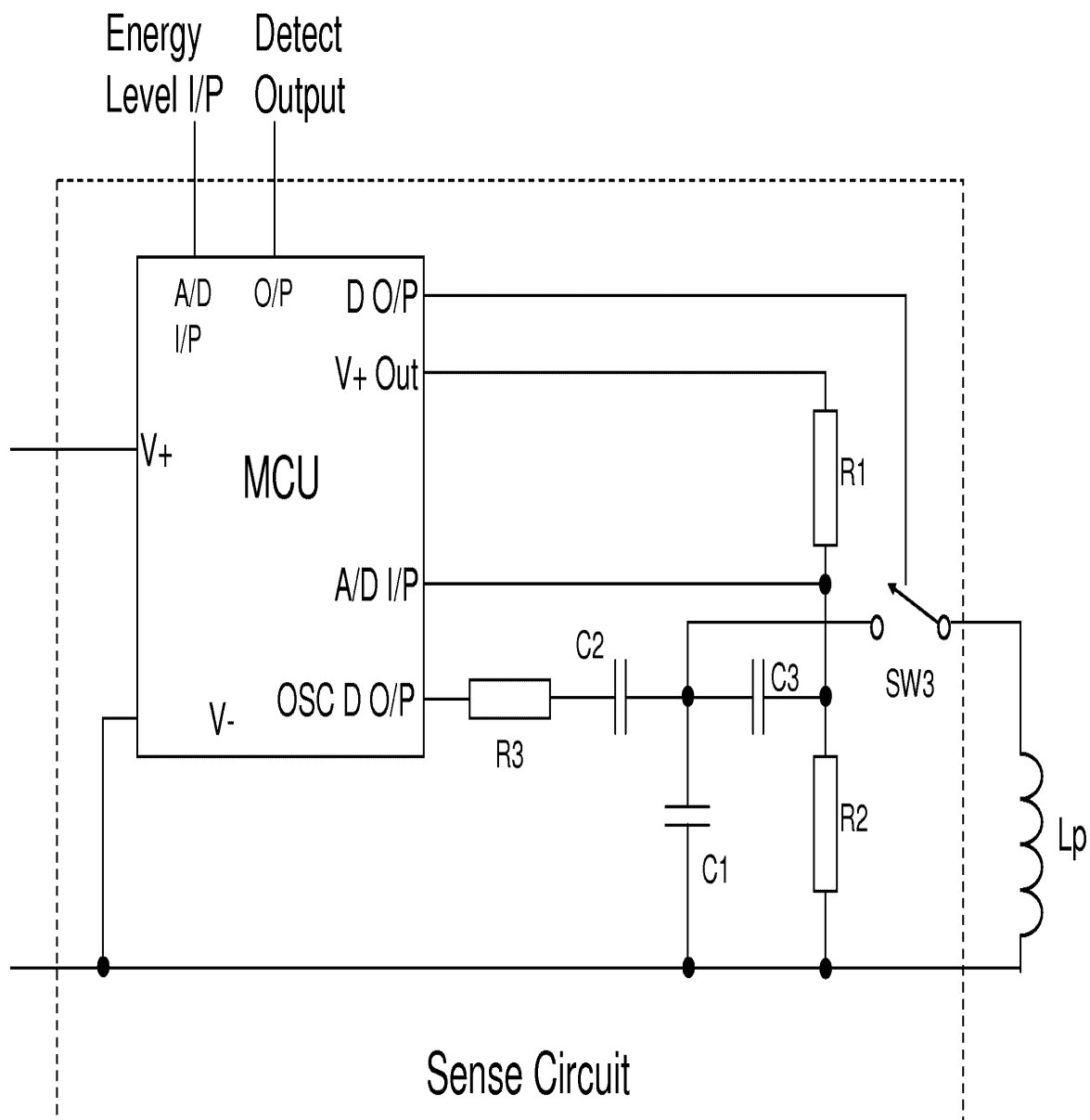
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Fig. 8



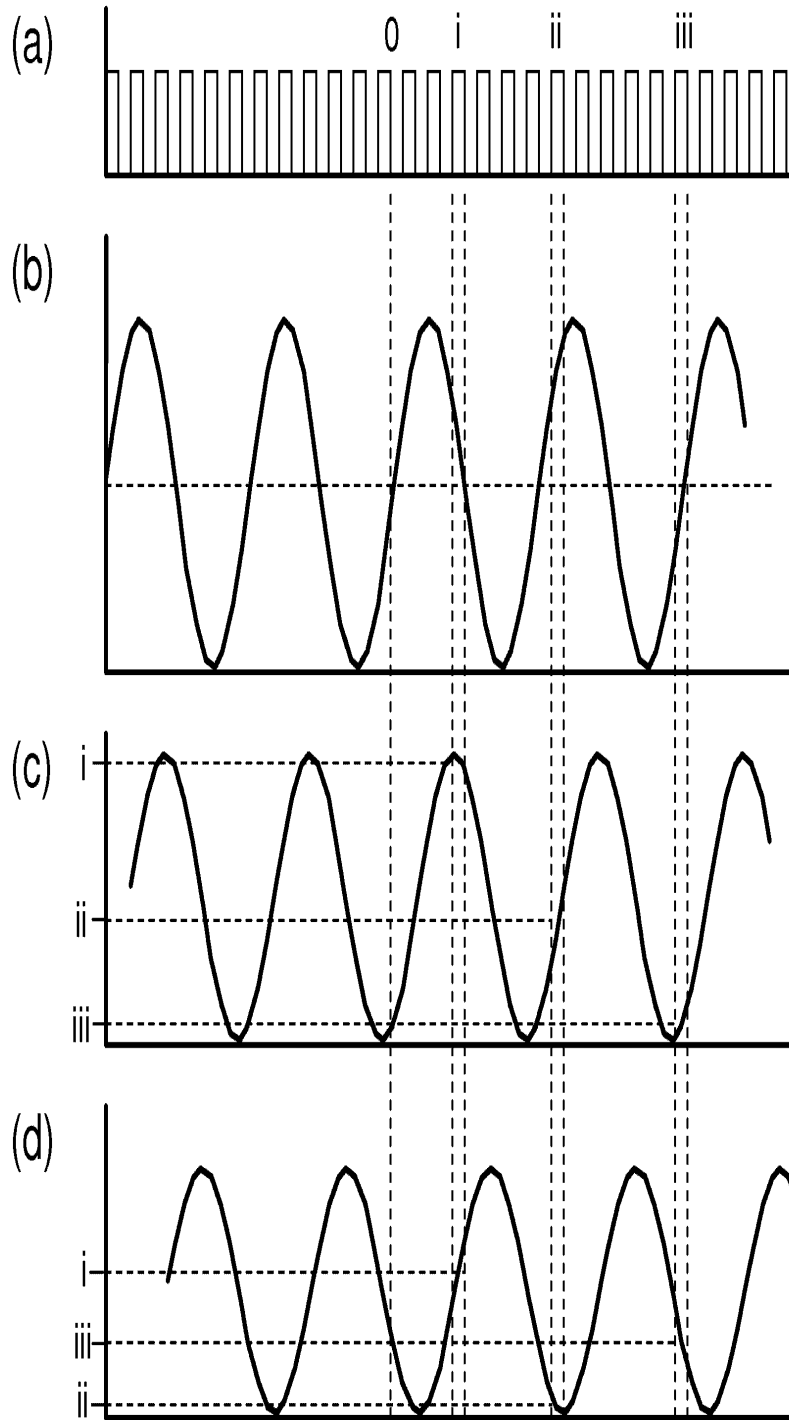
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Fig. 9



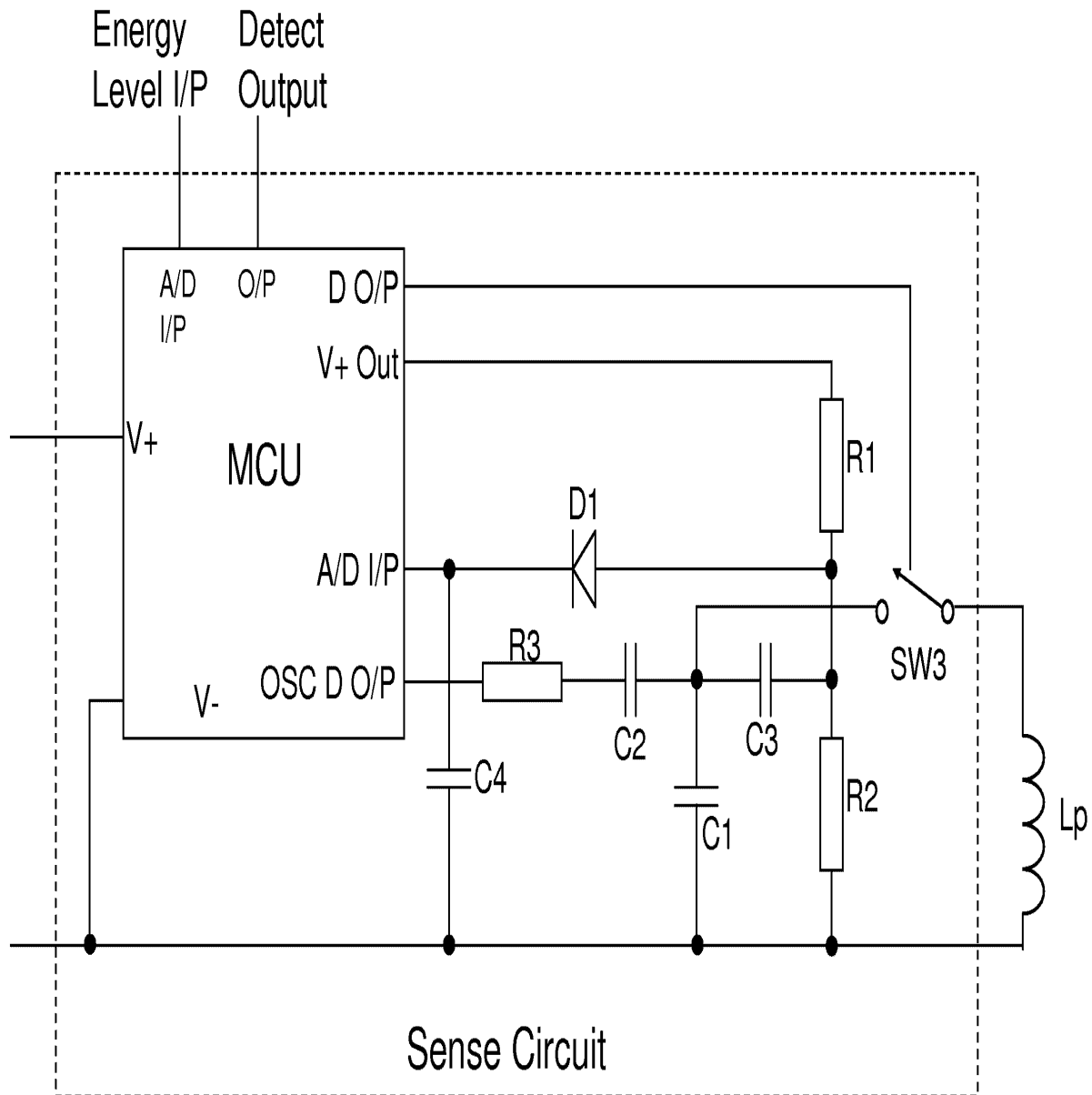
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Fig. 10



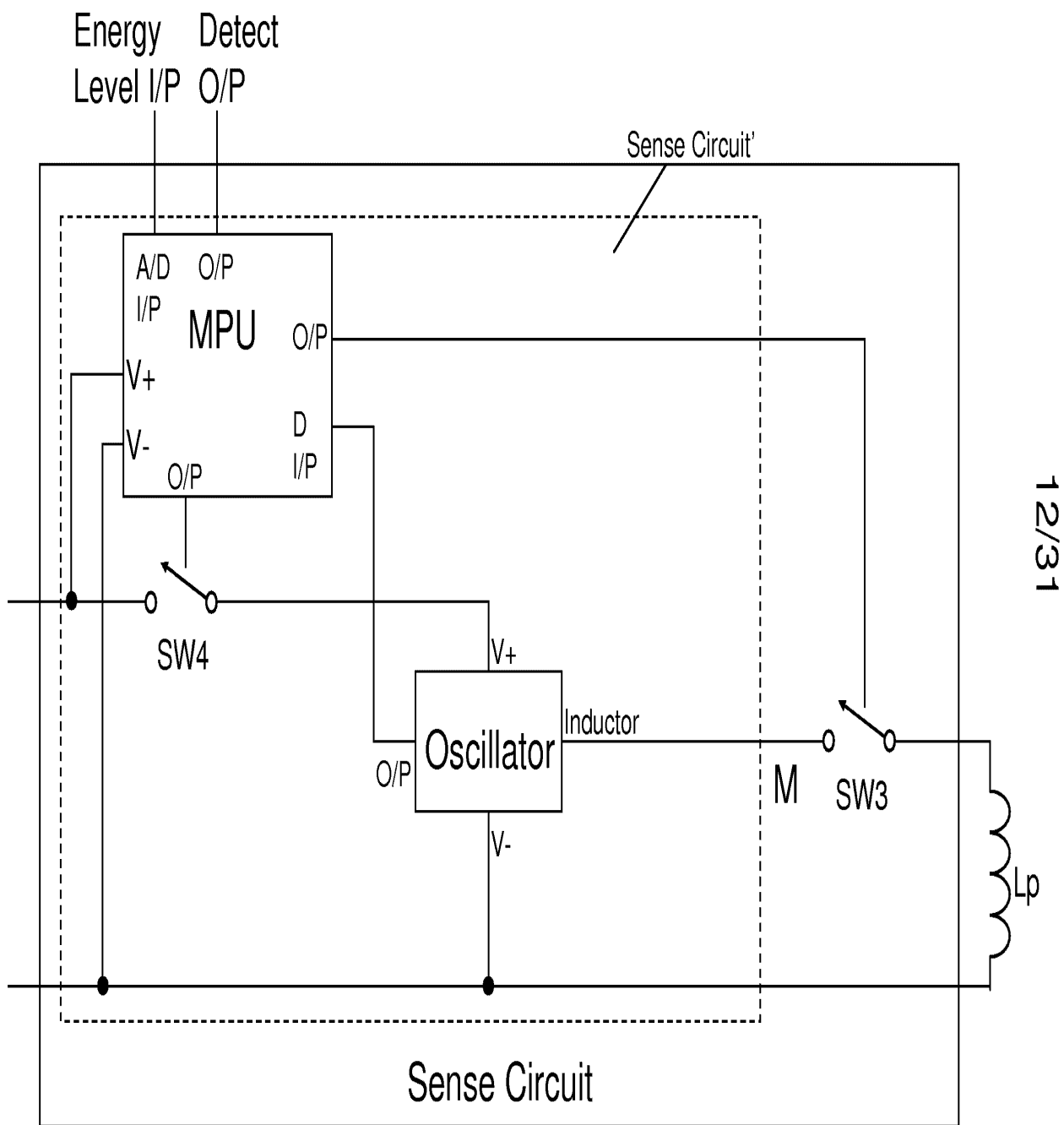
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Fig. 11



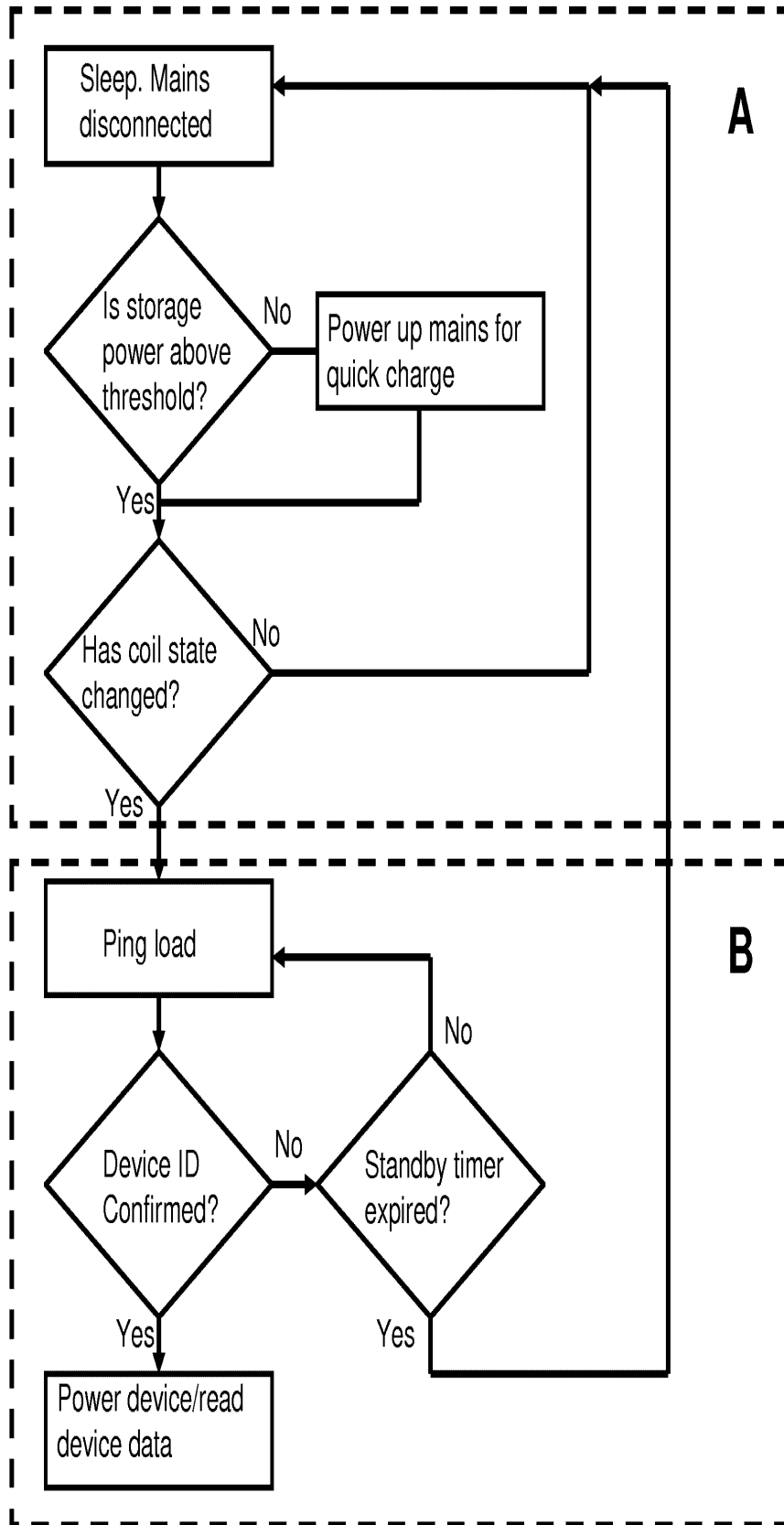
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Fig. 12



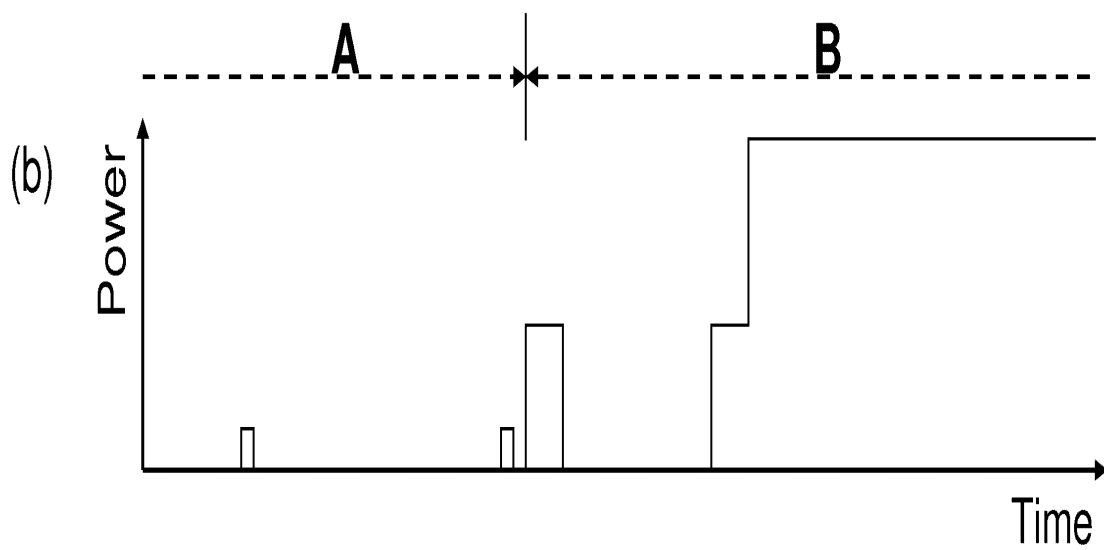
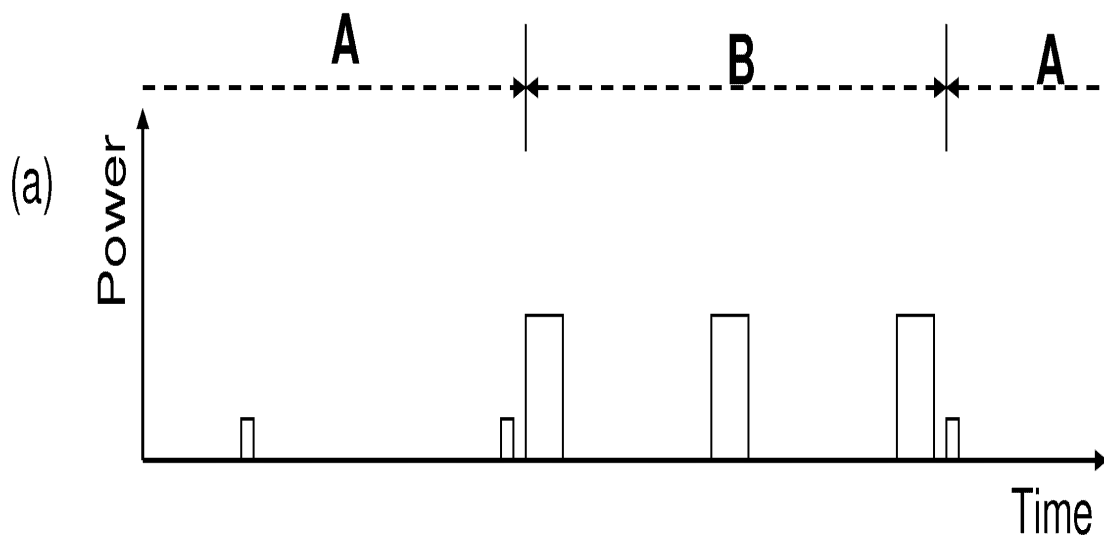
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Fig. 13



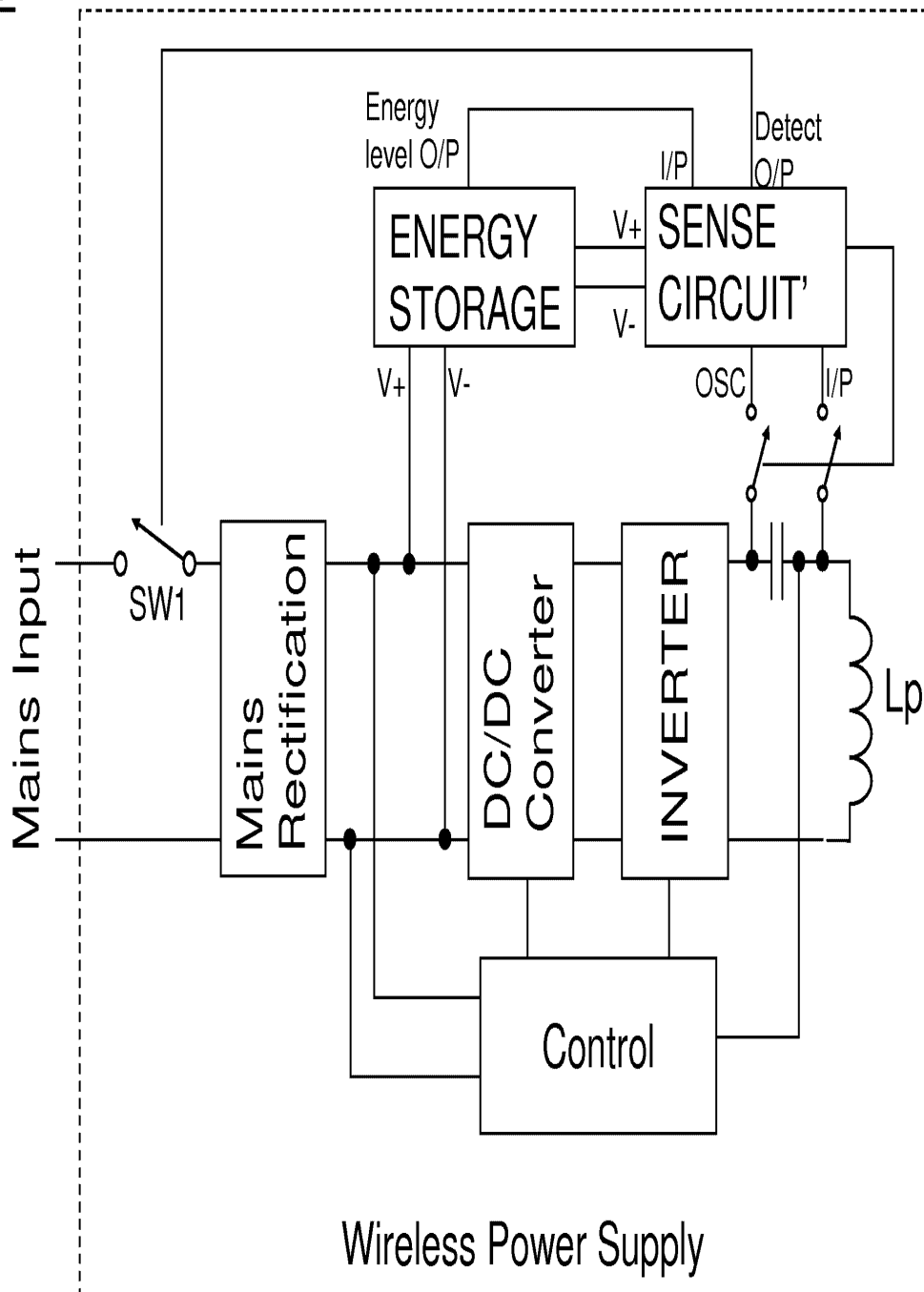
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Fig. 14



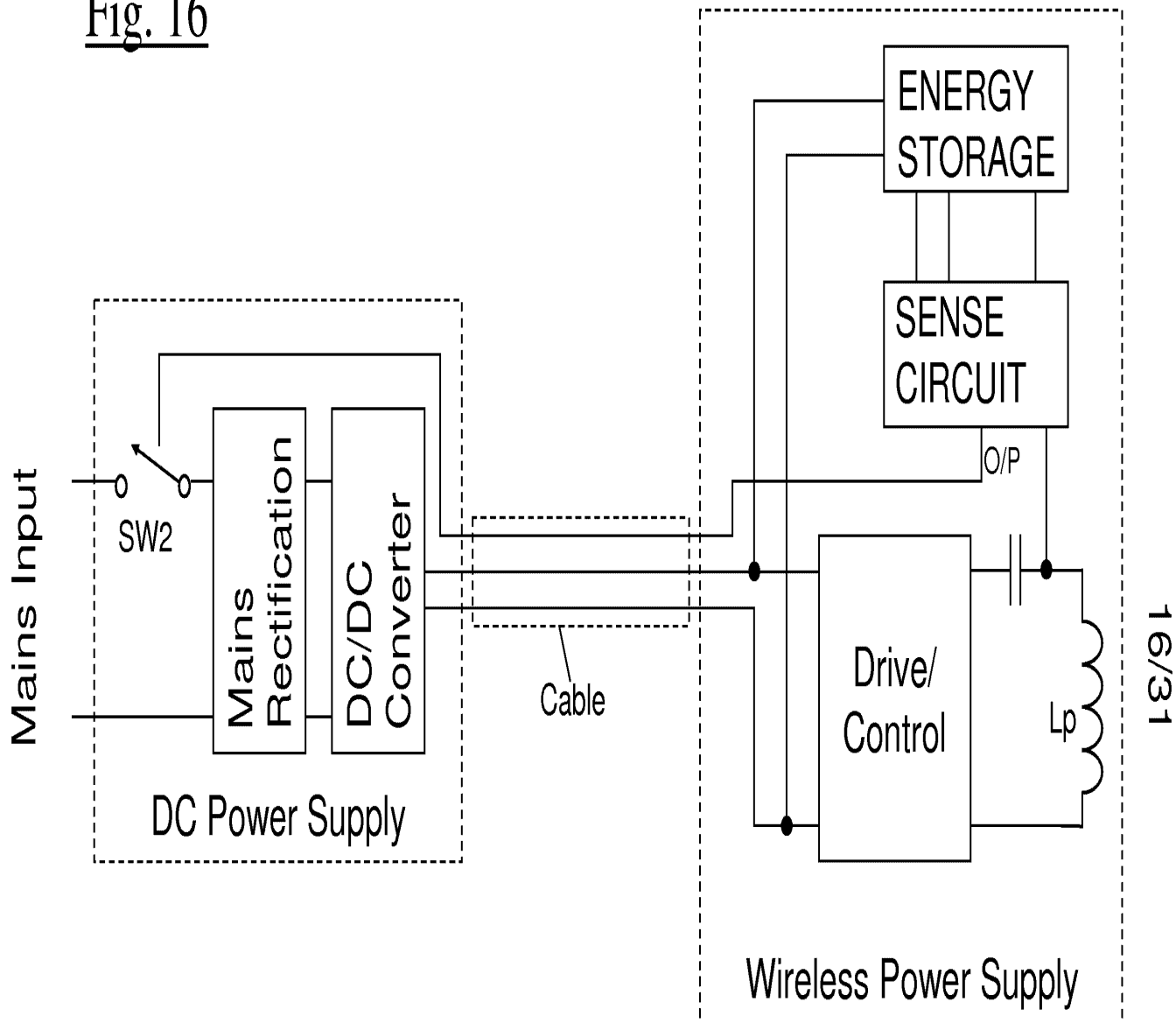
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Fig. 15



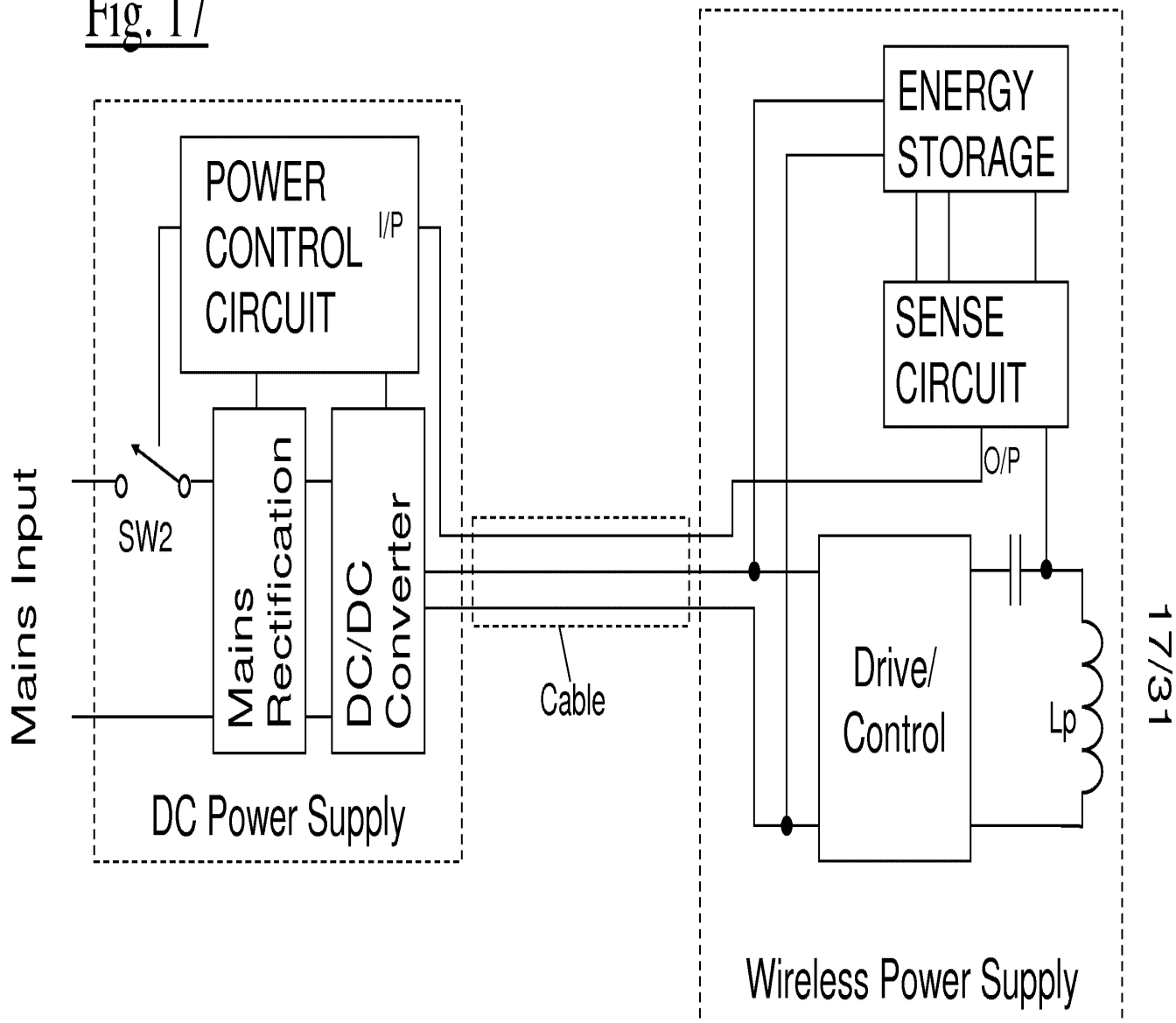
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Fig. 16



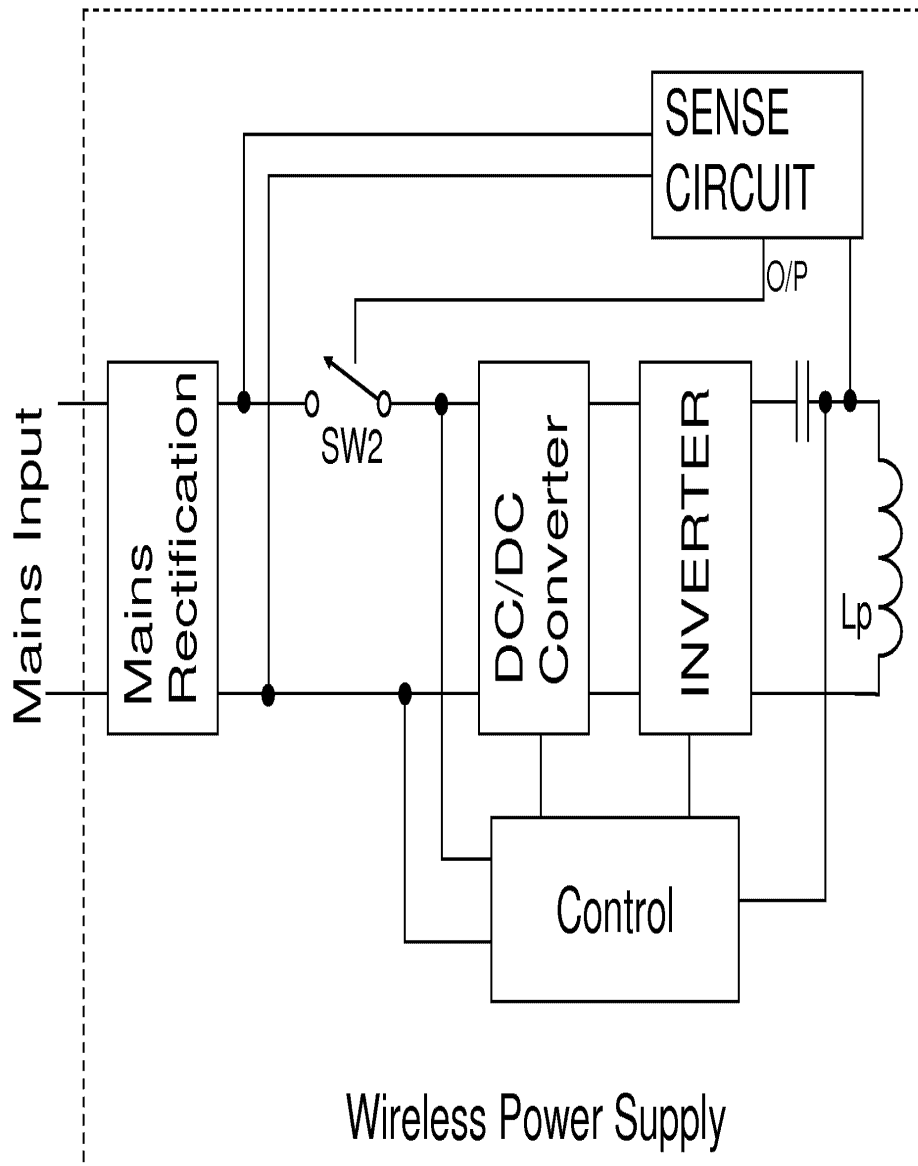
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Fig. 17



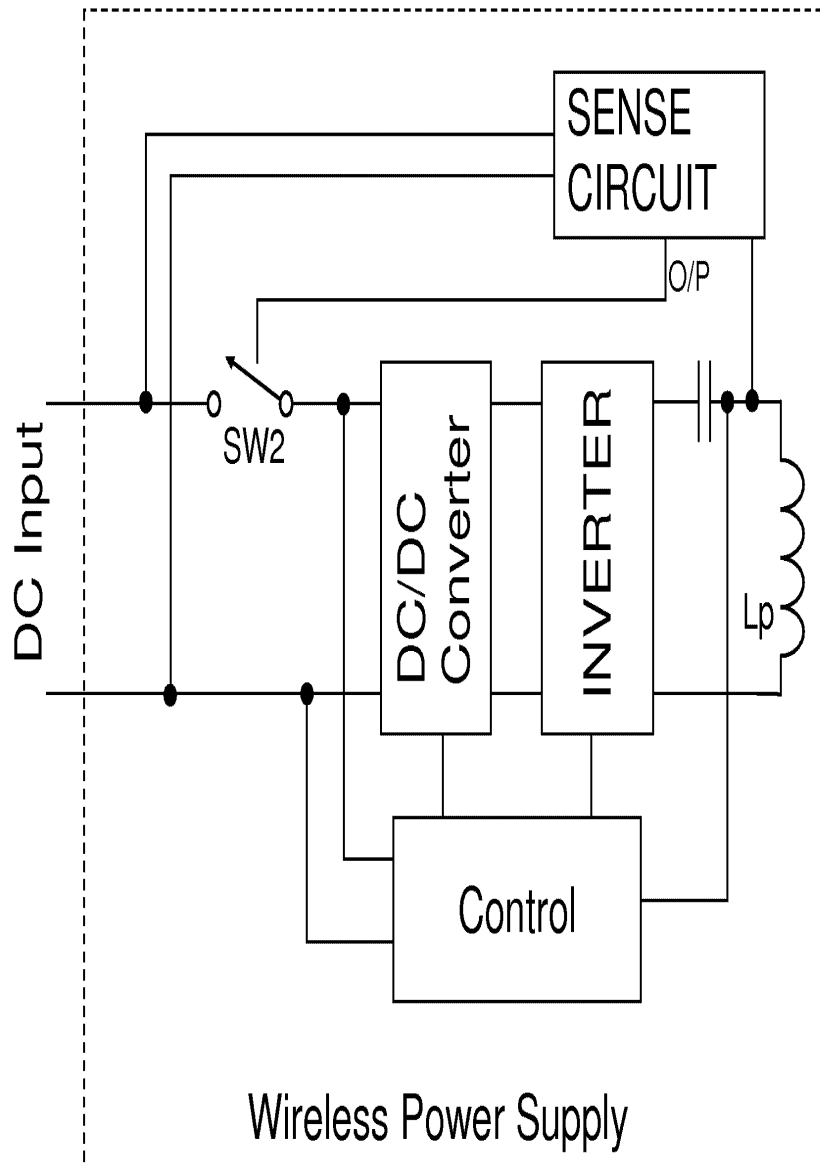
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Fig. 18



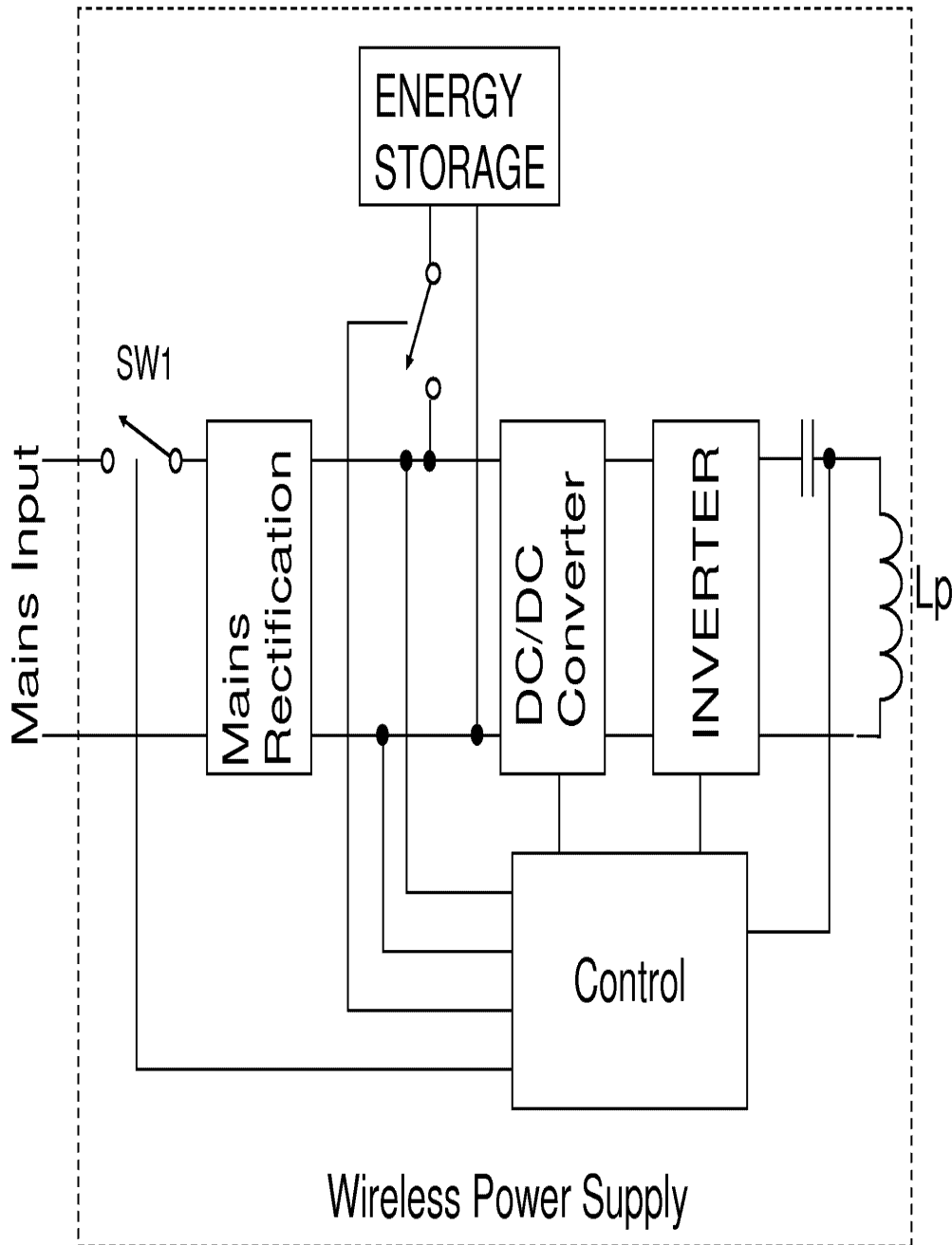
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Fig. 19



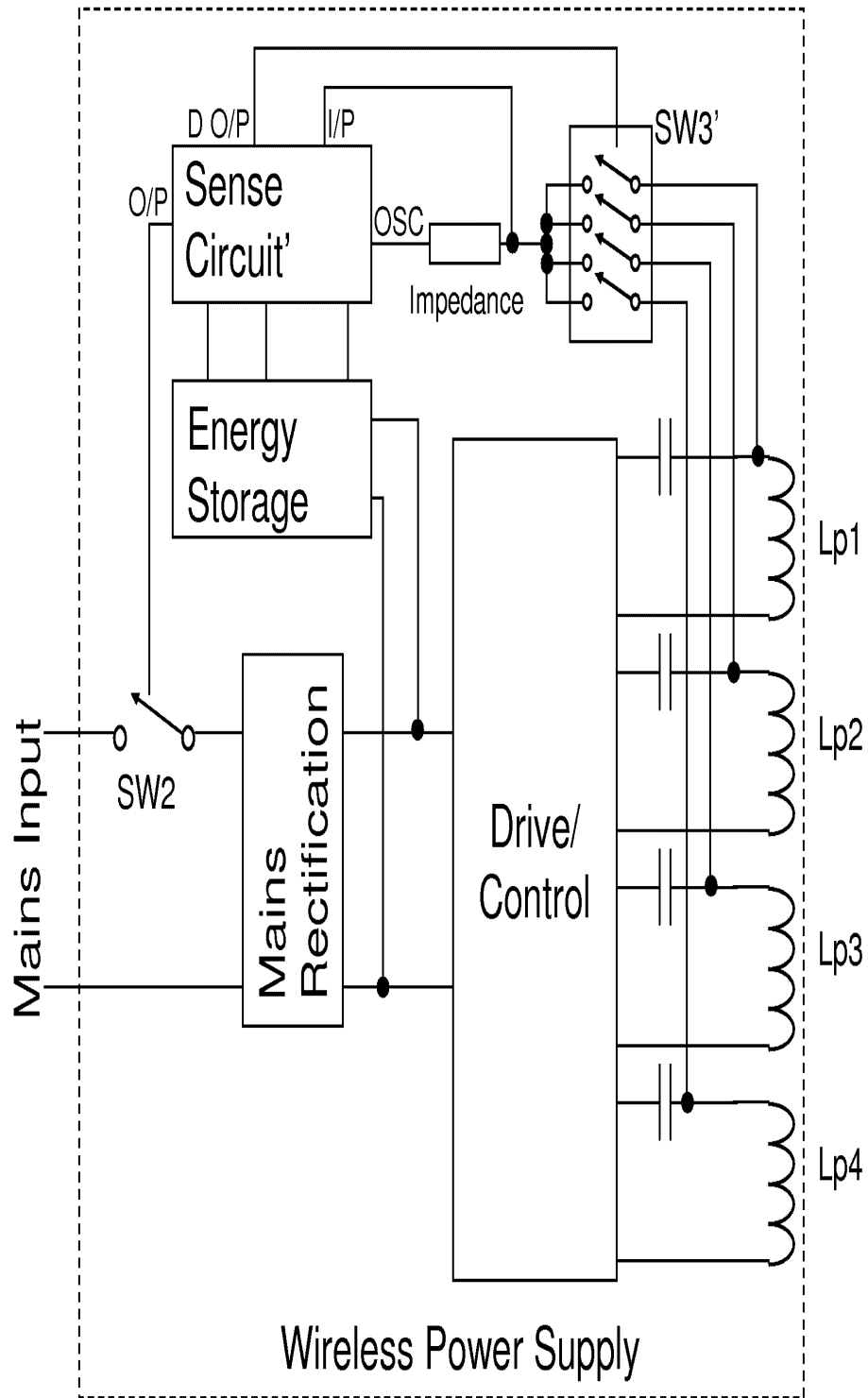
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Fig. 20



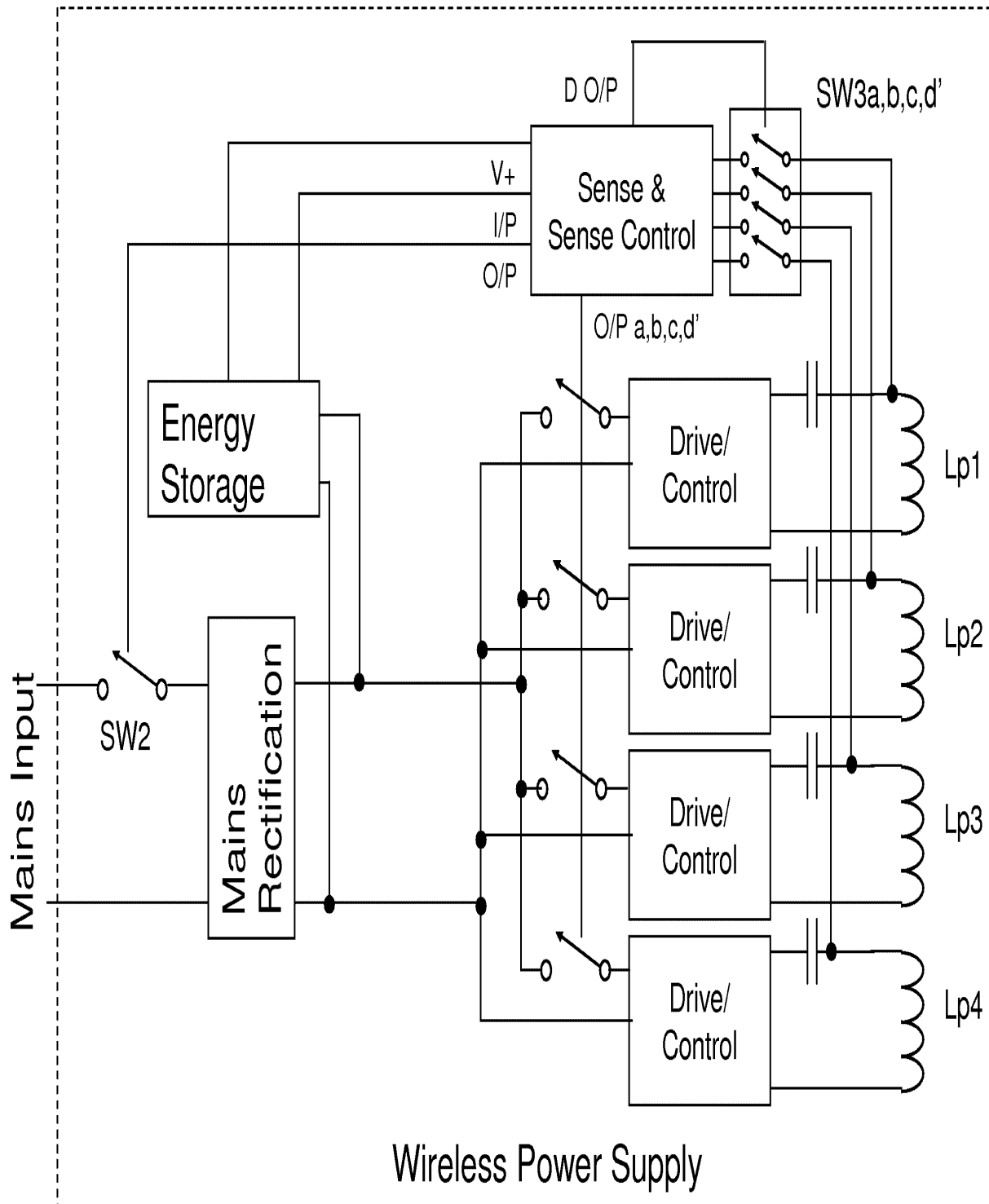
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Fig. 21



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Fig. 22



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Fig. 23

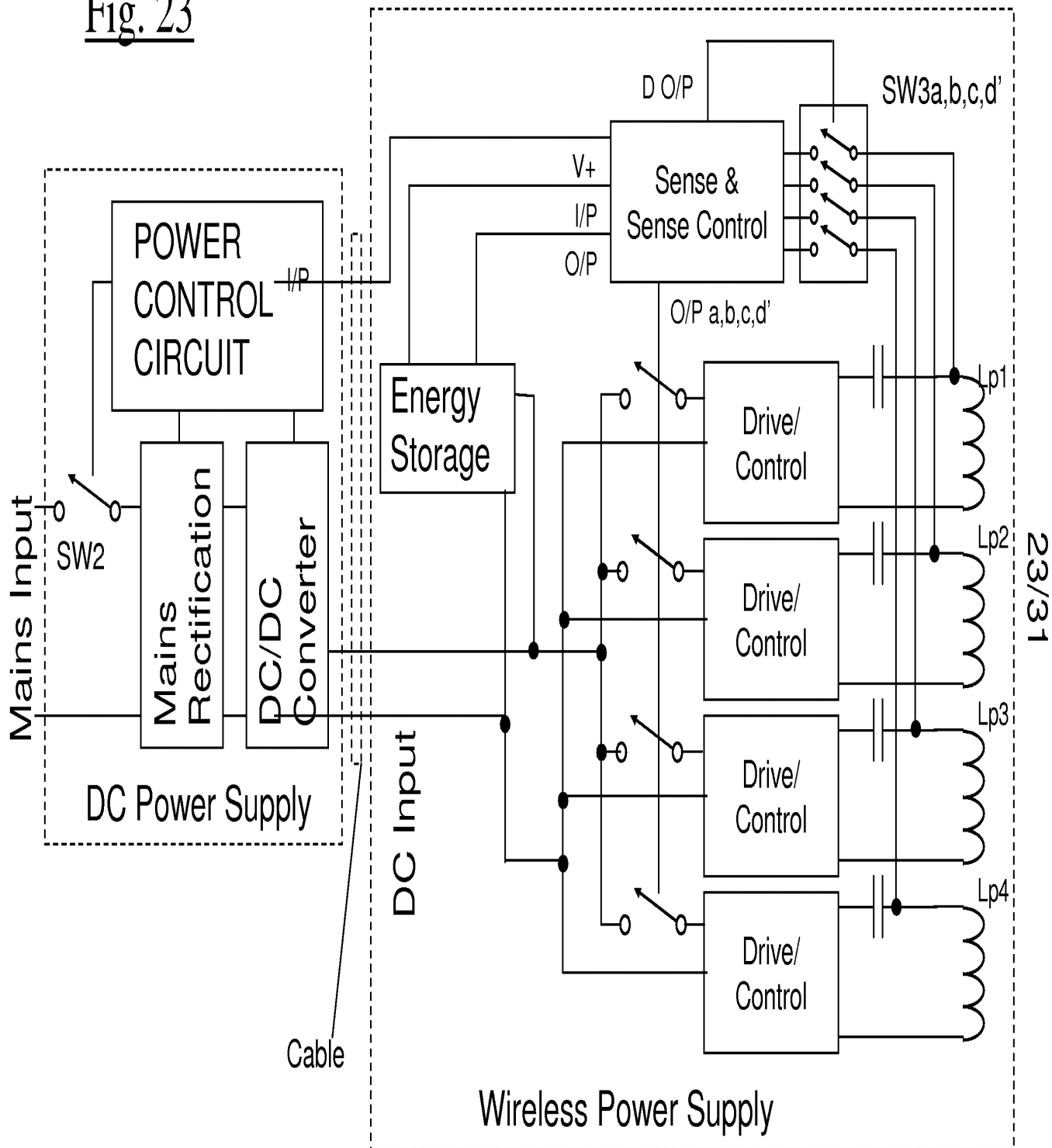


Fig. 24

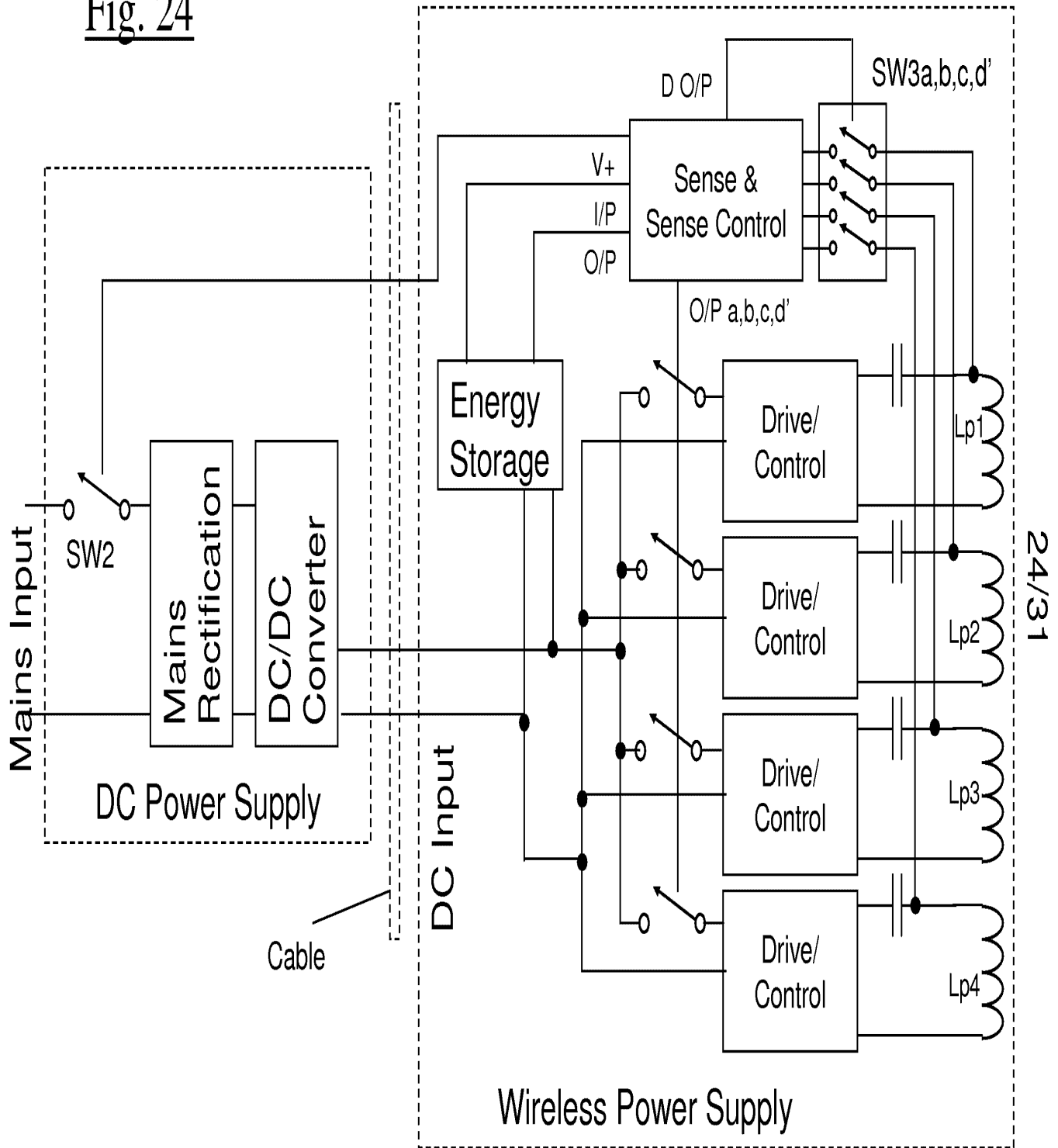
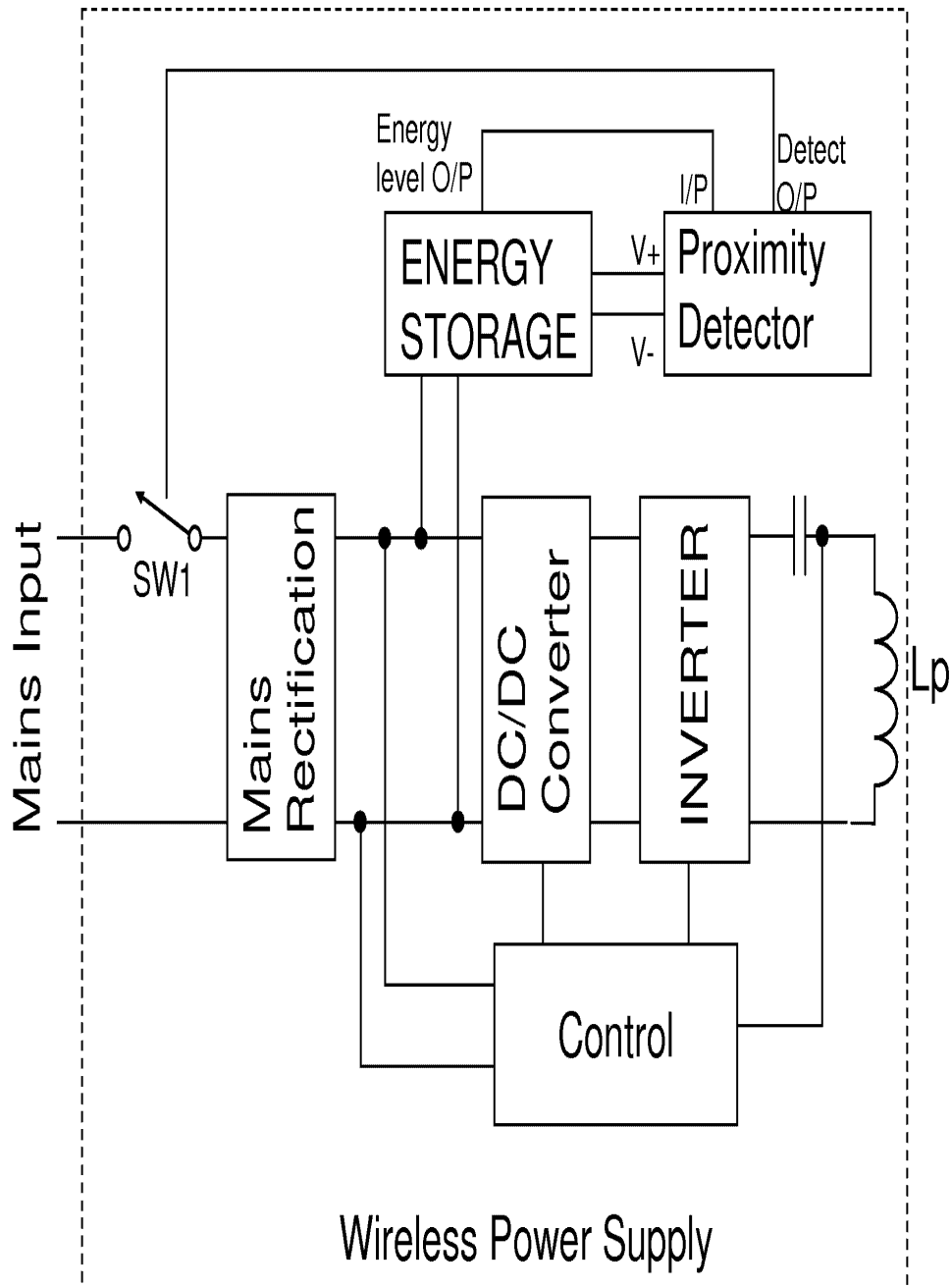
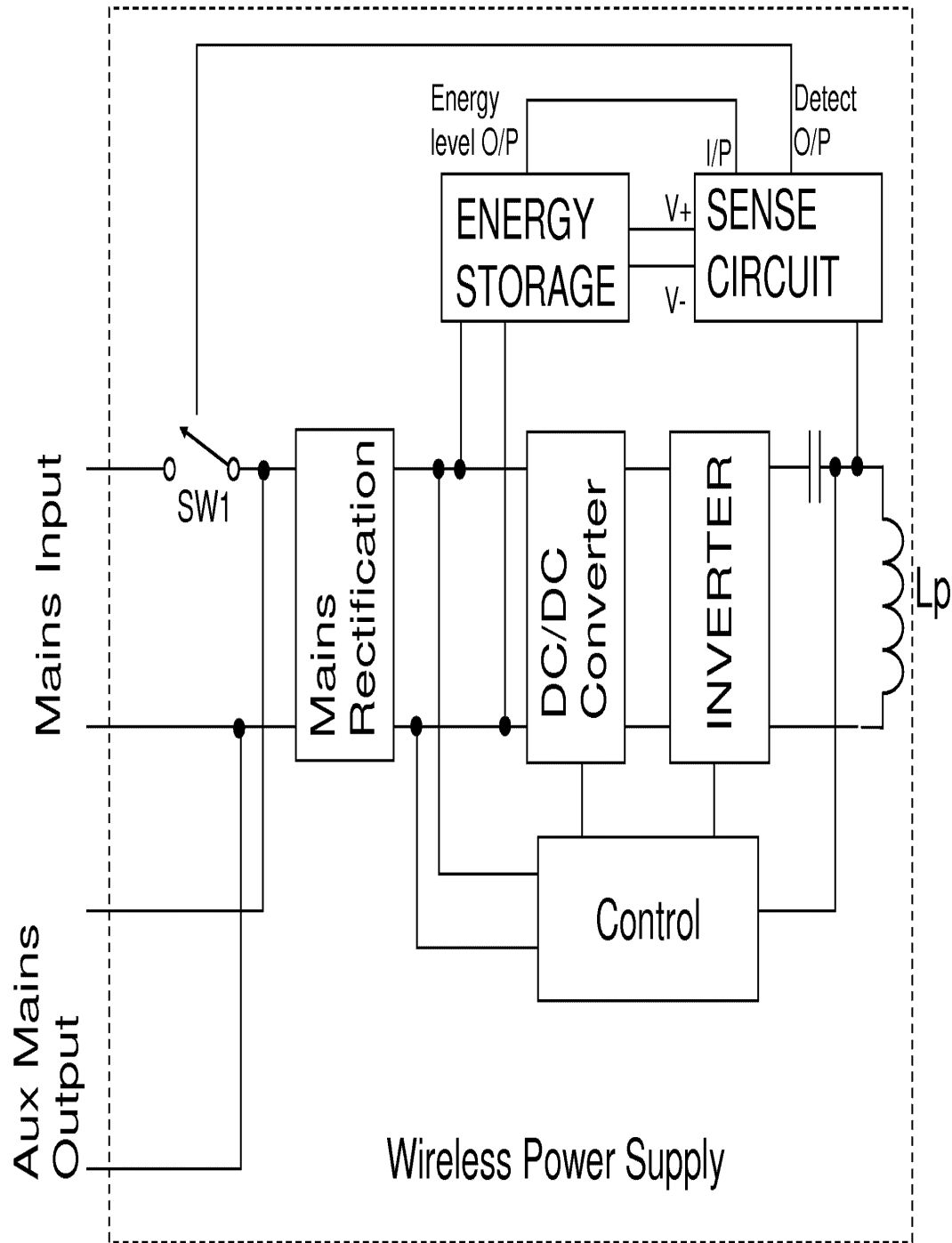


Fig. 25



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Fig. 26



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Fig. 27

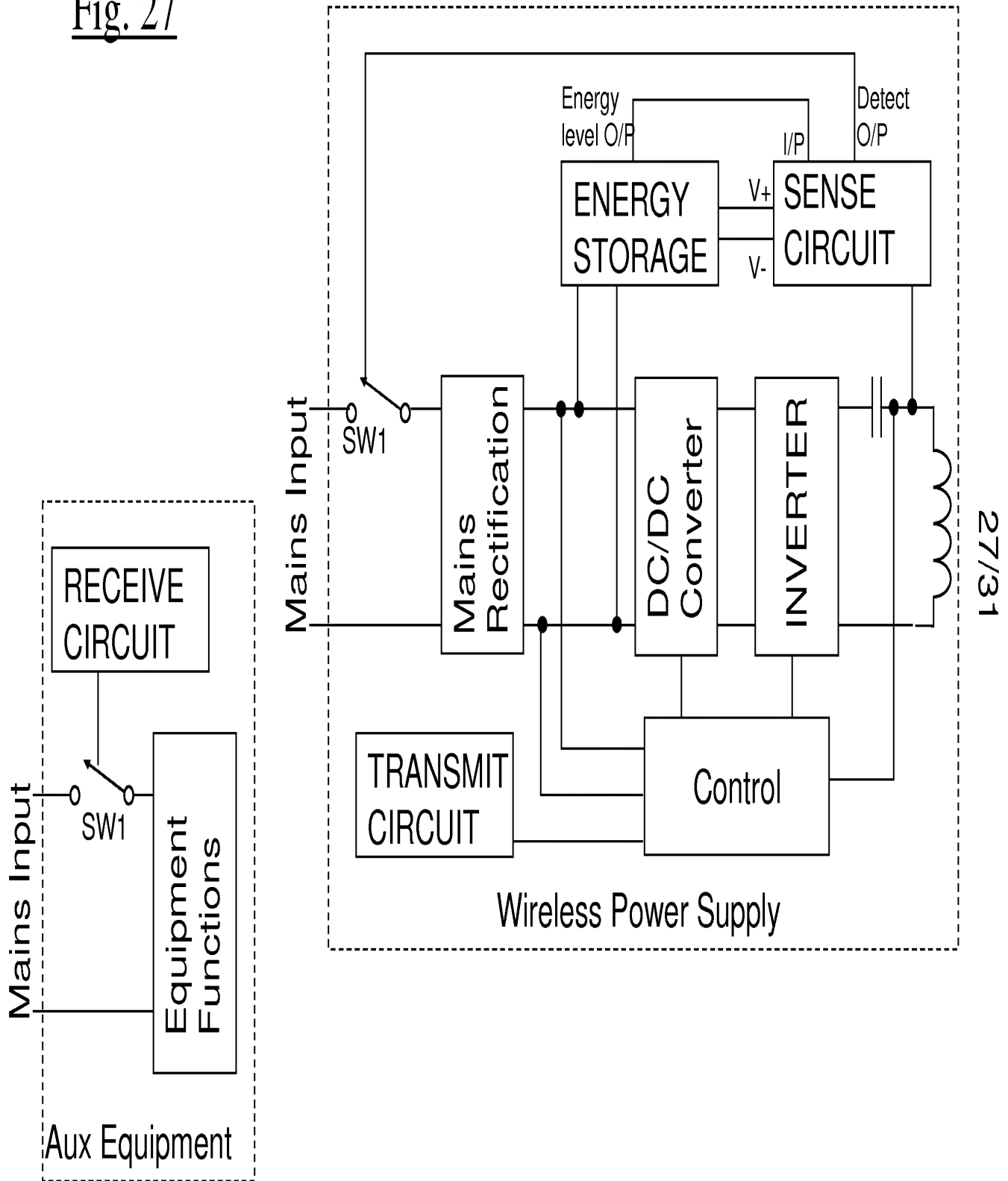


Fig. 28

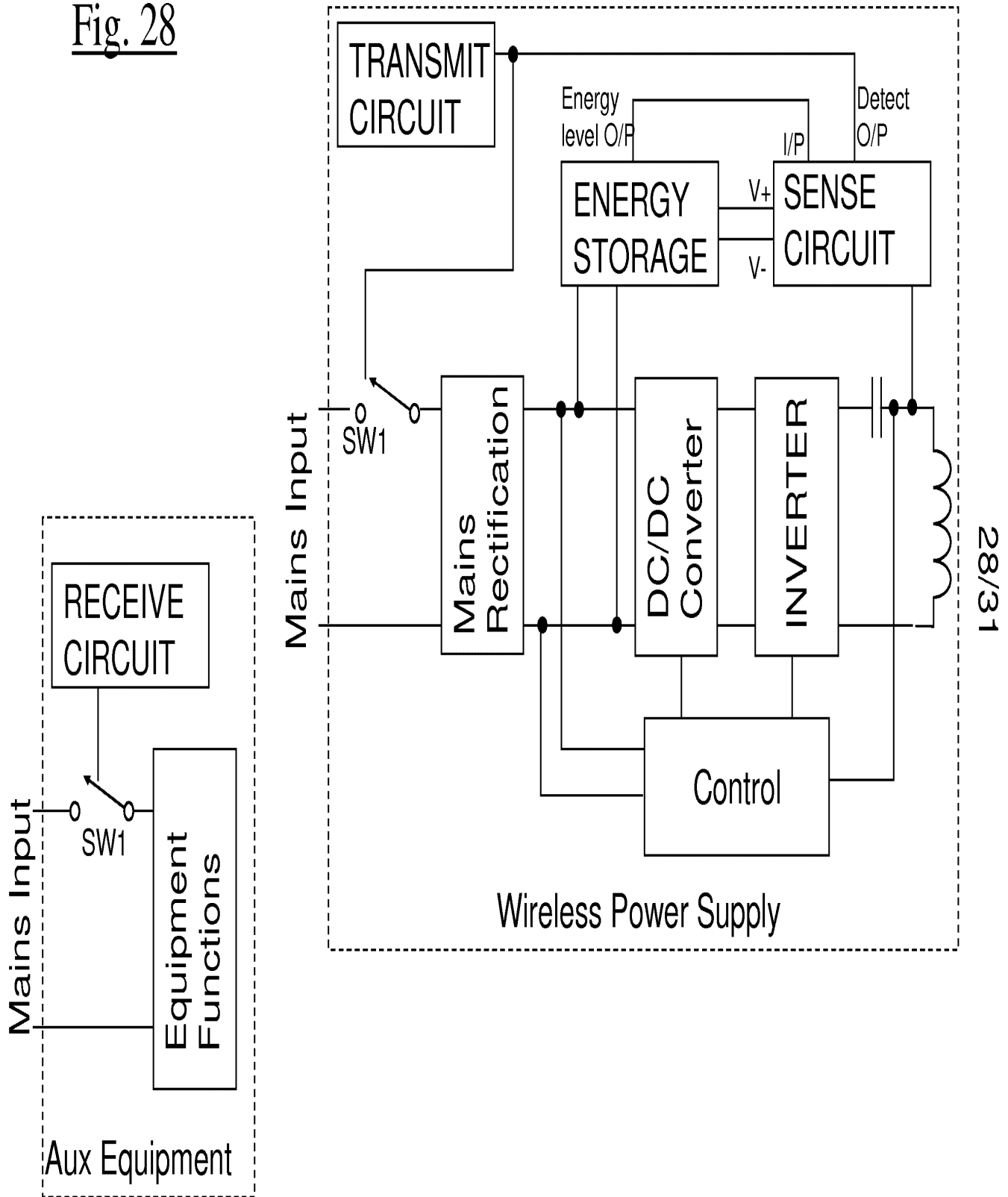
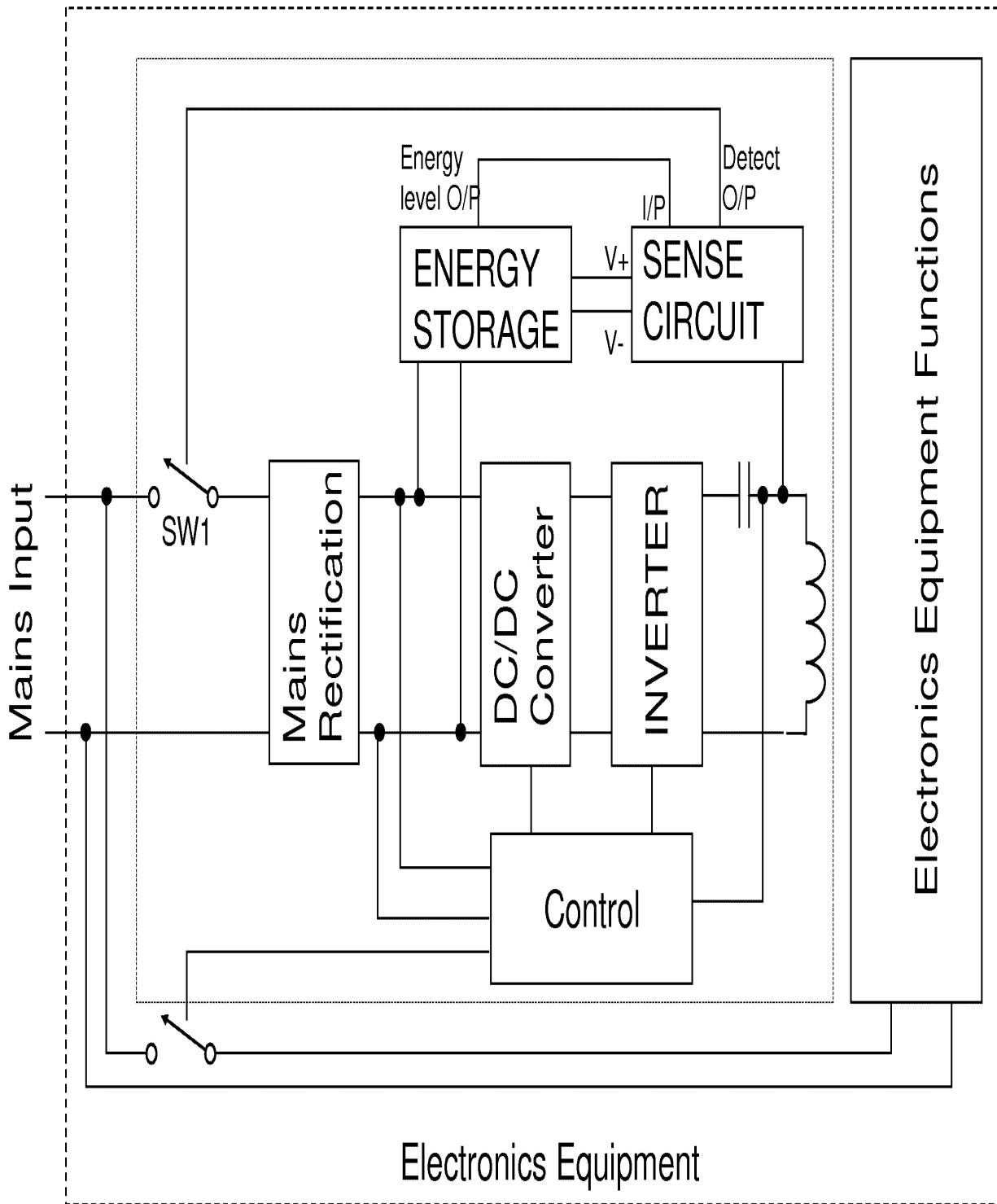
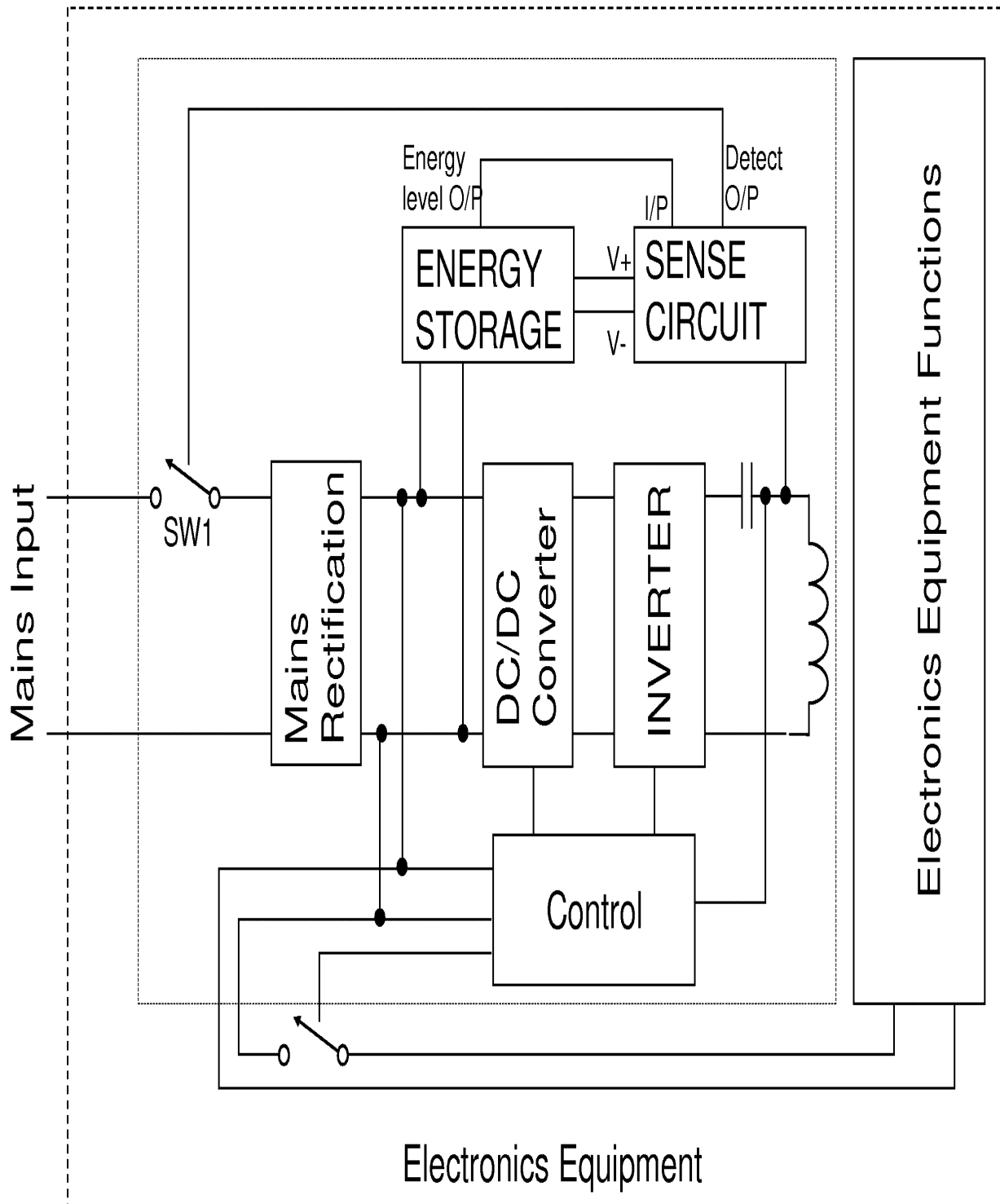


Fig. 29



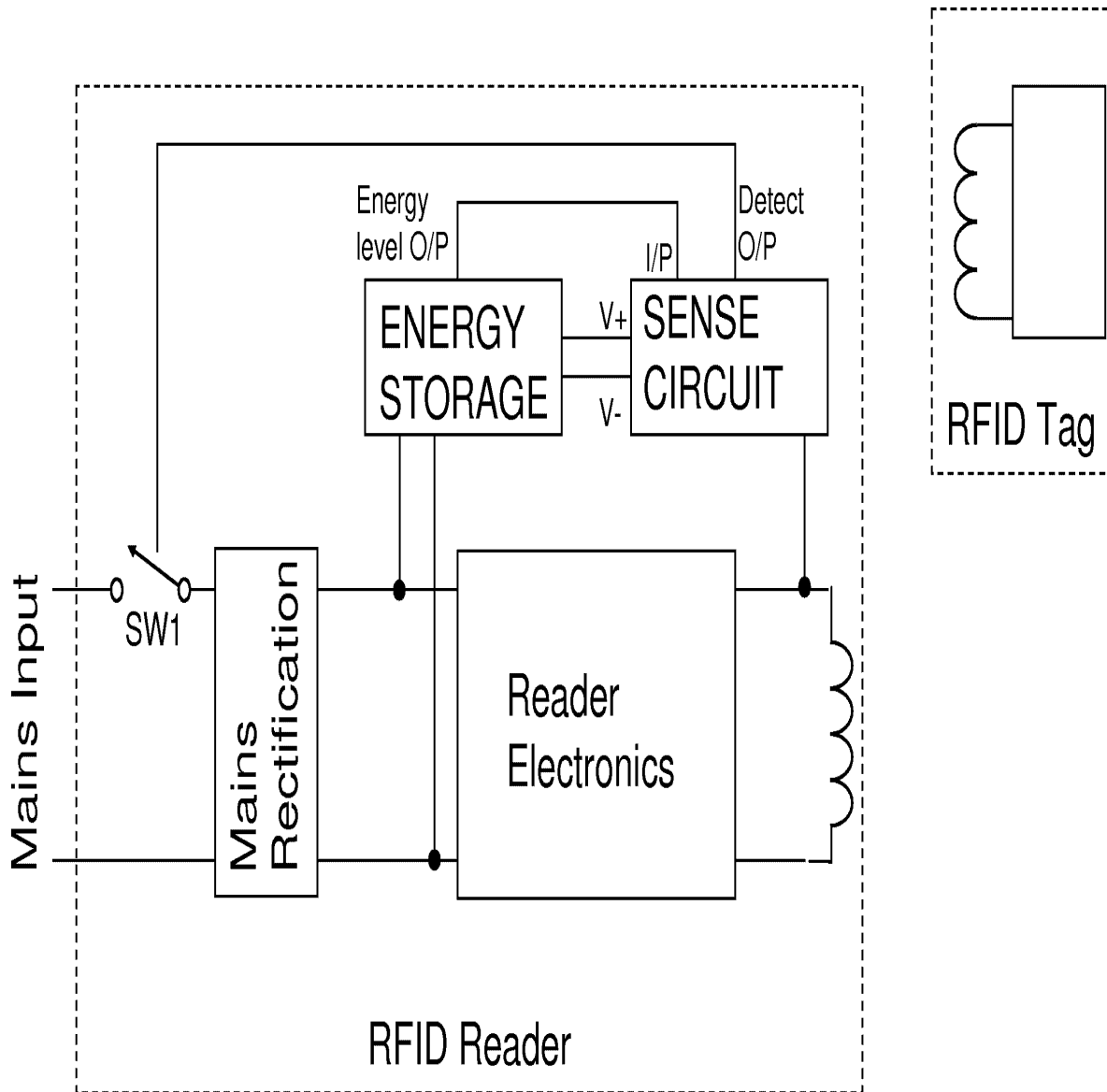
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Fig. 30



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Fig. 31



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