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(54) METHOD AND APPARATUS FOR WIRELESS POWER TRANSMISSION WITH HARMONIC NOISE CANCELLATION

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(73) Assignee: **SAMSUNG ELECTRONICS CO., LTD.**, Suwon-si (KR)

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H02J 7/02	(2016.01)
H01F 38/14	(2006.01)
H02J 7/00	(2006.01)
H02J 50/80	(2016.01)

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CPC ***H02J 7/00714*** (2020.01); ***H02J 50/12*** (2016.02); ***H02J 50/80*** (2016.02); *H01F 38/14* (2013.01); *H02J 50/40* (2016.02)

(58) **Field of Classification Search**
CPC .. H02J 50/12; H02J 5/005; H02J 7/025; H02J 50/40; H02F 38/14
See application file for complete search history.

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Primary Examiner — Woo H Choi
(74) *Attorney, Agent, or Firm* — Nixon & Vanderhye, P.C.

(57) **ABSTRACT**

A wireless power transmission apparatus includes a source resonator configured to transmit an output power from which a harmonic component has been cancelled to a wireless power reception apparatus by resonating with a target resonator of the wireless power transmission apparatus, and a resonant power generator configured to differentially input a first input signal and a second input signal to the source resonator, and cancel the harmonic component of the output power.

14 Claims, 18 Drawing Sheets

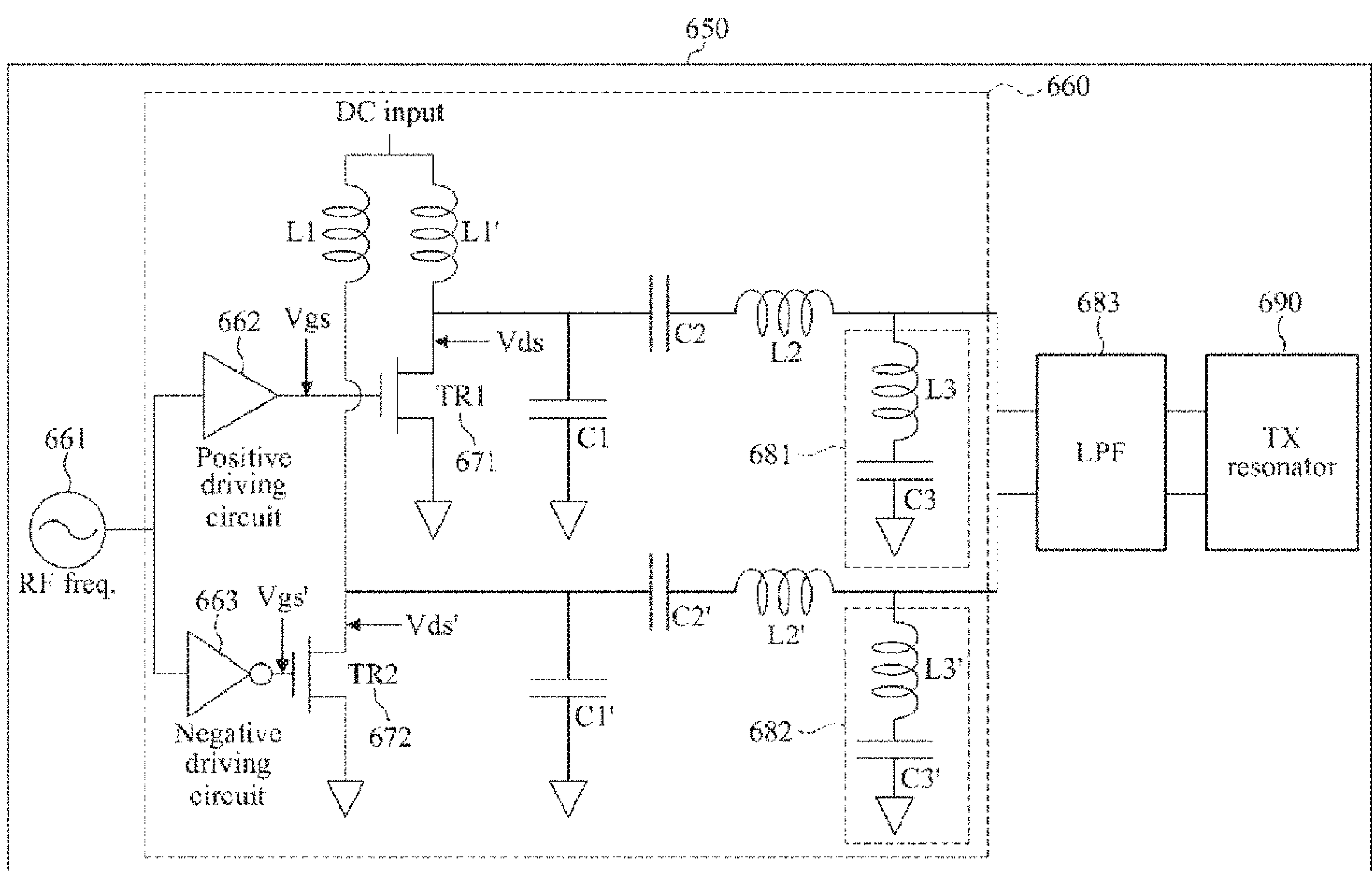

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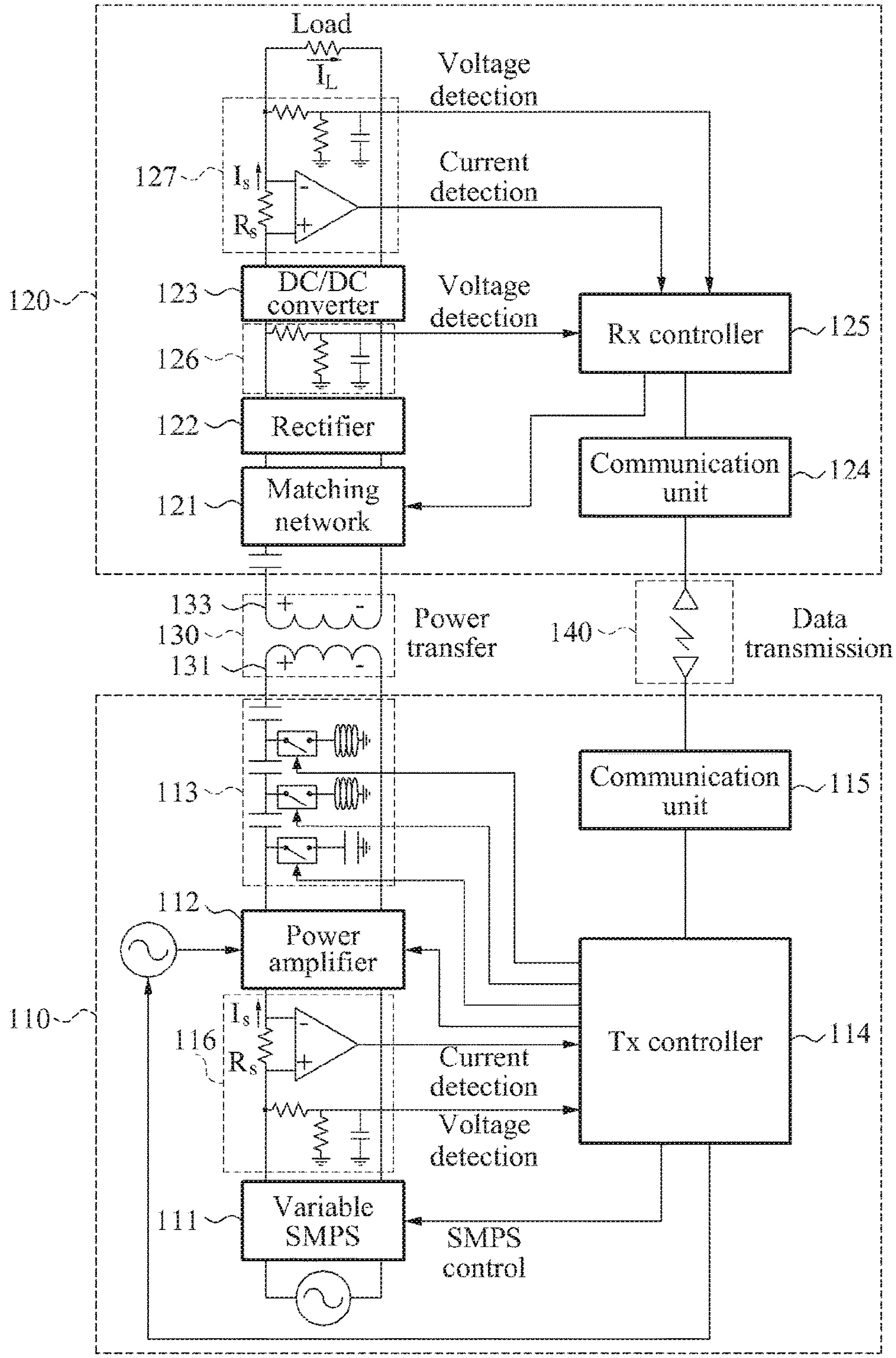
FIG. 1



Load
I_L
Voltage detection
127
I_s
R_s
Current detection
120
123
DC/DC converter
Voltage detection
Rx controller
125
126
122
Rectifier
Communication unit
124
121
Matching network
133
130
131
Power transfer
140
Data transmission
113
Communication unit
115
112
Power amplifier
110
116
I_s
R_s
Tx controller
114
Current detection
Voltage detection
111
Variable SMPS
SMPS control

FIG. 2A

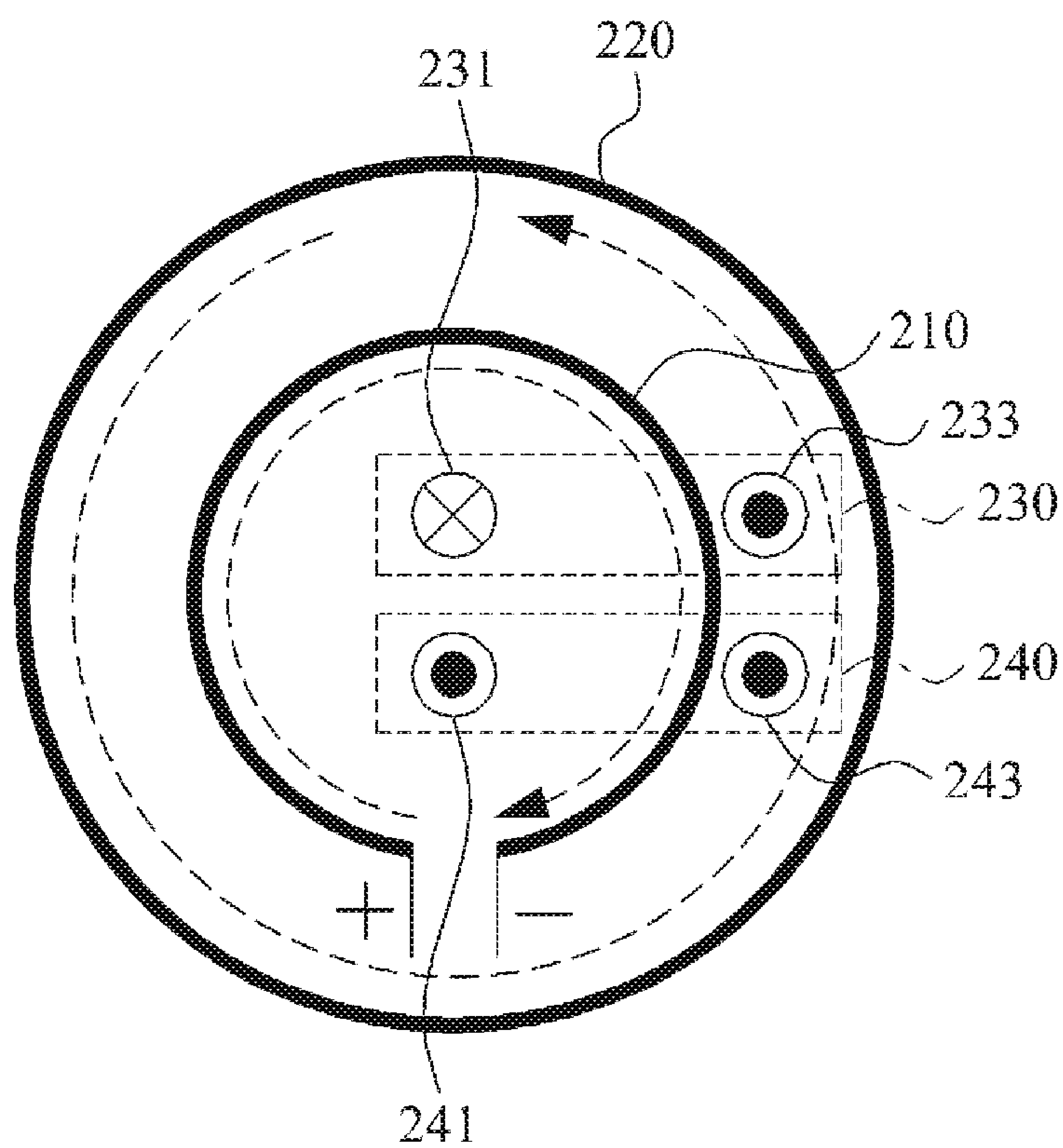


FIG. 2B

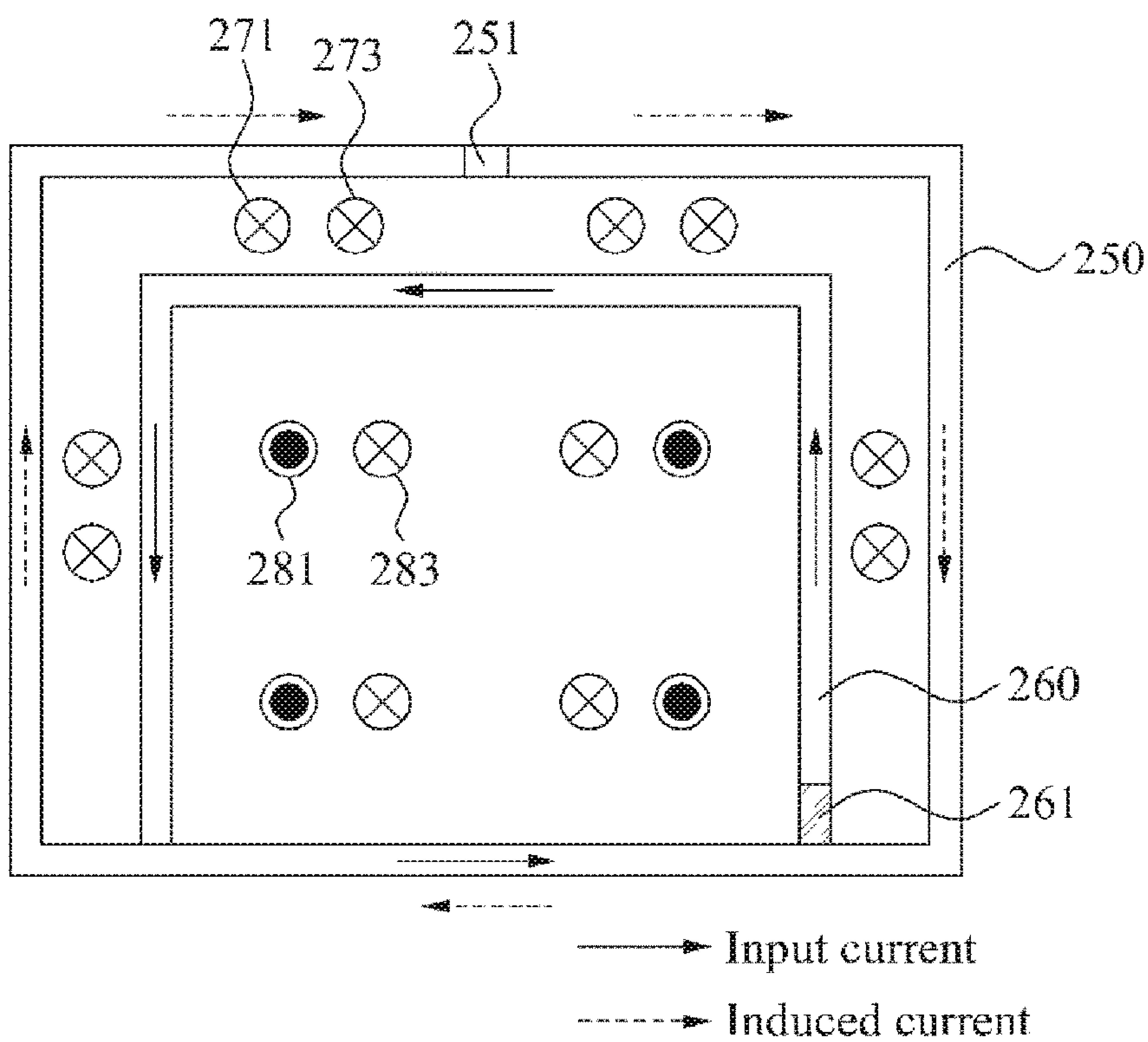

271
273
251
250
281
283
260
261
Input current
Induced current

FIG. 3A

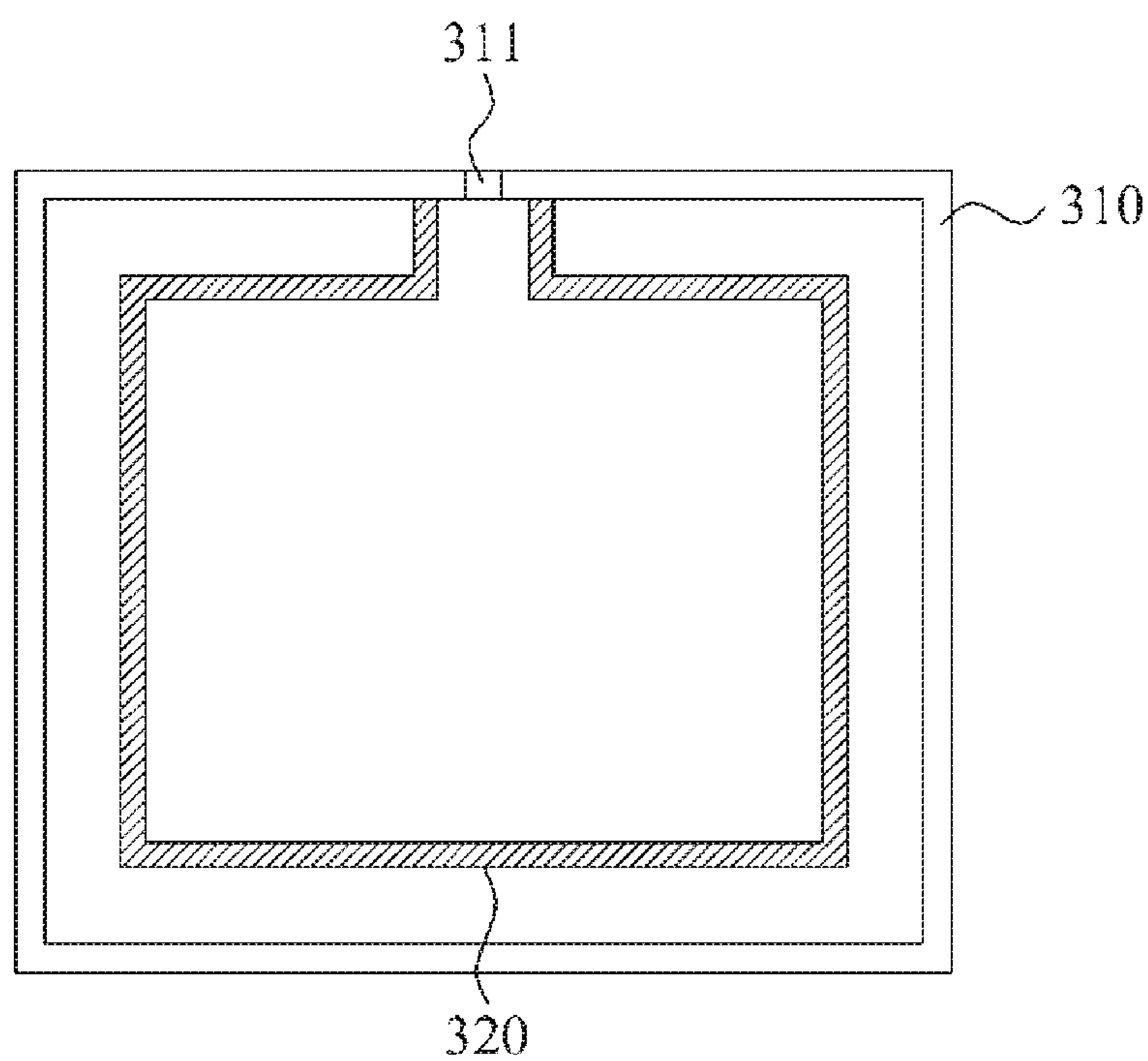


FIG. 3B

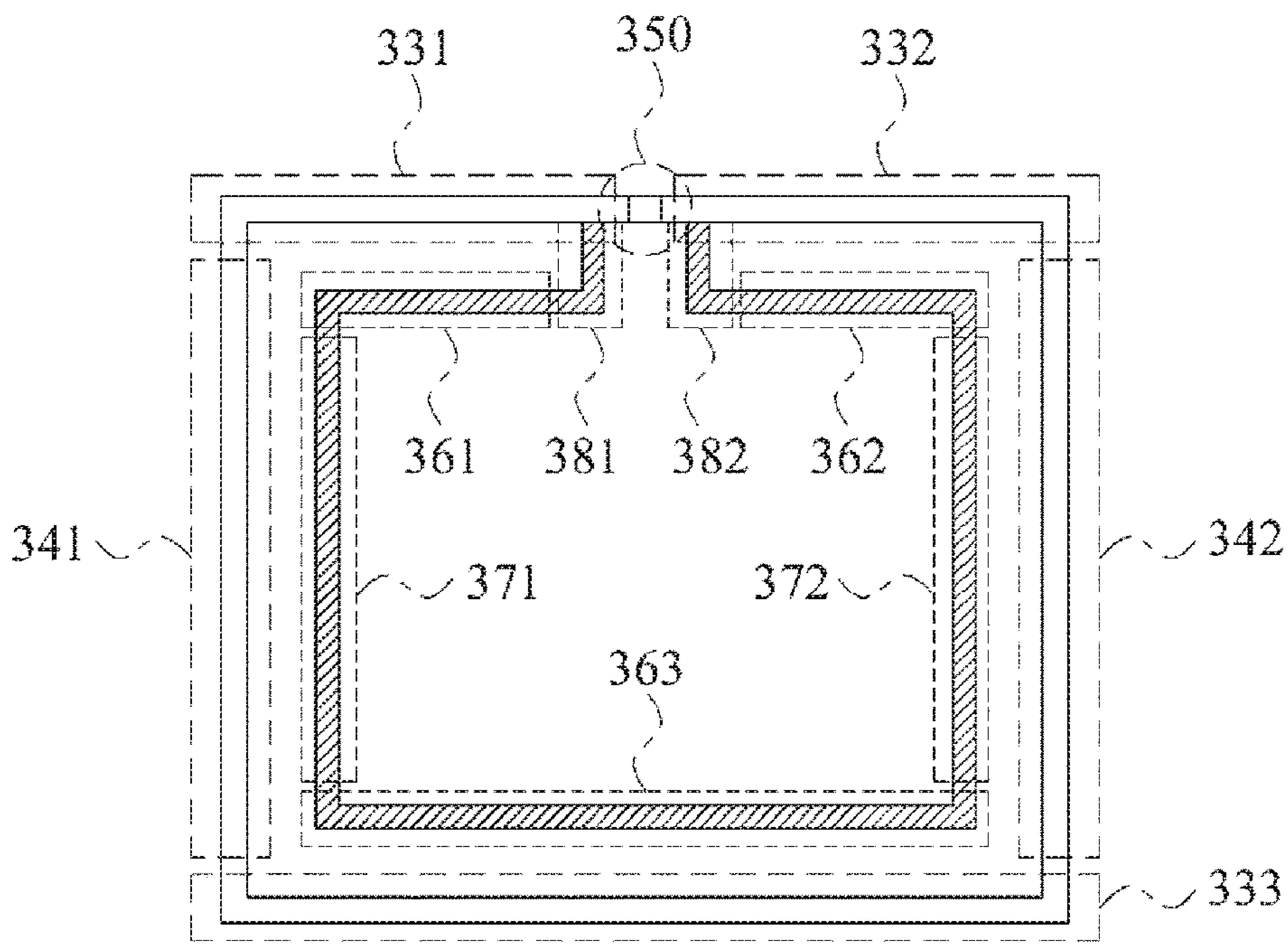


FIG. 4A

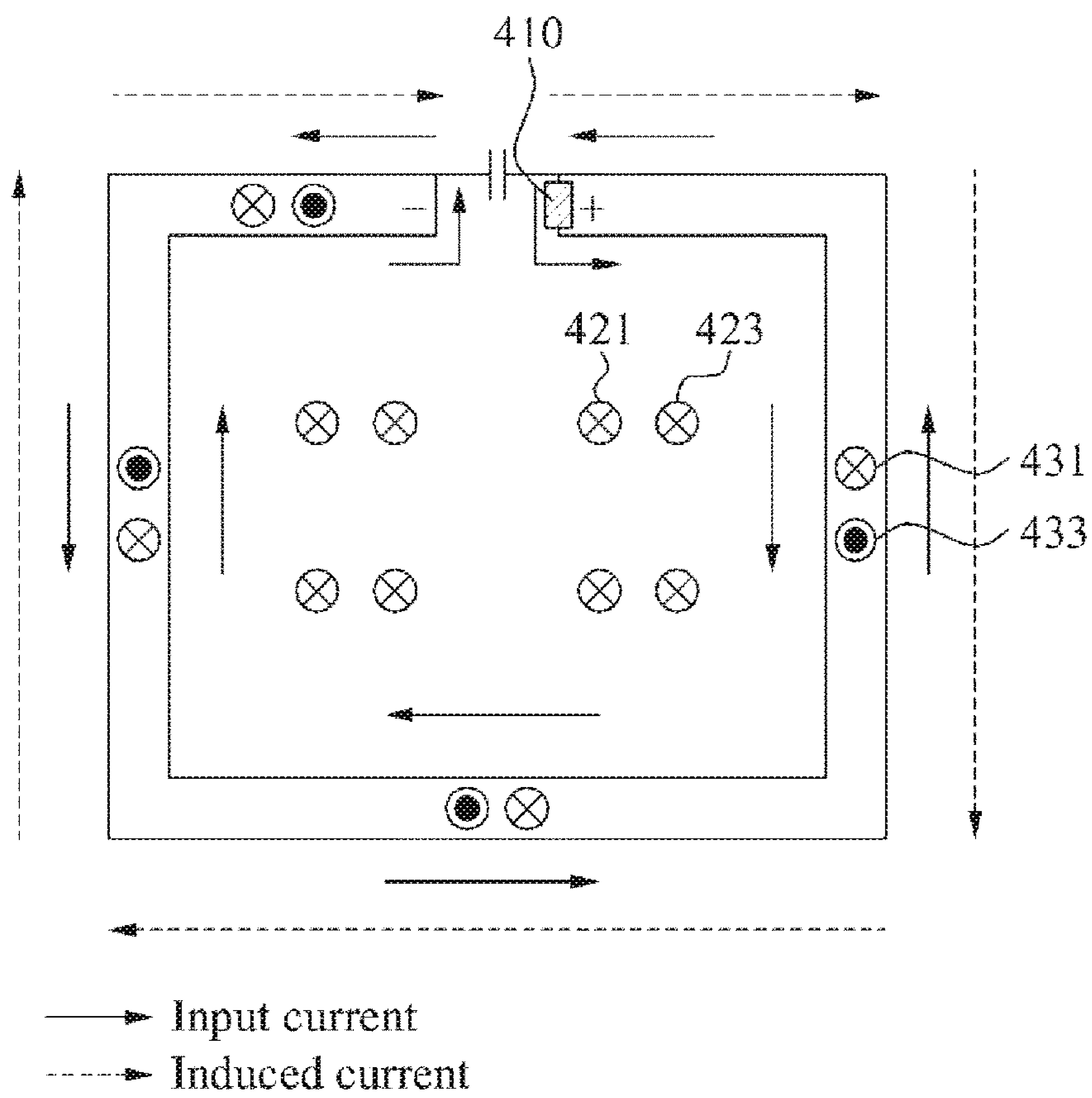


FIG. 4B

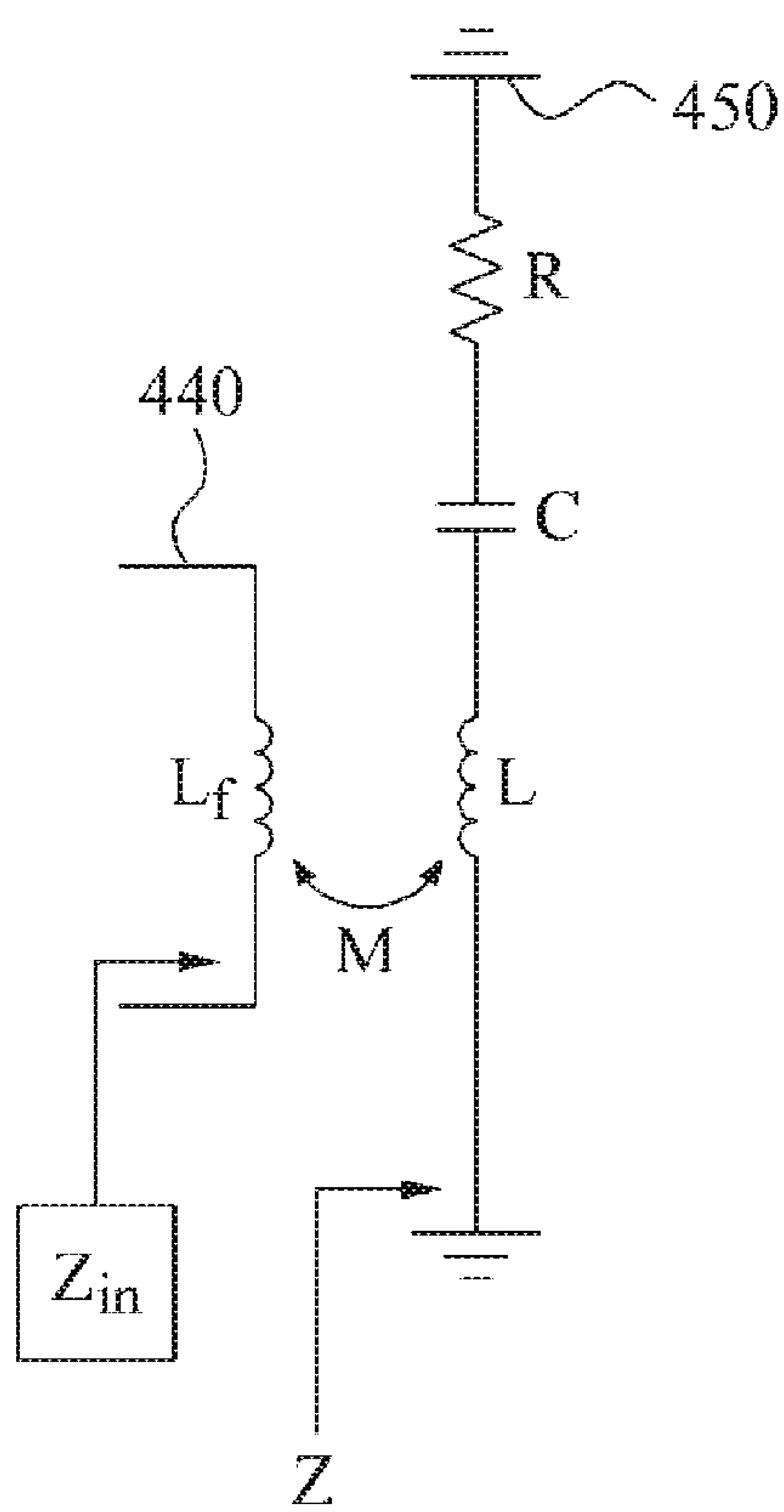
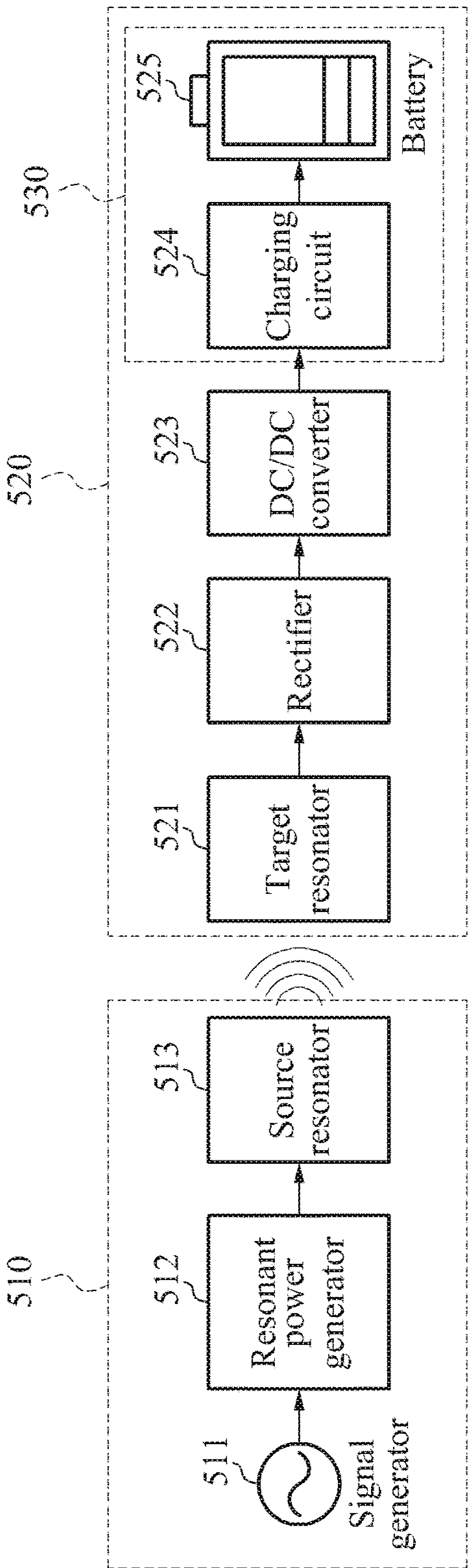


FIG. 5



510
511
Signal generator
512
Resonant power generator
513
Source resonator
520
521
Target resonator
522
Rectifier
523
DC/DC converter
530
524
Charging circuit
525
Battery

FIG. 6A

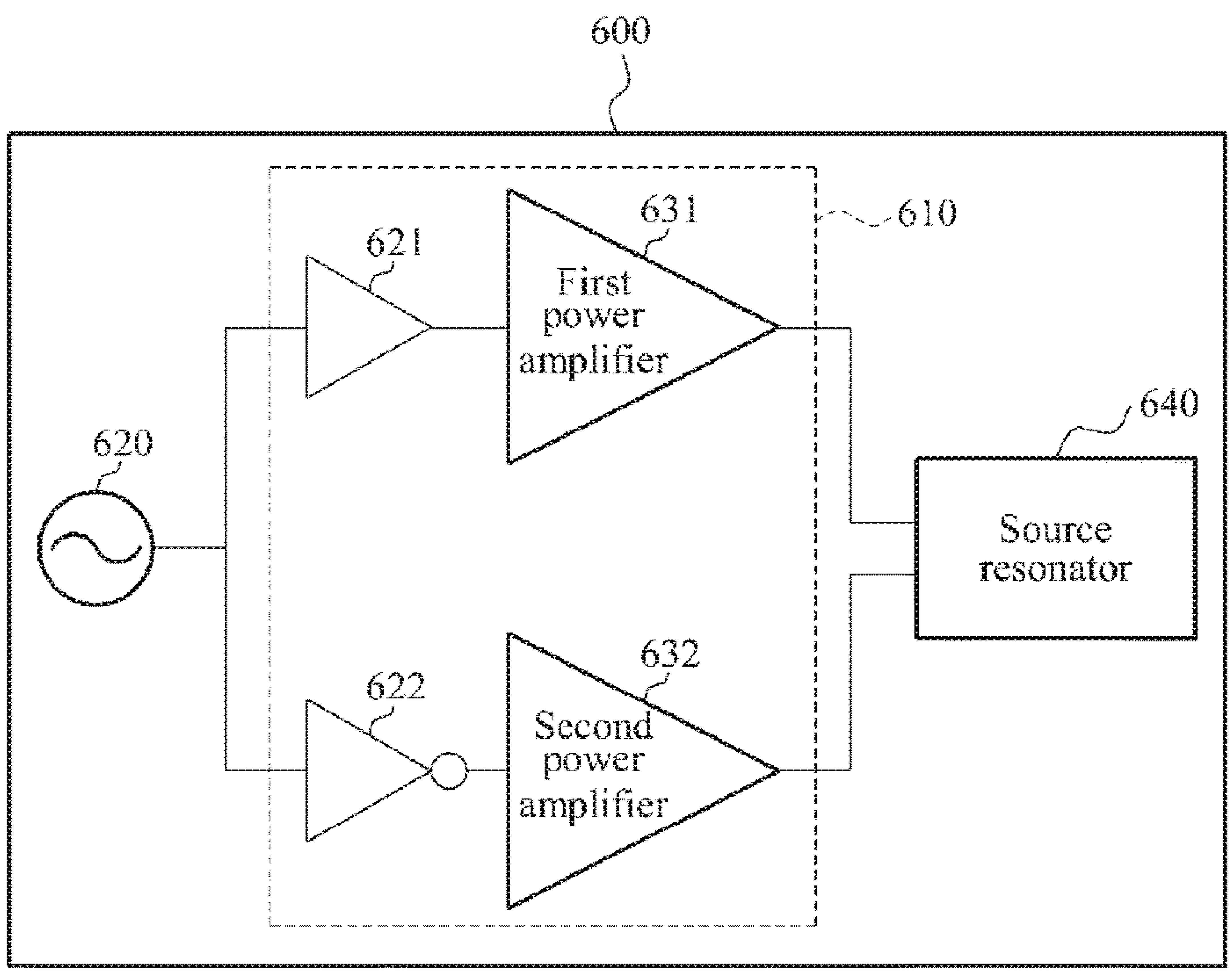
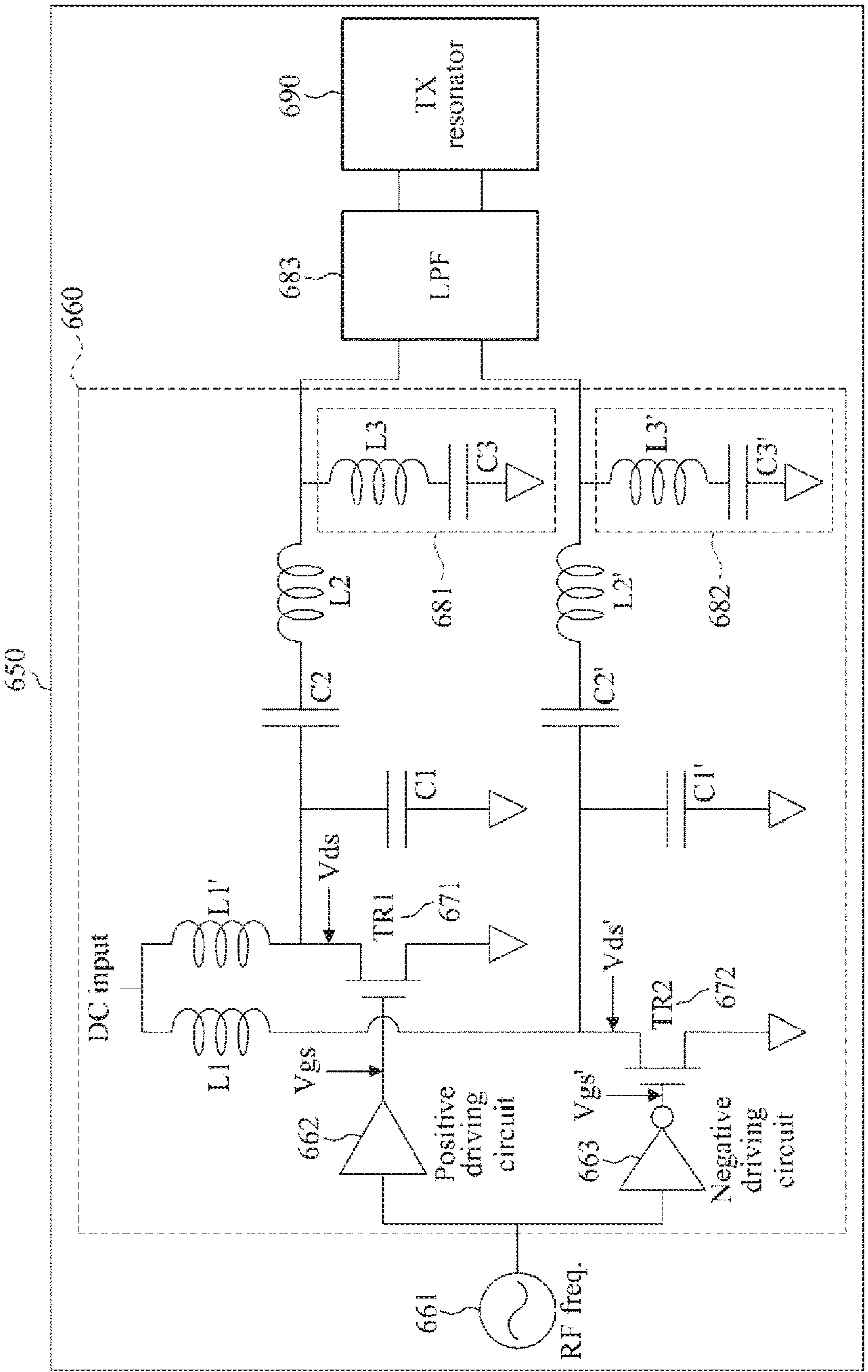

600
610
621
631
First power amplifier
620
640
Source resonator
622
632
Second power amplifier

FIG. 6B



650
660
690
TX resonator
683
LPF
L3
C3
681
L3'
C3'
682
L2
L2'
C2
C2'
C1
C1'
Vds
Vds'
L1'
L1
DC input
TR1
671
TR2
672
Vgs
Vgs'
662
Positive driving circuit
663
Negative driving circuit
661
RF freq.

FIG. 7

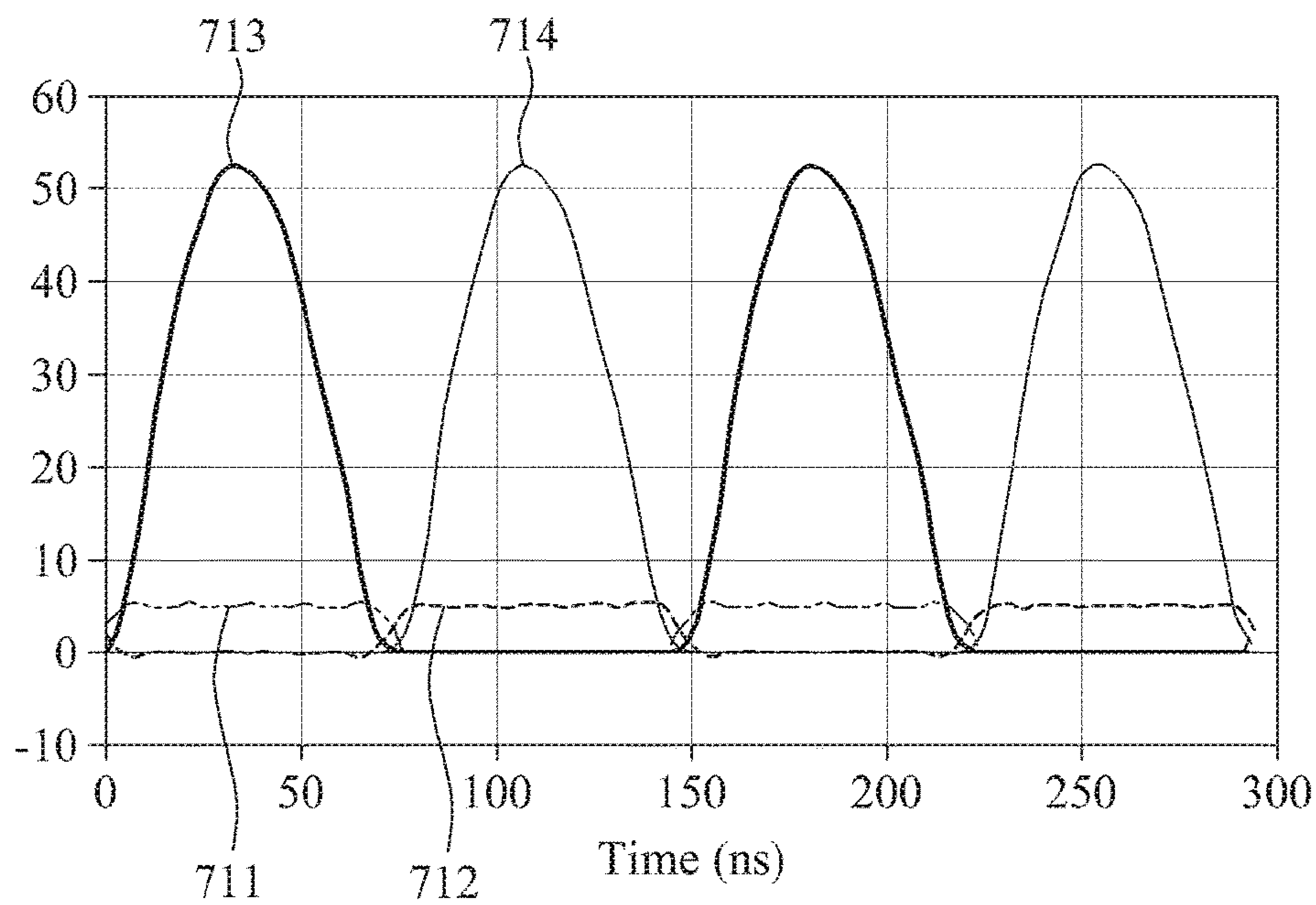

713
714
60
50
40
30
20
10
0
-10
0
50
100
150
200
250
300
Time (ns)
711
712

FIG. 8

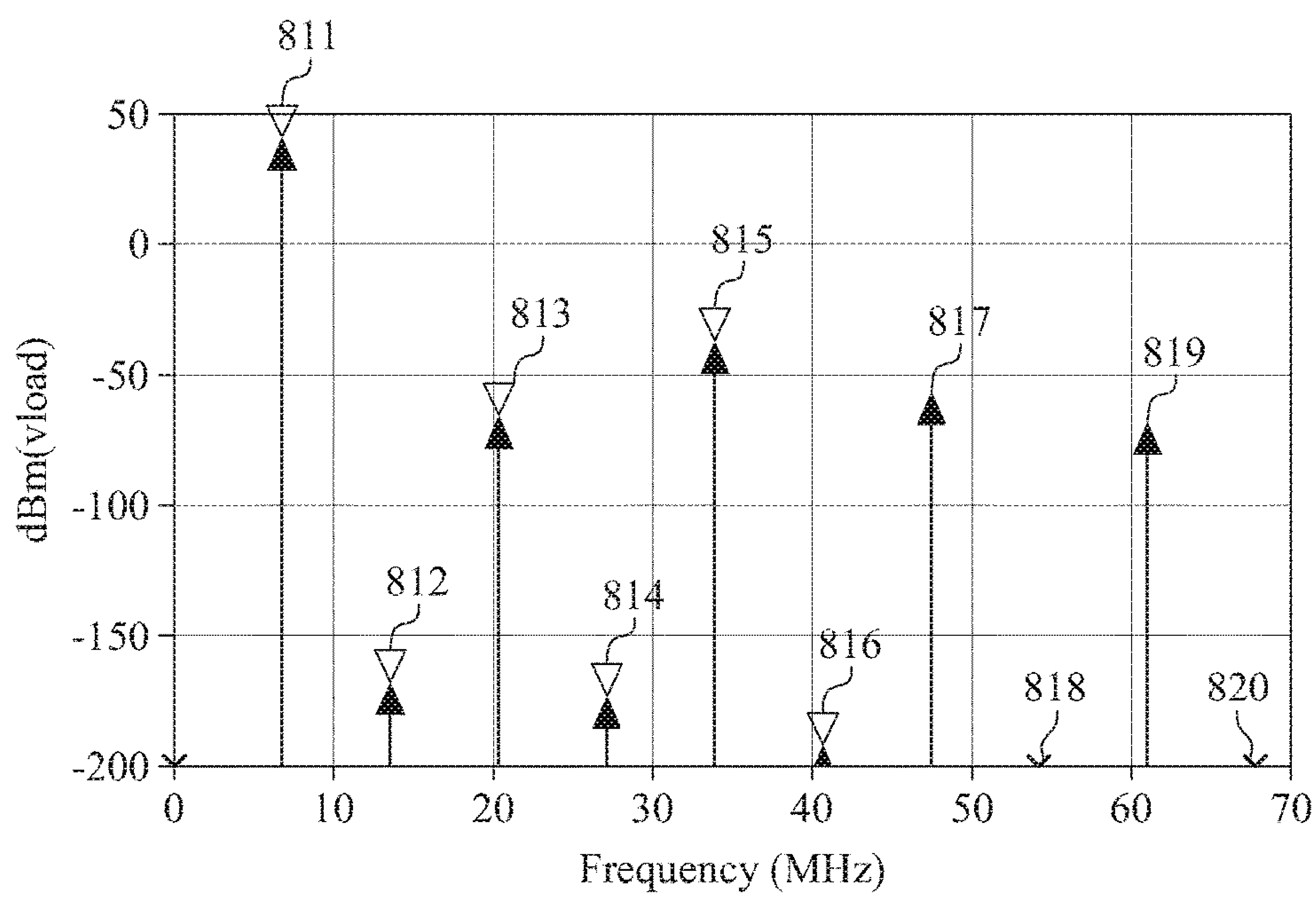

811
812
813
814
815
816
817
818
819
820
50
0
-50
-100
-150
-200
dBm(vload)
0
10
20
30
40
50
60
70
Frequency (MHz)

FIG. 9A

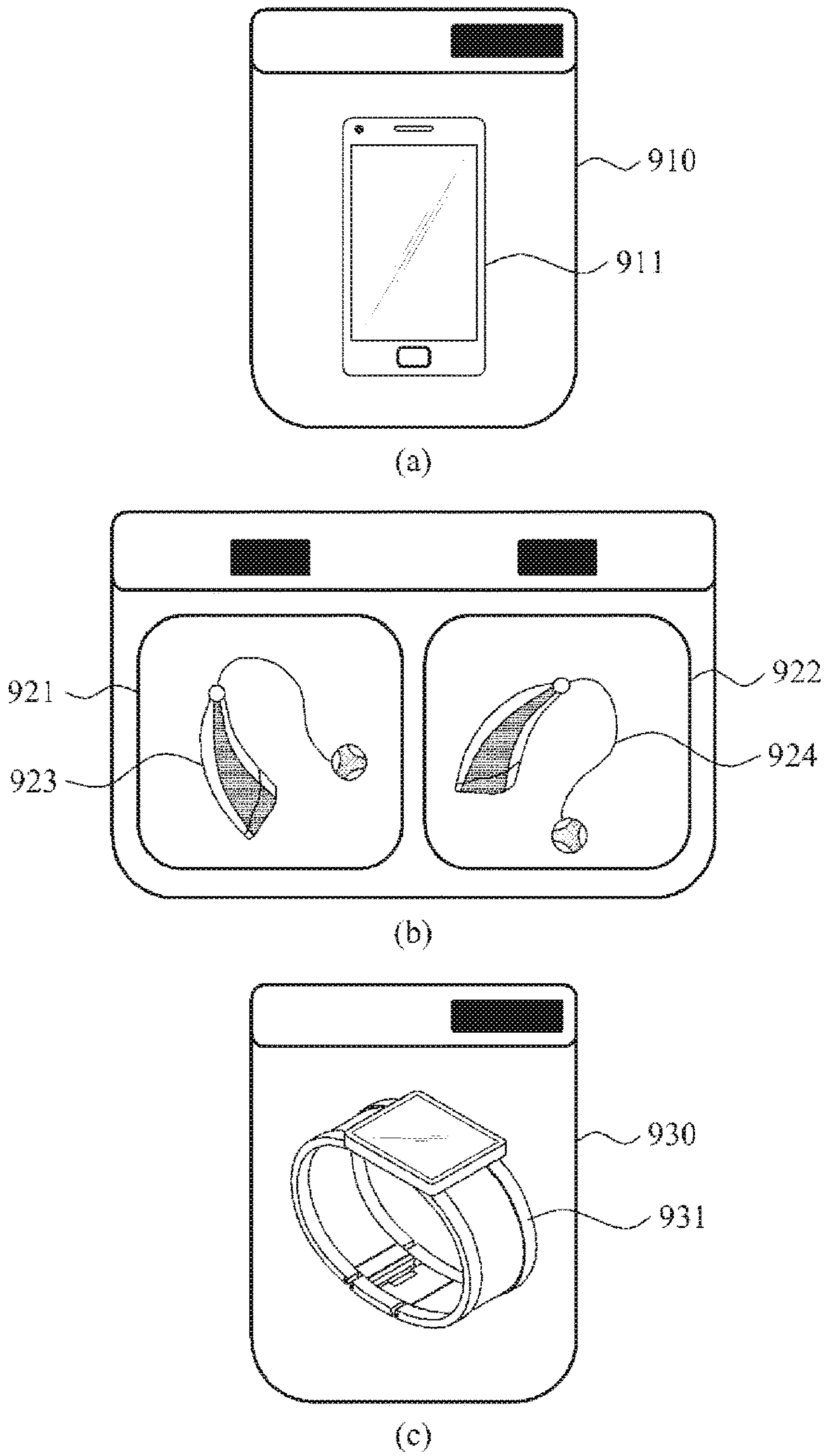
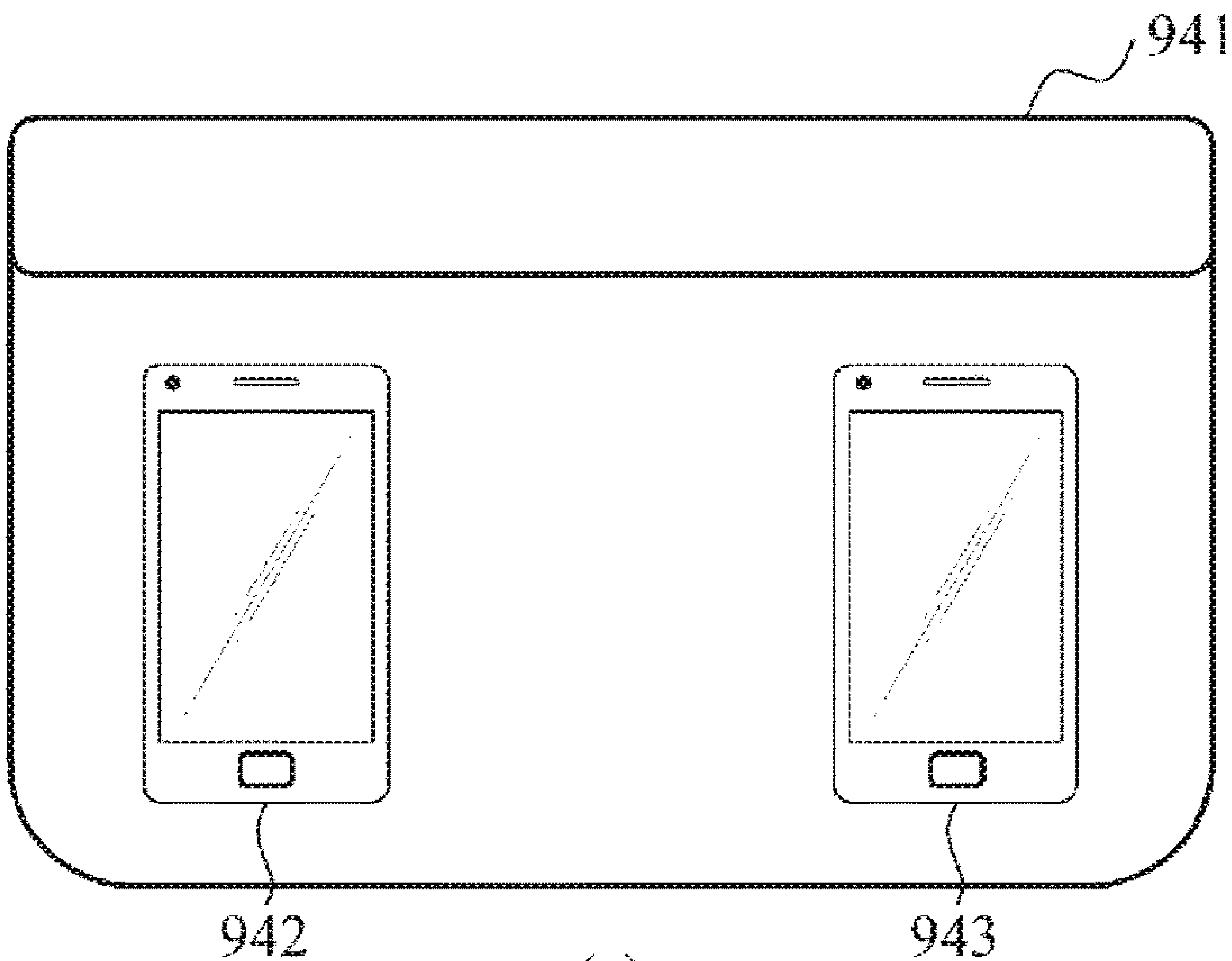
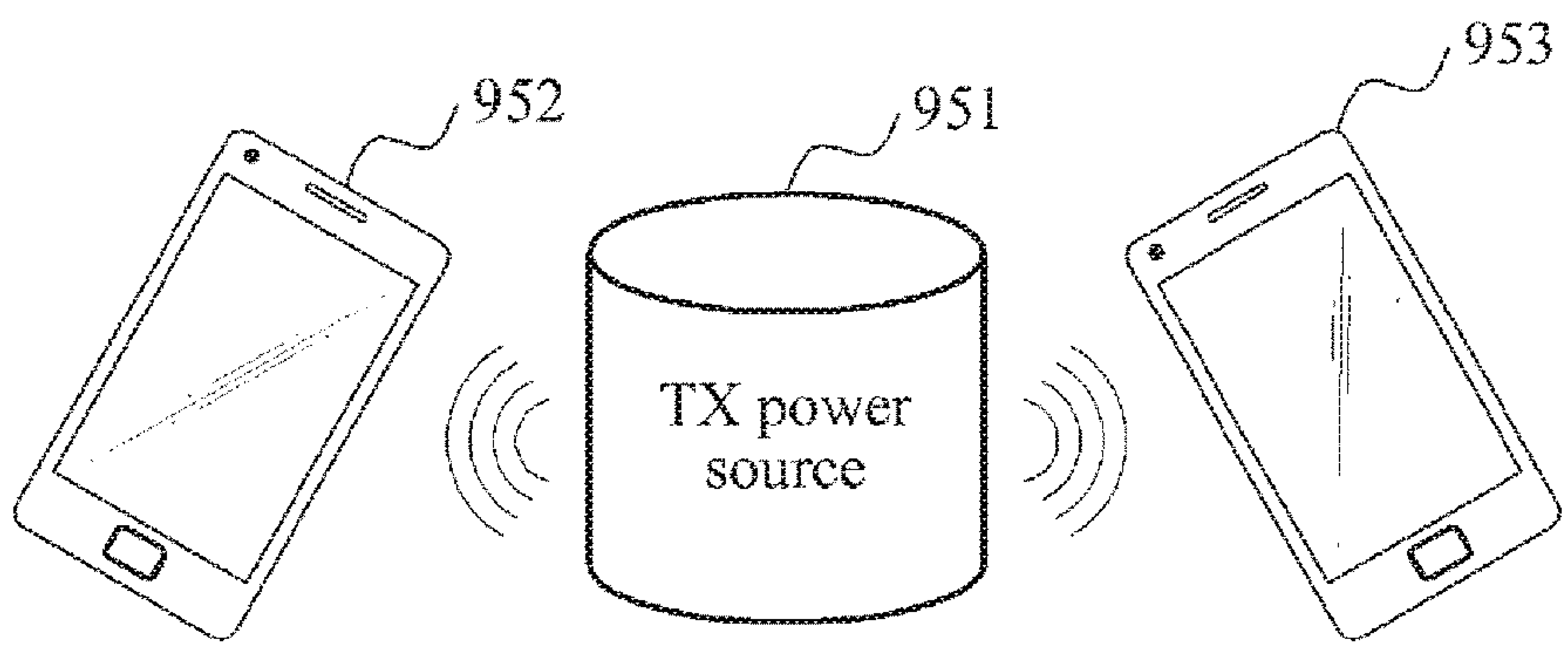


FIG. 9B



(a)



(b)

FIG. 10A

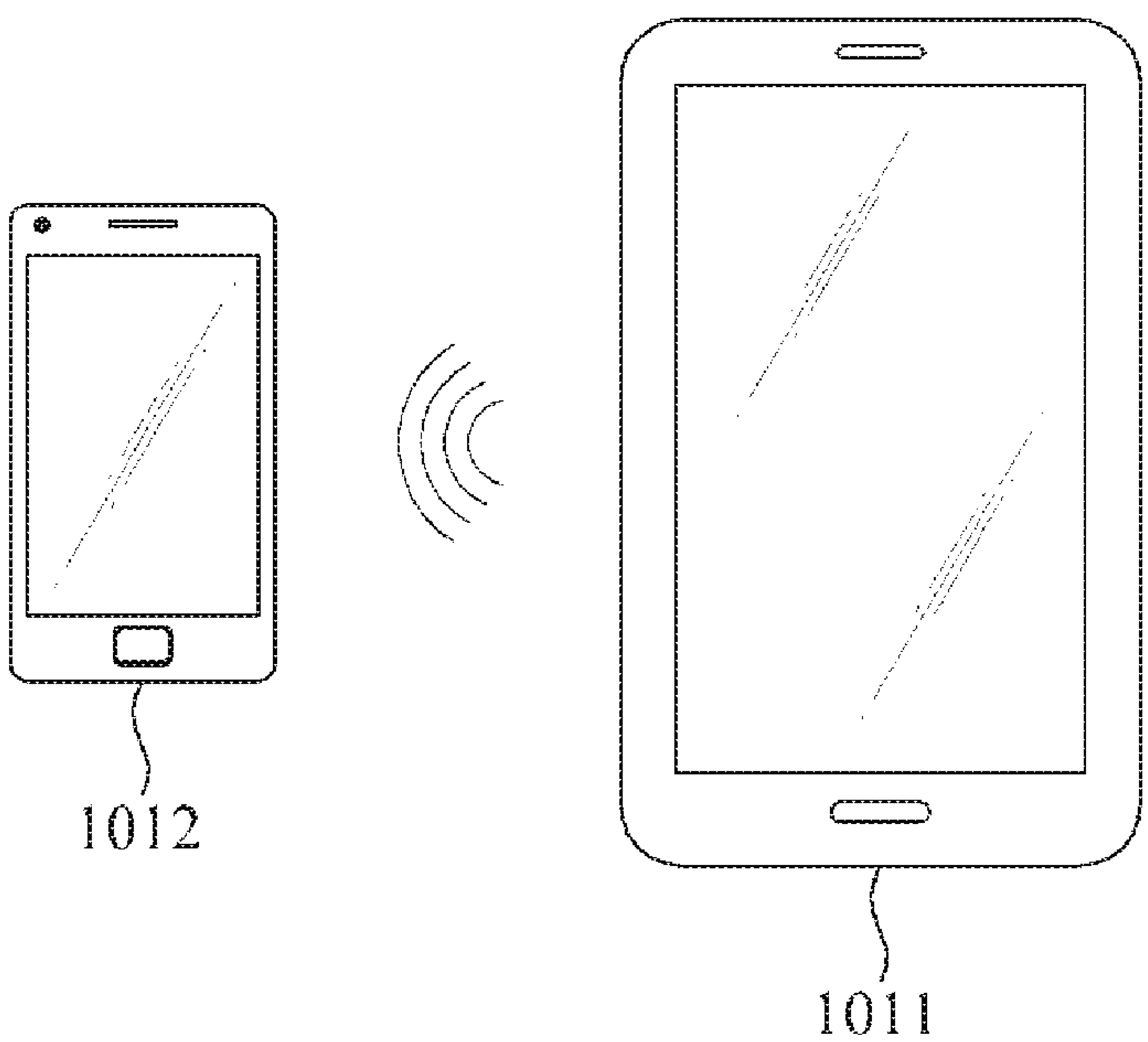


FIG. 10B

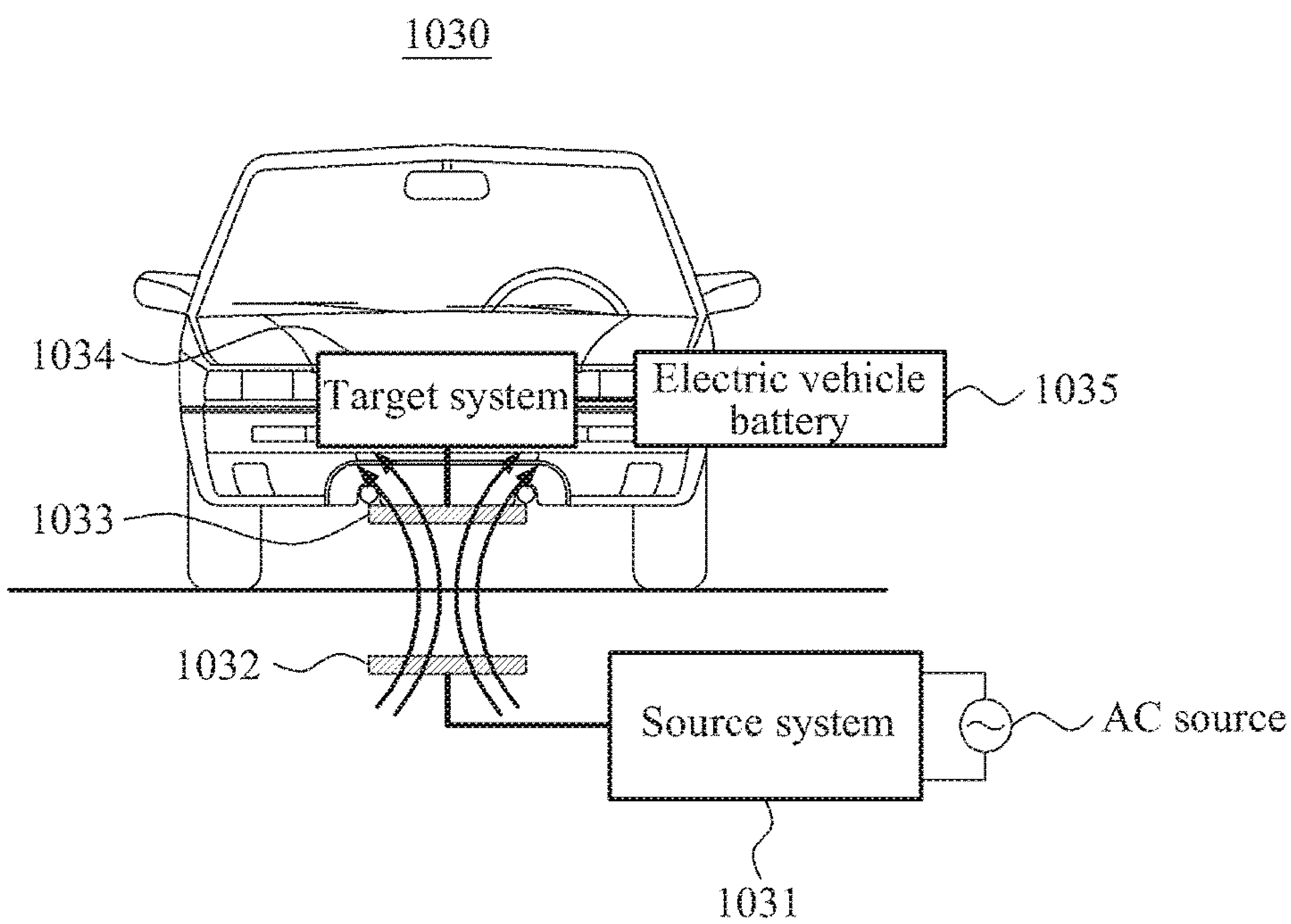

1030
1034
Target system
Electric vehicle battery
1035
1033
1032
Source system
AC source
1031

FIG. 10C

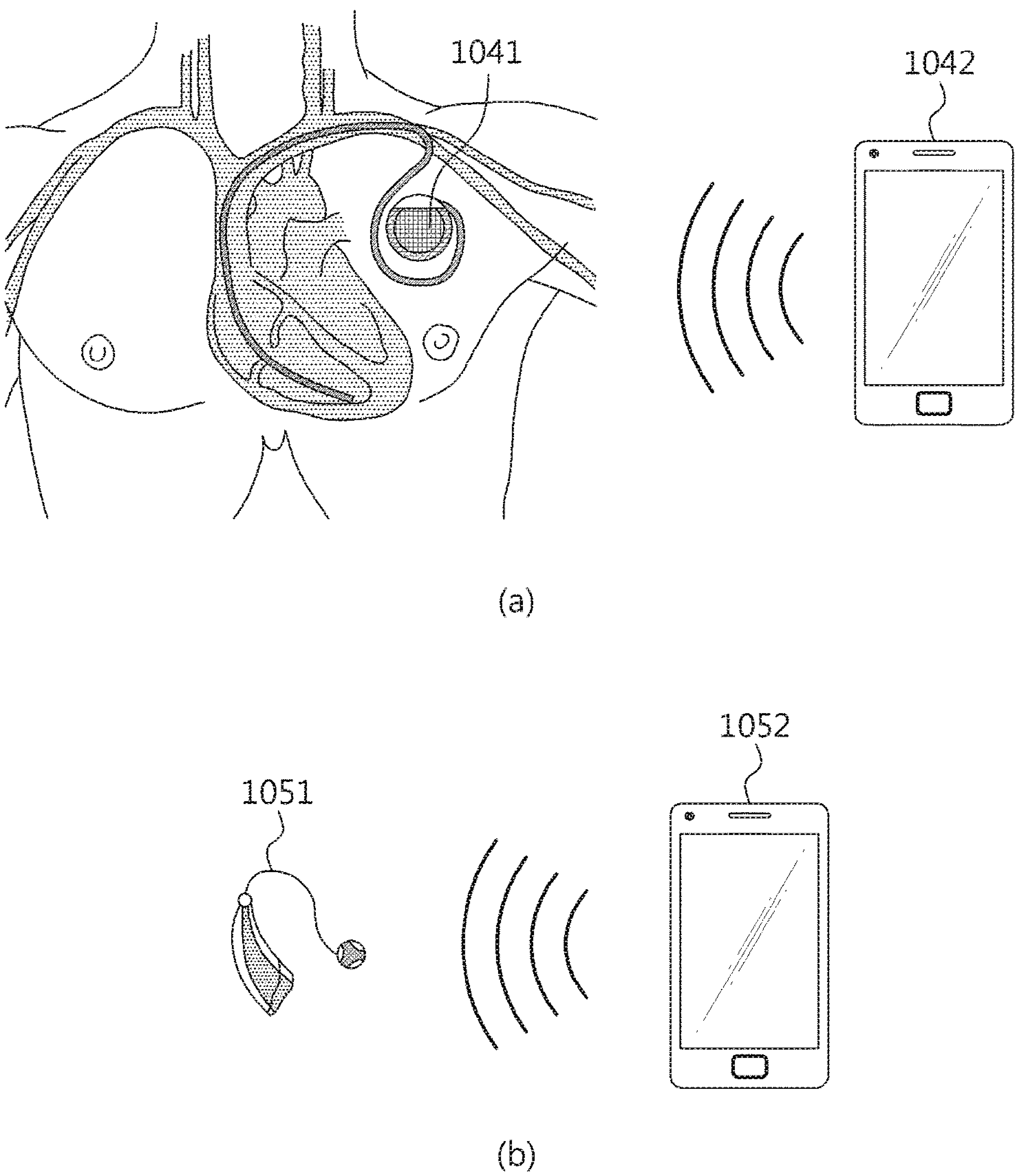
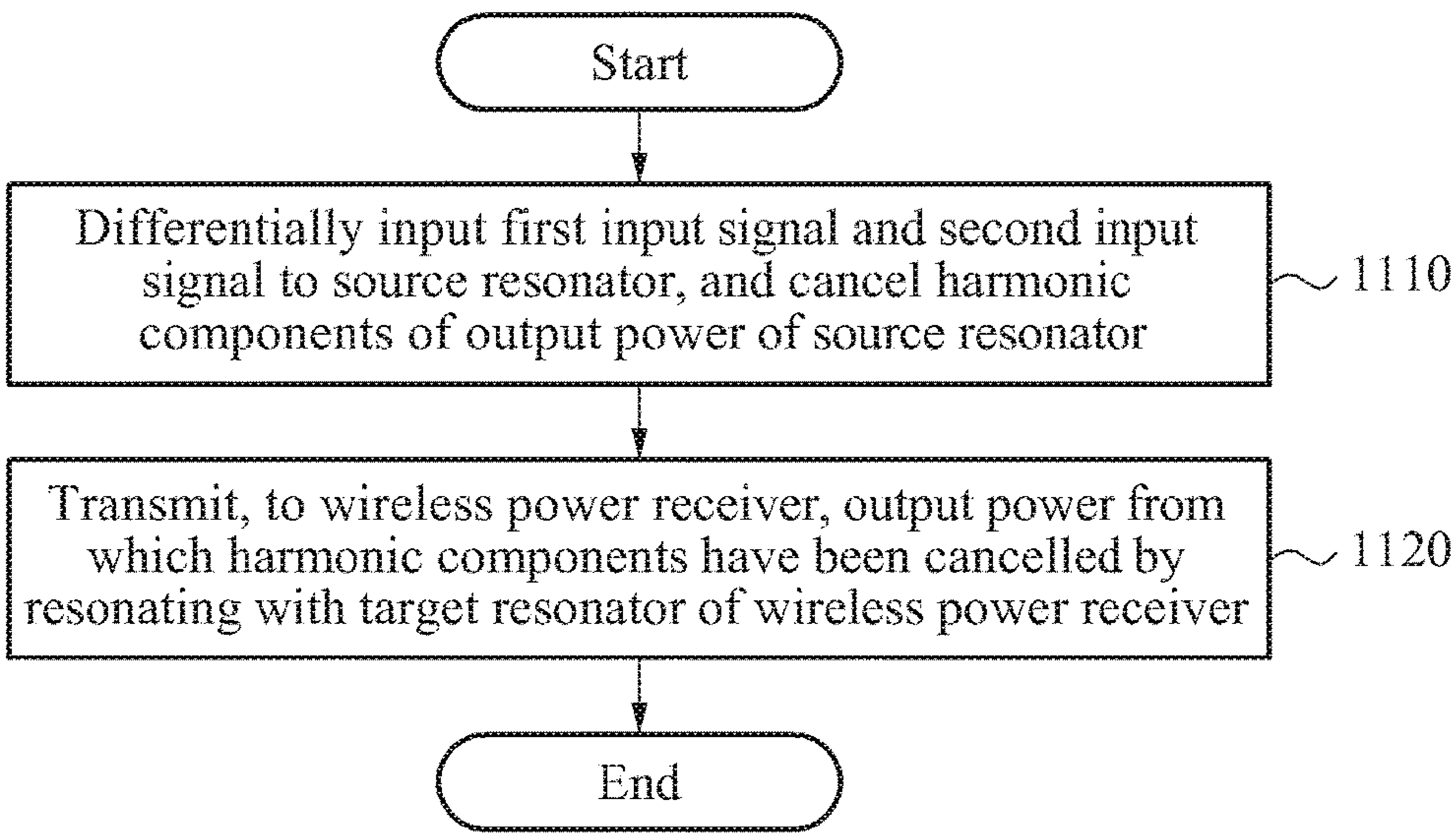


FIG. 11


Start
Differentially input first input signal and second input signal to source resonator, and cancel harmonic components of output power of source resonator
1110
Transmit, to wireless power receiver, output power from which harmonic components have been cancelled by resonating with target resonator of wireless power receiver
1120
End

METHOD AND APPARATUS FOR WIRELESS POWER TRANSMISSION WITH HARMONIC NOISE CANCELLATION

Matter enclosed in heavy brackets [ ] appears in the original patent but forms no part of this reissue specification; matter printed in italics indicates the additions made by reissue; a claim printed with strikethrough indicates that the claim was canceled, disclaimed, or held invalid by a prior post-patent action or proceeding.

CROSS-REFERENCE TO RELATED APPLICATIONS

This application claims the benefit under 35 USC 119(a) of Korean Patent Application No. 10-2013-0107844 filed on Sep. 9, 2013, in the Korean Intellectual Property Office, the entire disclosure of which is incorporated herein by reference for all purposes.

BACKGROUND

Field

The following description relates to a method and apparatus of wireless power transmission for cancelling harmonic noise.

Description of Related Art

A wireless power refers to energy transmitted to a power receiving unit (PRU) from a power transmitting unit (PTU) via a magnetic resonant coupling. Accordingly, a wireless power transmission system or a wireless power charging system may include a source device for wirelessly transmitting a power and a target device for wirelessly receiving a power. The source device may be referred to as a source or the PTU. Also, the target device may be referred to as a target or the PRU.

The source device may be provided with a source resonator, and the target device may be provided with a target resonator. For example, a magnetic coupling or a resonant coupling may be formed between the source resonator and the target resonator.

SUMMARY

This Summary is provided to introduce a selection of concepts in a simplified form that are further described below in the Detailed Description. This Summary is not intended to identify key features or essential features of the claimed subject matter, nor is it intended to be used as an aid in determining the scope of the claimed subject matter.

In one general aspect, a wireless power transmission apparatus includes a source resonator configured to transmit an output power from which a harmonic component has been cancelled to a wireless power reception apparatus by resonating with a target resonator of the wireless power reception apparatus; and a resonant power generator configured to differentially input a first input signal and a second input signal to the source resonator, and cancel the harmonic component of the output power.

The resonant power generator may include a first power amplifier configured to generate the first input signal; and a second power amplifier configured to generate the second input signal.

The resonant power generator may further include a first driving circuit coupled to the first power amplifier; and a second driving circuit coupled to the second power amplifier.

The first driving circuit and the second driving circuit may be configured to generate a 180 degree phase difference between the first input signal and the second input signal.

The first power amplifier may include a first notch filter; the second power amplifier may include a second notch filter; and the resonant power generator may be further configured to cancel a third harmonic component of the output power using the first notch filter and the second notch filter.

The first notch filter and the second notch filter may be configured to match an output impedance of the wireless power transmission apparatus to an input impedance of the wireless power reception apparatus.

The first power amplifier and the second power amplifier may be Class-E amplifiers.

The resonant power generator may be further configured to cancel an even-order harmonic component of the output power.

The apparatus may further include a low-pass filter (LPF) configured to cancel a fifth or higher odd-order harmonic component of the output power; and the source resonator may be further configured to transmit the output power from which the fifth or higher odd-order harmonic component has been cancelled to the wireless power reception apparatus.

The source resonator may be further configured to receive the first input signal and the second input signal via a differential input port including a separate grounding unit.

In another general aspect, a wireless power transmission apparatus includes a source resonator configured to transmit an output power to a wireless power reception apparatus by resonating with a target resonator of the wireless power reception apparatus; a resonant power generator including a first power amplifier including a first notch filter and configured to generate a first input signal, and a second power amplifier including a second notch filter and configured to generate a second input signal, wherein the resonant power generator is configured to cancel an even-order harmonic component of the output power by differentially inputting the first input signal and the second input signal to the source resonator, and cancel a third harmonic component of the output power using the first notch filter and the second notch filter; and a low-pass filter (LPF) configured to cancel a fifth or higher odd-order harmonic component of the output power; wherein the source resonator may be further configured to transmit, to the wireless power reception apparatus, the output power from which the even-order harmonic component, the third harmonic component, and the fifth or higher odd-order harmonic component have been cancelled.

In another general aspect, a wireless power transmission method includes differentially inputting a first input signal and a second input signal to a source resonator; cancelling a harmonic component of an output power of the source resonator; and transmitting the output power from which the harmonic component has been cancelled to a wireless power reception apparatus by resonating with a target resonator of the wireless power reception apparatus.

The cancelling of the harmonic component of the output power may include generating the first input signal using a first power amplifier; and generating the second input signal using a second power amplifier.

The cancelling of the harmonic component of the output power may further include generating a 180 degree phase difference between the first input signal and the second input signal using a first driving circuit coupled to the first power amplifier and a second driving circuit coupled to the second power amplifier.

The first output amplifier may include a first notch filter; the second output amplifier may include a second notch filter; and the cancelling of the harmonic component of the output power may further include cancelling a third harmonic component of the output power using the first notch filter and the second notch filter.

The first notch filter and the second notch filter may be configured to match an output impedance of the wireless power transmission apparatus to an input impedance of the wireless power reception apparatus.

The cancelling of the harmonic component of the output power may include cancelling an even-order harmonic component of the output power.

The method may further include cancelling a fifth or higher odd-order harmonic component of the output power using a low-pass filter (LPF); and the transmitting of the output power to an apparatus for wireless power reception may include transmitting the output power from which the fifth or higher odd-order harmonic component has been cancelled to the wireless power reception apparatus.

In another general aspect, a non-transitory computer-readable storage medium stores instructions for controlling a computer to perform the method described above.

In another general aspect, a wireless power transmitter includes a source resonator configured to transmit an output power to a wireless power receiver by resonating with a target resonator of the wireless power receiver; and a harmonic noise canceller configured to cancel harmonic components of the output power by a plurality of different methods so that the output power transmitted by the source resonator is free of the harmonic components.

The harmonic noise canceller may include a first harmonic component canceller configured to cancel even-order harmonic components of the output power; a second harmonic component canceller configured to cancel a third harmonic component of the output power; and a third harmonic component canceller configured to cancel fifth and higher odd-order harmonic components of the output power.

The first harmonic component canceller may be further configured to generate a first input signal and a second input signal having a 180 degree phase difference with respect to the first input signal; the source resonator may include a differential input port configured to receive the first input signal and the second input signal; and the 180 phase difference between the first input signal and the second input signal generated by the first harmonic canceller may result in cancellation of the even-order harmonic components of the output power at the differential input port.

The second harmonic component canceller may include a first notch filter configured to remove the third harmonic component from the first input signal; and a second notch filter configured to remove the third harmonic component from the first input signal.

The third harmonic component canceller may include a low-pass filter (LPF) configured to remove the fifth and higher odd-order harmonic components from the first input signal and the second input signal.

Other features and aspects will be apparent from the following detailed description, the drawings, and the claims.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** illustrates an example of a wireless power transmission and reception system.

FIGS. **2**A and **2**B illustrate examples of a distribution of a magnetic field in a resonator and a feeder.

FIGS. **3**A and **3**B illustrate examples of a configuration of a resonator and a feeder.

FIG. **4**A illustrates an example of a distribution of a magnetic field inside a resonator produced by feeding a feeder.

FIG. **4**B illustrates an example of equivalent circuits of a feeder and a resonator.

FIG. **5** illustrates an example of a wireless power transmission and reception system.

FIGS. **6**A and **6**B illustrate examples of a wireless power transmitter.

FIG. **7** illustrates an example of a phase difference between a first input signal and a second input signal.

FIG. **8** illustrates an example of harmonic components of an output power.

FIGS. **9**A and **9**B illustrate examples of a unidirectional wireless power transmission and reception system.

FIGS. **10**A through **10**C illustrate examples of a bidirectional wireless power transmission and reception system.

FIG. **11** illustrates an example of a method of wireless power transmission.

DETAILED DESCRIPTION

The following detailed description is provided to assist the reader in gaining a comprehensive understanding of the methods, apparatuses, and/or systems described herein. However, various changes, modifications, and equivalents of the methods, apparatuses, and/or systems described herein will be apparent to one of ordinary skill in the art. The sequences of operations described herein are merely examples, and are not limited to those set forth herein, but may be changed as will be apparent to one of ordinary skill in the art, with the exception of operations necessarily occurring in a certain order. Also, descriptions of functions and constructions that are well known to one of ordinary skill in the art may be omitted for increased clarity and conciseness.

Throughout the drawings and the detailed description, the same reference numerals refer to the same elements. The drawings may not be to scale, and the relative size, proportions, and depiction of elements in the drawings may be exaggerated for clarity, illustration, and convenience.

FIG. **1** illustrates an example of a wireless power transmission and reception system.

Referring to FIG. **1**, the wireless power transmission system includes a source **110** and a target **120**. The source **110** is a device configured to supply a wireless power, and may be any electronic device capable of supplying a power, for example, a pad, a terminal, a tablet personal computer (PC), a television (TV), a medical device, or an electric vehicle. The target **120** is a device configured to receive a wireless power, and may be any electronic device requiring a power to operate, for example, a pad, a terminal, a tablet PC, a smart watch, a medical device, an electric vehicle, a washing machine, a radio, or a lighting system.

The source **110** includes a variable switching mode power supply (SMPS) **111**, a power amplifier (PA) **112**, a matching network **113**, a transmission (Tx) controller **114** (for example, Tx control logic), a communication unit **115**, and a power detector **116**.

The variable SMPS **111** generates a direct current (DC) voltage by switching an alternating current (AC) voltage having a frequency in a band of tens of hertz (Hz) output from a power supply. The variable SMPS **111** may output a fixed DC voltage, or may output an adjustable DC voltage that may be adjusted under the control of the Tx controller **114**.

The variable SMPS **111** may control its output voltage supplied to the PA **112** based on a level of a power output from the PA **112** so that the PA **112** may operate in a saturation region with a high efficiency at all times, thereby enabling a maximum efficiency to be maintained at all levels of the output power of the PA **112**. The PA **112** may be, for example, a Class-E amplifier.

If a fixed SMPS is used instead of the variable SMPS **111**, a variable DC-to-DC (DC/DC) converter may be needed. In this example, the fixed SMPS outputs a fixed DC voltage to the variable DC/DC converter, and the variable DC/DC converter controls its output voltage supplied to the PA **112** based on the level of the power output from the PA **112** so that the PA **112**, which may be a Class-E amplifier, may operate in the saturation region with a high efficiency at all times, thereby enabling the maximum efficiency to be maintained at all levels of the output power of the PA **112**.

The power detector **116** detects an output current and an output voltage of the variable SMPS **111**, and transmits, to the Tx controller **114**, information on the detected output current and the detected output voltage. Also, the power detector **116** may detect an input current and an input voltage of the PA **112**.

The PA **112** generates a power by converting a DC voltage having a predetermined level supplied to the PA **112** by the variable SMPS **111** to an AC voltage using a switching pulse signal having a frequency in a band of a few megahertz (MHz) to tens of MHz. For example, the PA **112** may convert the DC voltage supplied to the PA **112** to an AC voltage having a reference resonant frequency F_{Ref}, and may generate a communication power used for communication, and/or a charging power used for charging. The communication power and the charging power may be used in a plurality of targets.

If a high power from a few kilowatts (kW) to tens of kW is transmitted using a resonant frequency in a band of tens of kilohertz (kHz) to hundreds of kHz, the PA **112** may be omitted, and a power may be supplied to a source resonator **131** from the variable SMPS **111** or a high-power power supply. For example, an inverter may be used in lieu of the PA **112**. The inverter may convert a DC power supplied from the high-power power supply to an AC power. In particular, the inverter may convert the power by converting a DC voltage having a predetermined level to an AC voltage using a switching pulse signal having a frequency in a band of tens of kHz to hundreds of kHz. For example, the inverter may convert the DC voltage having the predetermined level to an AC voltage having a resonant frequency of the source resonator **131** in a band of tens of kHz to hundreds of kHz.

As used herein, the term "communication power" refers to a low power of 0.1 milliwatt (mW) to 1 mW. The term "charging power" refers to a high power of a few mW to tens of kW consumed by a load of a target. As used herein, the term "charging" refers to supplying a power to a unit or element configured to charge a battery or other rechargeable device. Additionally, the term "charging" refers to supplying a power to a unit or element configured to consume a power. For example, the term "charging power" may refer to a power consumed by a target while operating, or a power used to charge a battery of the target. The unit or element may be, for example, a battery, a display, a sound output circuit, a main processor, or any of various types of sensors.

As used herein, the term "reference resonant frequency" refers to a resonant frequency nominally used by the source **110**, and the term "tracking frequency" refers to a resonant frequency used by the source **110** that has been adjusted based on a preset scheme.

The Tx controller **114** may detect a reflected wave of the communication power or the charging power, and may detect mismatching that occurs between a target resonator **133** and the source resonator **131** based on the detected reflected wave. To detect the mismatching, for example, the Tx controller **114** may detect an envelope of the reflected wave, a power amount of the reflected wave, or any other characteristic of the reflected wave that is affected by mismatching.

The matching network **113** compensates for impedance mismatching between the source resonator **131** and the target resonator **133** to achieve optimal matching under the control of the Tx controller **114**. The matching network **113** includes at least one inductor and at least one capacitor each connected to a respective switch controlled by the Tx controller **114**.

If a high power is to be transmitted using a resonant frequency in a band of tens of kHz to hundreds of kHz, the matching network **113** may be omitted from the source **110** because the effect of the matching network **113** may be reduced when transmitting the high power.

The Tx controller **114** may calculate a voltage standing wave ratio (VSWR) based on a level of an output voltage of the source resonator **131** or the PA **112** and a voltage level of the reflected wave. In one example, if the VSWR is greater than a predetermined value, the Tx controller **114** may determine that a mismatch is detected between the source resonator **131** and the target resonator **133**.

In another example, if the Tx controller **114** detects that the VSWR is greater than the predetermined value, the Tx controller **114** may calculate a wireless power transmission efficiency for each of N tracking frequencies, determine a tracking frequency F_{Best} providing the best wireless power transmission efficiency among the N tracking frequencies, and adjust the reference resonant frequency F_{Ref} to the tracking frequency F_{Best}. The N tracking frequencies may be set in advance.

The Tx controller **114** may adjust a frequency of the switching pulse signal used by the PA **112**. The frequency of the switching pulse signal may be determined under the control of the Tx controller **114**. For example, the Tx controller **114** may generate a modulated signal to be transmitted to the target **120** by controlling the PA **112**. The communication unit **115** may transmit a variety of data to the target **120** using in-band communication. The Tx controller **114** may also detect a reflected wave, and may demodulate a signal received from the target **120** from an envelope of the detected reflected wave.

The Tx controller **114** may generate a modulated signal for in-band communication using various methods. For example, the Tx controller **114** may generate the modulated signal by turning on or off a switching pulse signal used by the PA **112**, by performing delta-sigma modulation, or by any other modulation method known to one of ordinary skill in the art. Additionally, the Tx controller **114** may generate a pulse-width modulated (PWM) signal having a predetermined envelope.

The Tx controller **114** may determine an initial wireless power to be transmitted to the target **120** based on a change in a temperature of the source **110**, a battery state of the target **120**, a change in an amount of a power received by the target **120**, and/or a change in a temperature of the target **120**.

The source **110** may further include a temperature measurement sensor (not illustrated) configured to detect a change in a temperature of the source **110**. The source **110** may receive from the target **120** information regarding the battery state of the target **120**, the change in the amount of the power received by the target **120**, and/or the change in the temperature of the target **120** by communicating with the target **120**. The source **110** may detect the change in the temperature of the target **120** based on the information received from the target **120**.

The Tx controller **114** may adjust a voltage supplied to the PA **112** based on the change in the temperature of the target **120** using a lookup table (LUT). The LUT may store a level of the voltage to be supplied to the PA **112** based on the change in the temperature of the source **110**. For example, when the temperature of the source **110** rises, the Tx controller **114** may reduce the voltage to be supplied to the PA **112** by controlling the variable SMPS **111**.

The communication unit **115** may perform out-of-band communication using a separate communication channel. The communication unit **115** may include a communication module, such as a ZigBee module, a Bluetooth module, or any other communication module known to one of ordinary skill in the art, that the communication unit **115** may use to transmit and receive data **140** to and from the target **120** via the out-of-band communication.

The source resonator **131** transmits electromagnetic energy **130** to the target resonator **133**. For example, the source resonator **131** may transmit the communication power or the charging power to the target **120** via a magnetic coupling with the target resonator **133**.

The source resonator **131** may be made of a superconducting material. Also, although not shown in FIG. **1**, the source resonator **131** may be disposed in a container of refrigerant to enable the source resonator **131** to maintain a superconducting state. A heated refrigerant that has transitioned to a gaseous state may be liquefied to a liquid state by a cooler. The target resonator **133** may also be made of a superconducting material. In this instance, the target resonator **133** may also be disposed in a container of refrigerant to enable the target resonator **133** to maintain a superconducting state.

As illustrated in FIG. **1**, target **120** includes a matching network **121**, a rectifier **122**, a DC/DC converter **123**, a communication unit **124**, a reception (Rx) controller **125** (for example, Rx control logic), a voltage detector **126**, and a power detector **127**.

The target resonator **133** receives the electromagnetic energy **130** from the source resonator **131**. For example, the target resonator **133** may receive the communication power or the charging power from the source **110** via a magnetic coupling with the source resonator **131**. Additionally, the target resonator **133** may receive data from the source **110** via the in-band communication.

The target resonator **133** may receive the initial wireless power determined by the Tx controller **114** based on the change in the temperature of the source **110**, the battery state of the target **120**, the change in the amount of the power received by the target **120**, and/or the change in the temperature of the target **120**.

The matching network **121** matches an input impedance viewed from the source **110** to an output impedance viewed from a load of the target **120**. The matching network **121** may be configured to have at least one capacitor and at least one inductor.

The rectifier **122** generates a DC voltage by rectifying an AC voltage received by the target resonator **133**.

The DC/DC converter **123** adjusts a level of the DC voltage output from the rectifier **122** based on a voltage required by the load. As an example, the DC/DC converter **123** may adjust the level of the DC voltage output from the rectifier **122** to a level in a range of 3 volts (V) to 10 V.

The voltage detector **126** detects a voltage of an input terminal of the DC/DC converter **123**, and the power detector **127** detects a current and a voltage of an output terminal of the DC/DC converter **123**. The detected voltage of the input terminal may be used to calculate a wireless power transmission efficiency of the power received from the source **110**. The detected current and the detected voltage of the output terminal may be used by the Rx controller **125** to calculate an amount of a power actually transferred to the load. The Tx controller **114** of the source **110** may calculate an amount of a power that needs to be transmitted by the source **110** to the target **120** based on an amount of a power required by the load and the amount of the power actually transferred to the load.

If the amount of the power actually transferred to the load calculated by the Rx controller **125** is transmitted to the source **110** by the communication unit **124**, the Tx controller **114** may calculate the amount of the power that needs to be transmitted to the target **120**, and may control either one or both of the variable SMPS **111** and the PA **112** to generate an amount of power that will enable the calculated amount of power to be transmitted by the source **110**.

The Rx controller **125** may perform in-band communication to transmit and receive data to and from the source **110** using a resonant frequency. During the in-band communication, the Rx controller **125** may demodulate a received signal by detecting a signal between the target resonator **133** and the rectifier **122**, or detecting an output signal of the rectifier **122**. In particular, the Rx controller **125** may demodulate a message received via the in-band communication.

Additionally, the Rx controller **125** may adjust an input impedance of the target resonator **133** using the matching network **121** to modulate a signal to be transmitted to the source **110**. For example, the Rx controller **125** may adjust the matching network **121** to increase the input impedance of the target resonator **133** so that a reflected wave will be detected by the Tx controller **114** of the source **110**. Depending on whether the reflected wave is detected, the Tx controller **114** of the source **110** may detect a first value, for example, a binary number "0," or a second value, for example, a binary number "1." For example, when the reflected wave is detected, the Tx controller **114** may detect "0", and when the reflected wave is not detected, the Tx controller **114** may detect "1". Alternatively, when the reflected wave is detected, the Tx controller **114** may detect "1", and when the reflected wave is not detected, the Tx controller **114** may detect "0".

The communication unit **124** of the target **120** may transmit a response message to the communication unit **115** of the source **110**. For example, the response message may include any one or any combination of a product type of the target **120**, manufacturer information of the target **120**, a model name of the target **120**, a battery type of the target **120**, a charging scheme of the target **120**, an impedance value of a load of the target **120**, information on characteristics of the target resonator **133** of the target **120**, information on a frequency band used by the target **120**, an amount of a power consumed by the target **120**, an identifier (ID) of the target **120**, product version information of the target **120**, standard information of the target **120**, and any other information about the target **120**.

The communication unit **124** may perform out-of-band communication using a separate communication channel. For example, the communication unit **124** may include a communication module, such as a ZigBee module, a Bluetooth module, or any other communication module known to one of ordinary skill in the art that the communication unit **124** may use to transmit and receive the data **140** to and from the source **110** via the out-of-band communication.

The communication unit **124** may receive a wake-up request message from the source **110**, and the power detector **127** may detect an amount of a power received by the target resonator **133**. The communication unit **124** may transmit to the source **110** information on the detected amount of the power received by the target resonator **133**. The information on the detected amount of the power received by the target resonator **133** may include, for example, an input voltage value and an input current value of the rectifier **122**, an output voltage value and an output current value of the rectifier **122**, an output voltage value and an output current value of the DC/DC converter **123**, and any other information about the detected amount of the power received by the target resonator **133**.

In the following description of FIGS. **2** through **4**, unless otherwise indicated, the term "resonator" may refer to both a source resonator and a target resonator. The resonator of FIGS. **2**A through **4**B may be used as the resonators described with respect to FIGS. **1** and **5** through **11**.

FIGS. **2**A and **2**B illustrate examples of a distribution of a magnetic field in a resonator and a feeder.

When a power is supplied to a resonator through a separate feeder, a magnetic field is generated in both the feeder and the resonator.

A source resonator and a target resonator may each have a dual loop structure including an external loop and an internal loop.

FIG. **2**A illustrates an example of a structure of a wireless power transmitter in which a feeder **210** and a resonator **220** do not have a common ground. Referring to FIG. **2**A, when an input current flows into the feeder **210** through a terminal labeled "+" and out of the feeder **210** through a terminal labeled "−", a magnetic field **230** is generated by the input current. A direction **231** of the magnetic field **230** inside the feeder **210** is into the plane of FIG. **2**A, and is opposite to a direction **233** of the magnetic field **230** outside the feeder **210**, which is out of the plane of FIG. **2**A. The magnetic field **230** generated by the feeder **210** induces a current in the resonator **220**. A direction of the induced current in the resonator **220** is opposite to a direction of the input current in the feeder **210** as indicated by the dashed lines with arrowheads in FIG. **2**A.

The induced current in the resonator **220** generates a magnetic field **240**. Directions of the magnetic field **240** generated by the resonator **220** are the same at all positions inside the resonator **220**, and are out of the plane of FIG. **2**A. Accordingly, a direction **241** of the magnetic field **240** generated by the resonator **220** inside the feeder **210** is the same as a direction **243** of the magnetic field **240** generated by the resonator **220** outside the feeder **210**.

Consequently, when the magnetic field **230** generated by the feeder **210** and the magnetic field **240** generated by the resonator **220** are combined, a strength of the total magnetic field decreases inside the feeder **210**, but increases outside the feeder **210**. Accordingly, when a power is supplied to the resonator **220** via the feeder **210** in the structure of FIG. **2**A, the strength of the total magnetic field decreases in the portion of the resonator **220** inside the feeder **210**, but increases in the portion of the resonator **220** outside the feeder **210**. When a distribution of the magnetic field in the resonator **220** is random or not uniform, performing impedance matching may be difficult because an input impedance may frequently vary. Also, when the strength of the total magnetic field increases, a wireless power transmission efficiency increases. Conversely, when the strength of the total magnetic field decreases, the wireless power transmission efficiency decreases. Accordingly, the wireless power transmission may be reduced on average.

FIG. **2**B illustrates an example of a structure of a wireless power transmitter in which a resonator **250** and a feeder **260** have a common ground. The resonator **250** includes a capacitor **251**. The feeder **260** receives a radio frequency (RF) signal via a port **261**. When the RF signal is input to the feeder **260**, an input current is generated in the feeder **260**. The input current flowing in the feeder **260** generates a magnetic field, and a current is induced in the resonator **250** by the magnetic field. Also, another magnetic field is generated by the induced current flowing in the resonator **250**. In this example, a direction of the input current flowing in the feeder **260** is opposite to a direction of the induced current flowing in the resonator **250**. Accordingly, the strength of the total magnetic field increases in a region between the resonator **250** and the feeder **260** because a direction **271** of the magnetic field generated by the input current is the same as a direction **273** of the magnetic field generated by the induced current in the region between the resonator **250** and the feeder **260**. Conversely, the strength of the total magnetic field decreases inside the feeder **260** because a direction **281** of the magnetic field generated by the input current is opposite to a direction **283** of the magnetic field generated by the induced current. Therefore, the strength of the total magnetic field decreases in the portion of the resonator **250** inside the feeder **260**, i.e., a center of the resonator **250**, but increases in the portion of the resonator **250** outside the feeder **260**, i.e., near an outer periphery of the resonator **250**.

An input impedance may be adjusted by adjusting an internal area of the feeder **260**. The input impedance refers to an impedance viewed in a direction from the feeder **260** to the resonator **250**. When the internal area of the feeder **260** increases, the input impedance increases, and when the internal area of the feeder **260** decreases, the input impedance decreases. However, if the magnetic field is randomly or not uniformly distributed in the resonator **250**, the input impedance may vary based on a location of a target even if the internal area of the feeder **260** has been adjusted to adjust the input impedance to match an output impedance of a power amplifier for a specific location of the target device. Accordingly, a separate matching network may be needed to match the input impedance to the output impedance of the power amplifier. For example, when the input impedance increases, a separate matching network may be needed to match the increased input impedance to a relatively low output impedance of the power amplifier.

FIGS. **3**A and **3**B illustrate examples of a configuration of a resonator and a feeder.

Referring to FIG. **3**A, a resonator **310** includes a capacitor **311**. A feeder **320** is electrically connected to both ends of the capacitor **311**.

FIG. **3**B illustrates the structure of FIG. **3**A in greater detail. The resonator **310** includes a first transmission line (not identified by a reference numeral in FIG. **3**B, but formed by various elements in FIG. **3**B as discussed below), a first conductor **341**, a second conductor **342**, and at least one capacitor **350**.

The capacitor **350** is connected in series between a first signal conducting portion **331** and a second signal conducting portion **332** in the first transmission line, causing an electric field to be confined in the capacitor **350**. In general, a transmission line includes at least one conductor disposed in an upper portion of the transmission line, and at least one conductor disposed in a lower portion of the transmission line. A current may flow through the at least one conductor disposed in the upper portion of the transmission line, and the at least one conductor disposed in the lower portion of the transmission line may be electrically grounded. In the example in FIG. **3**B, a conductor disposed in the upper portion of the first transmission line is separated into two portions that will be referred to as the first signal conducting portion **331** and the second signal conducting portion **332**, and a conductor disposed in the lower portion of the first transmission line will be referred to as a first ground conducting portion **333**.

As shown in FIG. **3**B, the resonator **310** has a generally two-dimensional (2D) structure. The first transmission line includes the first signal conducting portion **331** and the second signal conducting portion **332** disposed in the upper portion of the first transmission line, and the first ground conducting portion **333** disposed in the lower portion of the first transmission line. The first signal conducting portion **331** and the second signal conducting portion **332** are disposed to face the first ground conducting portion **333**. A current flows through the first signal conducting portion **331** and the second signal conducting portion **332**.

Also, as shown in FIG. **3**B, one end of the first signal conducting portion **331** is connected to one end of the first conductor **341**, the other end of the first signal conducting portion **331** is connected to one end of the capacitor **350**, and the other end of the first conductor **341** is connected to one end of the first ground conducting portion **333**. One end of the second signal conducting portion **332** is connected to one end of the second conductor **342**, the other end of the second signal conducting portion **332** is connected to the other end of the capacitor **350**, and the other end of the second conductor **342** is connected to the other end of the first ground conducting portion **333**. Accordingly, the first signal conducting portion **331**, the second signal conducting portion **332**, the first ground conducting portion **333**, the first conductor **341**, and the second conductor **342** are connected to one another, causing the resonator **310** to have an electrically closed loop structure. The term "loop structure" includes a polygonal structure, a circular structure, a rectangular structure, and any other geometrical structure that is closed, i.e., a geometrical structure that does not have any opening in its perimeter. The expression "having a loop structure" indicates a structure that is electrically closed.

The capacitor **350** is inserted into an intermediate portion of the first transmission line. In the example in FIG. **3**B, the capacitor **350** is inserted between the first signal conducting portion **331** and the second signal conducting portion **332**. The capacitor **350** may be a lumped element capacitor, a distributed element capacitor, or any other type of capacitor known to one of ordinary skill in the art. For example, a distributed element capacitor may include zigzagged conductor lines and a dielectric material having a high permittivity disposed between the zigzagged conductor lines.

The capacitor **350** inserted into the first transmission line may cause the resonator **310** to have a characteristic of a metamaterial. A metamaterial is a material having an electrical characteristic that is not found in nature, and thus may have an artificially designed structure. All materials existing in nature have a permittivity and a magnetic permeability, and most materials have a positive permittivity and/or a positive magnetic permeability.

A right-hand rule may be applied to an electric field, a magnetic field, and a Poynting vector in most materials, so the corresponding materials may be referred to as right-handed materials (RHMs). However, a metamaterial having a permittivity and/or a magnetic permeability that is not found in nature may be classified into an epsilon negative (ENG) material, a mu negative (MNG) material, a double negative (DNG) material, a negative refractive index (NRI) material, a left-handed (LH) material, and any other metamaterial classification known to one of ordinary skill in the art based on a sign of the permittivity of the metamaterial and a sign of the magnetic permeability of the metamaterial.

If the capacitor **350** is a lumped element capacitor and a capacitance of the capacitor **350** is appropriately determined, the resonator **310** may have a characteristic of a metamaterial. If the resonator **310** is caused to have a negative magnetic permeability by appropriately adjusting the capacitance of the capacitor **350**, the resonator **310** may also be referred to as an MNG resonator. Various criteria may be applied to determine the capacitance of the capacitor **350**. For example, the various criteria may include a criterion for enabling the resonator **310** to have the characteristic of the metamaterial, a criterion for enabling the resonator **310** to have a negative magnetic permeability at a target frequency, a criterion for enabling the resonator **310** to have a zeroth-order resonance characteristic at the target frequency, and any other suitable criterion. Based on any one criterion or any combination of the aforementioned criteria, the capacitance of the capacitor **350** may be appropriately determined.

The resonator **310**, hereinafter referred to as the MNG resonator **310**, may have a zeroth-order resonance characteristic of having a resonant frequency when a propagation constant is "0". When the MNG resonator **310** has the zeroth-order resonance characteristic, the resonant frequency is independent of a physical size of the MNG resonator **310**. The resonant frequency of the MNG resonator **310** having the zeroth-order characteristic may be changed without changing the physical size of the MNG resonator **310** by changing the capacitance of the capacitor **350**.

In a near field, the electric field is concentrated in the capacitor **350** inserted into the first transmission line, causing the magnetic field to become dominant in the near field. The MNG resonator **310** has a relatively high Q-factor when the capacitor **350** is a lumped element capacitor, thereby increasing a wireless power transmission efficiency. The Q-factor indicates a level of an ohmic loss or a ratio of a reactance with respect to a resistance in the wireless power transmission. As will be understood by one of ordinary skill in the art, the wireless power transmission efficiency will increase as the Q-factor increases.

Although not illustrated in FIG. **3**B, a magnetic core passing through the MNG resonator **310** may be provided to increase a wireless power transmission distance.

Referring to FIG. **3**B, the feeder **320** includes a second transmission line (not identified by a reference numeral in FIG. **3**B, but formed by various elements in FIG. **3**B as discussed below), a third conductor **371**, a fourth conductor **372**, a fifth conductor **381**, and a sixth conductor **382**.

The second transmission line includes a third signal conducting portion **361** and a fourth signal conducting portion **362** disposed in an upper portion of the second transmission line, and a second ground conducting portion **363** disposed in a lower portion of the second transmission line. The third signal conducting portion **361** and the fourth signal conducting portion **362** are disposed to face the second ground conducting portion **363**. A current flows through the third signal conducting portion **361** and the fourth signal conducting portion **362**.

Additionally, as shown in FIG. 3B, one end of the third signal conducting portion **361** is connected to one end of the third conductor **371**, the other end of the third signal conducting portion **361** is connected to one end of the fifth conductor **381**, and the other end of the third conductor **371** is connected to one end of the second ground conducting portion **363**. One end of the fourth signal conducting portion **362** is connected to one end of the fourth conductor **372**, the other end of the fourth signal conducting portion **362** is connected to one end of the sixth conductor **382**, and the other end of the fourth conductor **372** is connected to the other end of the second ground conducting portion **363**. The other end of the fifth conductor **381** is connected to the first signal conducting portion **331** at or near where the first signal conducting portion **331** is connected to one end of the capacitor **350**, and the other end of the sixth conductor **382** is connected to the second signal conducting portion **332** at or near where the second signal conducting portion **332** is connected to the other end of the capacitor **350**. Thus, the fifth conductor **381** and the sixth conductor **382** are connected in parallel with both ends of the capacitor **350**. The fifth conductor **381** and the sixth conductor **382** may be used as input ports to receive an RF signal as an input.

Accordingly, the third signal conducting portion **361**, the fourth signal conducting portion **362**, the second ground conducting portion **363**, the third conductor **371**, the fourth conductor **372**, the fifth conductor **381**, the sixth conductor **382**, and the resonator **310** are connected to one another, causing the resonator **310** and the feeder **320** to have an electrically closed loop structure. The term "loop structure" includes a polygonal structure, a circular structure, a rectangular structure, and any other geometrical structure that is closed, i.e., a geometrical structure that does not have any opening in its perimeter. The expression "having a loop structure" indicates a structure that is electrically closed.

If an RF signal is input to the fifth conductor **381** or the sixth conductor **382**, an input current flows in the feeder **320** and the resonator **310**, generating a magnetic field that induces a current in the resonator **310**. A direction of the input current flowing in the feeder **320** is the same as a direction of the induced current flowing in the resonator **310**, thereby causing a strength of a total magnetic field in the resonator **310** to increase inside the feeder **320**, but decrease outside the feeder **320**.

An input impedance is determined by an area of a region between the resonator **310** and the feeder **320**. Accordingly, a separate matching network used to match the input impedance to an output impedance of a power amplifier may not be needed. However, even if a matching network is used, the input impedance may be adjusted by adjusting a size of the feeder **320**, and accordingly a structure of the matching network may be simplified. The simplified structure of the matching network reduces a matching loss of the matching network.

The second transmission line, the third conductor **371**, the fourth conductor **372**, the fifth conductor **381**, and the sixth conductor **382** of the feeder **320** may have the same structure as the resonator **310**. For example, if the resonator **310** has a loop structure, the feeder **320** may also have a loop structure. As another example, if the resonator **310** has a circular structure, the feeder **320** may also have a circular structure.

FIG. **4**A illustrates an example of a distribution of a magnetic field inside a resonator produced by feeding a feeder. FIG. **4**A more simply illustrates the resonator **310** and the feeder **320** of FIGS. **3**A and **3**B, and the names and the reference numerals of the various elements in FIG. **3**B will be used in the following description of FIG. **4**A for ease of description.

A feeding operation may be an operation of supplying a power to a source resonator in wireless power transmission, or an operation of supplying an AC power to a rectifier in the wireless power transmission. FIG. **4**A illustrates a direction of an input current flowing in the feeder **320**, and a direction of an induced current flowing in the source resonator **310**. Additionally, FIG. **4**A illustrates a direction of a magnetic field generated by the input current of the feeder **320**, and a direction of a magnetic field generated by the induced current of the resonator **310**.

Referring to FIG. **4**A, the fifth conductor **381** or the sixth conductor **382** of the feeder **320** of FIG. **3**A may be used as an input port **410**. In FIG. **4**A, the sixth conductor **382** of the feeder **320** is being used as the input port **410**. The input port **410** receives an RF signal as an input. The RF signal may be output from a power amplifier. The power amplifier may increase or decrease an amplitude of the RF signal based on a power requirement of a target. The RF signal received by the input port **410** is represented in FIG. **4**A as an input current flowing in the feeder **320**. The input current flows in a clockwise direction in the feeder **320** along the second transmission line of the feeder **320**. The fifth conductor **381** and the sixth conductor **382** of the feeder **320** are electrically connected to the resonator **310**. More particularly, the fifth conductor **381** of the feeder **320** is connected to the first signal conducting portion **331** of the resonator **310**, and the sixth conductor **382** of the feeder **320** is connected to the second signal conducting portion **332** of the resonator **310**. Accordingly, the input current flows in both the resonator **310** and the feeder **320**. The input current flows in a counterclockwise direction in the resonator **310** along the first transmission line of the resonator **310**. The input current flowing in the resonator **310** generates a magnetic field, and the magnetic field induces a current in the resonator **310**. The induced current flows in a clockwise direction in the resonator **310** along the first transmission line of the resonator **310**. The induced current in the resonator **310** supplies energy to the capacitor **311** of the resonator **310**, and also generates a magnetic field. In this example, the input current flowing in the feeder **320** and the resonator **310** is indicated by the solid lines with arrowheads in FIG. **4**A, and the induced current flowing in the resonator **310** is indicated by the dashed lines with arrowheads in FIG. **4**A.

A direction of a magnetic field generated by a current is determined based on the right-hand rule. As illustrated in FIG. **4**A, inside the feeder **320**, a direction **421** of the magnetic field generated by the input current flowing in the feeder **320** is the same as a direction **423** of the magnetic field generated by the induced current flowing in the resonator **310**. Accordingly, the strength of the total magnetic field increases inside the feeder **320**.

In contrast, as illustrated in FIG. **4**A, in a region between the feeder **320** and the resonator **310**, a direction **433** of the magnetic field generated by the input current flowing in the feeder **320** is opposite to a direction **431** of the magnetic field generated by the induced current flowing in the source resonator **310**. Accordingly, the strength of the total magnetic field decreases in the region between the feeder **320** and the resonator **310**.

Typically, in a resonator having a loop structure, a strength of a magnetic field decreases in the center of the resonator, and increases near an outer periphery of the resonator. However, referring to FIG. **4**A, since the feeder **320** is electrically connected to both ends of the capacitor **311** of the resonator **310**, the direction of the induced current in the resonator **310** is the same as the direction of the input current in the feeder **320**. Since the direction of the induced current in the resonator **310** is the same as the direction of the input current in the feeder **320**, the strength of the total magnetic field increases inside the feeder **320**, and decreases outside the feeder **320**. As a result, due to the feeder **320**, the strength of the total magnetic field increases in the center of the resonator having the loop structure, and decreases near the outer periphery of the resonator, thereby compensating for the normal characteristic of the resonator **310** having the loop structure in which the strength of the magnetic field decreases in the center of the resonator **310**, and increases near the outer periphery of the resonator **310**. Thus, the strength of the total magnetic field may be constant inside the resonator **310**.

A wireless power transmission efficiency of transmitting a power from a source resonator to a target resonator is proportional to the strength of the total magnetic field generated in the source resonator. Accordingly, when the strength of the total magnetic field increases in the center of the source resonator, the wireless power transmission efficiency also increases.

FIG. **4**B illustrates an example of equivalent circuits of a feeder and a resonator.

Referring to FIG. **4**B, a feeder **440** and a resonator **450** may be represented by the equivalent circuits in FIG. **4**B. The feeder **440** is represented as an inductor having an inductance L_f, and the resonator **450** is represented as a series connection of an inductor having an inductance L coupled to the inductance L_f of the feeder **440** by a mutual inductance M, a capacitor having a capacitance C, and a resistor having a resistance R. An example of an input impedance Z_{in} viewed in a direction from the feeder **440** to the resonator **450** may be expressed by the following Equation 1:

$$Z_{in} = \frac{(\omega M)^2}{Z} \qquad (1)$$

In Equation 1, M denotes a mutual inductance between the feeder **440** and the resonator **450**, ω denotes a resonant frequency of the feeder **440** and the resonator **450**, and Z denotes an impedance viewed in a direction from the resonator **450** to a target. As can be seen from Equation 1, the input impedance Z_{in} is proportional to the square of the mutual inductance M. Accordingly, the input impedance Z_{in} may be adjusted by adjusting the mutual inductance M between the feeder **440** and the resonator **450**. The mutual inductance M depends on an area of a region between the feeder **440** and the resonator **450**. The area of the region between the feeder **440** and the resonator **450** may be adjusted by adjusting a size of the feeder **440**, thereby adjusting the mutual inductance M and the input impedance Z_{in}. Since the input impedance Z_{in} may be adjusted by adjusting the size of the feeder **440**, it may be unnecessary to use a separate matching network to perform impedance matching with an output impedance of a power amplifier.

In the resonator **450** and the feeder **440** included in a wireless power reception apparatus, a magnetic field may be distributed as illustrated in FIG. **4**A. The resonator **450** may operate as a target resonator **450**. For example, the target resonator **450** may receive a wireless power from a source resonator via a magnetic coupling with the source resonator. The received wireless power induces a current in the target resonator **450**. The induced current in the target resonator **450** generates a magnetic field, which induces a current in the feeder **440**. If the target resonator **450** is connected to the feeder **440** as illustrated in FIG. **4**A, a direction of the induced current flowing in the target resonator **450** will be the same as a direction of the induced current flowing in the feeder. Accordingly, for the reasons discussed above in connection with FIG. **4**A, the strength of the total magnetic field will increase inside the feeder **440**, but will decrease in a region between the feeder **440** and the target resonator **450**.

FIG. **5** illustrates an example of a wireless power transmission and reception system.

Referring to FIG. **5**, the wireless power transmission and reception system includes a wireless power transmitter **510**, a wireless power receiver **520**, and a load **530**.

The wireless power transmitter **510** includes a signal generator **511**, a resonant power generator **512**, and a source resonator **513**.

The signal generator **511** generates a signal for wireless power transmission. The signal may have a predetermined frequency. In one example, the signal may be an AC voltage having a frequency in a band of tens of Hz.

The resonant power generator **512** differentially inputs a first input signal and a second input signal to the source resonator **513**, and cancels a harmonic component of an output power. The resonant power generator **512** includes a first power amplifier and a second power amplifier. In one example, the first power amplifier generates the first input signal by amplifying the signal generated by the signal generator **511**, and the second power amplifier generates the second input signal by amplifying the signal generated by the signal generator **511**. In this example, the first input signal and the second input signal have a 180 degree phase difference. Descriptions pertaining to the resonant power generator **512** will be provided with reference to FIGS. **6**A and **6**B.

The source resonator **513** transmits the output power from which the harmonic component has been cancelled to a target resonator **521** of the wireless power receiver **520** by resonating with the target resonator **521**. The source resonator **513** transmits, to the target resonator **521**, the output power generated based on the first input signal and the second input signal differentially input to the source resonator **513** as electromagnetic energy. For example, the source resonator **513** transmits the output power to the wireless power receiver **520** via a magnetic coupling with the target resonator **521**.

The wireless power receiver **520** includes the target resonator **521**, a rectifier **522**, and a DC/DC converter **523**.

The target resonator **521** receives the electromagnetic energy transmitted from the source resonator **513**. For example, the target resonator **521** receives the output power from the wireless power transmitter **510** via a magnetic coupling with the source resonator **513**.

The target resonator **521** generates a signal by receiving the power transmitted from the source resonator **513** of the wireless power transmitter **510**. The generated signal may be an AC voltage. The target resonator **521** outputs the generated signal. For example, an AC power or an AC voltage may be output from the target resonator **521**.

The rectifier **522** generates a rectified signal by rectifying the generated signal output from the target resonator **521**.

The rectifier **522** outputs the rectified signal to the DC/DC converter **523**. The rectifier **522** converts the AC power or the AC voltage output from the target resonator **521** to a stable DC voltage.

The DC/DC converter **523** generates a charging power by changing a voltage level of the rectified signal.

The load **530** consumes a power. In the example in FIG. **5**, the load **530** is a portion of the wireless power receiver **520**, but the load **530** may be separate from the wireless power receiver **520**. The load **530** is a device to consume the power wirelessly received from the wireless power receiver **520**. For example, the load **530** may be a mobile device.

The load **530** includes a charging circuit **531** and a battery **532**. The charging circuit **531** adjusts a voltage level and a current level of a charging power based on a charging state of the battery **532** for a stable charging operation of the battery **532**. The charging circuit **531** sets a constant charging current based on a capacity of the battery **532**, and provides a stable power to the battery **532** based on the setting of the constant charging current.

The battery **532** is provided with the charging power, and charges by storing a current of the provided charging power in the battery **532**.

FIGS. **6**A and **6**B illustrate examples of a wireless power transmitter **600**.

Referring to FIG. **6**A, the wireless power transmitter **600** includes a signal generator **620**, a first driving circuit **621**, a second driving circuit **622**, a first power amplifier **631**, a second power amplifier **632**, and a source resonator **640**. The first driving circuit **621**, the second driving circuit **622**, the first power amplifier **631**, and the second power amplifier **632** are included in a resonant power generator **610**.

The signal generator **620** generates a signal for wireless power transmission. A signal may have a predetermined frequency band. For example, the frequency band of the signal may be 6.78 MHz.

The first power amplifier **631** is coupled to the first driving circuit **621**, and the second power amplifier **632** is coupled to the second driving circuit **622**. In one example, the first driving circuit **621** may be a positive driving circuit, and the second driving circuit **622** may be a negative driving circuit. The first driving circuit **621** and the second driving circuit **622** receive a same signal from the signal generator **620**. A first transmission signal output from the first driving circuit **621** and a second transmission signal output the second driving circuit **622** have a 180 degree phase difference. For example, the first driving circuit **621** may not reverse a phase of a signal received from the signal generator **620**, and the second driving circuit **622** may reverse a phase of a signal received from the signal generator **620** by 180 degrees.

The first power amplifier **631** amplifies the first transmission signal received from the first driving circuit **621** as a first input signal, and the second power amplifier **632** amplifies the second transmission signal received from the second driving circuit **622** as a second input signal. The first power amplifier **631** and the second power amplifier **632** may each be a Class-E amplifier. The first transmission signal input to the first power amplifier **631** and the second transmission signal input to the second power amplifier **632** have a 180 degree phase difference. Accordingly, the first input signal generated by the first power amplifier **631** and the second input signal generated by the second power amplifier **632** have the 180 degree phase difference.

The first power amplifier **631** and the second power amplifier **632** differentially input the first input signal and the second input signal to a source resonator **640**. In one example, the source resonator **640** receives the first input signal and the second input signal via a differential input port having a separate grounding unit. Since the first input signal and the second input signal are differentially input to the source resonator **640**, even-order harmonic components are cancelled by common mode rejection among harmonic components of an output power generated by the source resonator **640**. In one example, the first power amplifier **631** and the second power amplifier **632** convert a DC voltage provided to the first power amplifier **631** and the second power amplifier **632** to an AC voltage using a reference resonant frequency F_{Ref}, and generate a communication power or a charging power to be used in a wireless power receiver.

The source resonator **640** generates the output power based on the first input signal and the second input signal differentially input to the source resonator **640**. The even-mode harmonic components of the output power are cancelled by the differentially input first input signal and second input signal. The source resonator **640** transmits the output power from which the even-mode harmonic components have been cancelled to a target resonator of the wireless power receiver by resonating. In one example, the source resonator **640** transmits the output power to the wireless power receiver via a magnetic coupling with the target resonator.

Referring to FIG. **6**B, a wireless power transmitter **650** includes a signal generator **661**, a resonant power generator **660**, a low-pass filter (LPF) **683**, and a source resonator **690**. The resonant power generator **660** includes a first driving circuit **662**, a second driving circuit **663**, a first power amplifier, and a second power amplifier.

The first power amplifier and the second power amplifier each include a transistor **671** or **672**, a plurality of inductors, and a plurality of capacitors. The first driving circuit **662** and the second driving circuit **663** receive a same signal from the signal generator **661**. In one example, a frequency band of a signal received from the signal generator **661** may be 6.78 MHz. The first driving circuit **662** may be a positive driving circuit, and the second driving circuit **663** may be a negative driving circuit. The first driving circuit **662** may not reverse a phase of the signal received from the signal generator **661**, and the second driving circuit **663** may reverse a phase of the signal received from the signal generator **661** by 180 degrees.

The first power amplifier receives a first transmission signal output from the first driving circuit **662**, and the second power amplifier receives a second transmission signal output from the second driving circuit **663**. The first power amplifier and the second power amplifier amplify the first transmission signal and the second transmission signal, and generate a first input signal and a second input signal. In one example, when the first transmission signal and the second transmission signal are provided as voltages, the first transmission signal and the second transmission signal are respectively applied to a transistor **671** of the first power amplifier and a transistor **672** of the second power amplifier as a gate source voltage. The transistor **671** of the first power amplifier outputs a first drain source voltage, for example, Vds, based on a first gate source voltage, for example, Vgs, and the second transistor **672** outputs a second drain source voltage, for example, Vds', based on a second gate source voltage, for example, Vgs'. A phase difference between the first drain source voltage and the second drain source voltage is 180 degrees because a phase difference between the first gate source voltage and the second gate source voltage is 180 degrees.

The first power amplifier generates the first input signal based on the first drain source voltage, and the second power amplifier generates the second input signal based on the second drain source voltage. A phase difference between the first input signal and the second input signal is 180 degrees because the phase difference between the first drain source voltage and the second drain source voltage is 180 degrees. When the first input signal and the second input signal are differentially input to the source resonator **690**, even-order harmonic components are cancelled among harmonic components of an output power generated by the source resonator **690** by common mode rejection since the phase difference between the first input signal and the second input signal is 180 degrees.

The first power amplifier and the second power amplifier respectively include a first notch filter **681** and a second notch filter **682**. The first notch filter **681** and the second notch filter **682** may each be a third order notch filter. The first notch filter **681** and the second notch filter **682** each include a capacitor and an inductor. The first notch filter **681** and the second notch filter **682** cancel a third harmonic component of an output signal generated by a source resonator **690** based on the first input signal and the second input signal.

The first notch filter **681** and the second notch filter **682** also match an output impedance of the wireless power transmitter **650** to an input impedance of a wireless power receiver. The first notch filter **681** and the second notch filter **682** compensate for impedance mismatching between the source resonator **690** and the target resonator to achieve optimal matching. The first power amplifier and the second power amplifier may not need an additional matching network because the first notch filter **681** and the second notch filter **682** are included in the first power amplifier and the second power amplifier.

The LPF **683** cancels fifth and higher odd-order harmonic components of the first input signal and the second input signal. If the LPF **683** is set to also cancel a third harmonic component of the first input signal and the second input signal, a loss may occur in the first input signal and the second input signal. Accordingly, the loss occurring in the first input signal and the second input signal may be prevented by setting the LPF **683** to cancel the fifth and higher odd-order harmonic components. Since the fifth and higher harmonic components of the first input signal and the second input signal are cancelled by the LPF **683**, fifth and higher harmonic components of the output signal generated by the source resonator **690** are cancelled based on the first input signal and the second input signal.

In one example, the LPF **683** may be set to cancel fifth and higher odd-order harmonic components of the first input signal and the second input signal to prevent the loss in the first input signal and the second input signal.

In another example, the LPF **683** may enable the source resonator **690**, the first power amplifier, and the second power amplifier to have a load-pull behavior characteristic.

The source resonator **690** receives the first input signal and the second input signal from the first power amplifier and the second power amplifier. In one example, the source resonator **690** receives the first input signal and the second input signal via the differential input port having the separate grounding unit.

As previously described, the third harmonic component of the output power is cancelled by the first notch filter **681** and the second notch filter **682**, and the fifth and higher odd-order harmonic components of the output power are cancelled by the LPF **683**. The even-order harmonic components of the output power are cancelled from the output signal of the source resonator **690** because the first input signal and the second input signal are differentially input to the source resonator **690**. Accordingly, the source resonator **690** transmits, by resonating with the target resonator, the output signal from which the harmonic components are cancelled to the wireless power receiver.

FIG. **7** illustrates an example of a phase difference between a first input signal and a second input signal.

In a graph of FIG. **7**, an x axis indicates a time axis and a y axis indicates a voltage value. Referring to FIG. **7**, a first power amplifier generates the first input signal based on a first transmission signal output from a first driving circuit, and a second power amplifier generates the second input signal based on a second transmission signal output from a second driving circuit. When the first transmission signal and the second transmission signal are provided as voltages, the first transmission signal is input to a gate source voltage **711**, hereinafter also referred to as a first gate source voltage, of a transistor of the first power amplifier, and the second transmission signal is input to a gate source voltage **712**, hereinafter also referred to as a second gate source voltage, of a transistor of the second power amplifier. When the first gate source voltage **711** is input to the transistor of the first power amplifier, the transistor of the first power amplifier outputs a first drain source voltage **714**, and the transistor of the second power amplifier outputs a second drain source voltage **713**. Although a magnitude of the first gate source voltage **711** is equal to a magnitude of the second gate source voltage **712**, a phase difference between the first gate source voltage **711** and the second gate source voltage **712** is 180 degrees due to a first driving circuit and a second driving circuit generating the 180 phase difference. Accordingly, the first drain source voltage **714** and the second drain source voltage **713** also have a 180 degree phase difference. The first power amplifier generates a first input signal based on the first drain source voltage **714**, and the second power amplifier generates a second input signal based on the second drain source voltage **713**. The first input signal and the second input signal have a 180 degree phase difference in response to the phase difference between the first drain source voltage **714** and the second drain source voltage **713** being 180 degrees, and even-order harmonic components of an output signal of a source resonator are cancelled because the first input signal and the second input signal are differentially input to the source resonator.

FIG. **8** illustrates an example of harmonic components **812**, **813**, **814**, **815**, **816**, **817**, **818**, **819**, and **820** of an output power **811**.

In a graph of FIG. **8**, an x axis indicates a frequency band of a power and a y axis indicates a magnitude of a power. Referring to FIG. **8**, the graph illustrates the output power **811** and a second harmonic component **812** through a tenth harmonic component **820**. A first power amplifier generates a first input signal, and a second power amplifier generates a second input signal. In this example, the first input signal and the second input signal have a 180 degree phase difference due to a first driving circuit coupled to the first power amplifier and a second driving circuit coupled to the second power amplifier generating the 180 degree phase difference. The first input signal and the second input signal are differentially input to a source resonator, causing even-order harmonic components, for example, second, fourth, sixth, eighth, and tenth harmonic components, **812**, **814**, **816**, **818**, and **820**, of an output power of the source resonator to be cancelled. The first power amplifier and the second power amplifier respectively include a first notch filter and a second notch filter. In this example, the first notch filter and the second notch filter are each a third order notch filter. The first notch filter and the second notch filter cancel a third harmonic component **813** of the output power **811**. The first input signal and the second input signal pass through an LPF. In this example, the LPF is set to cancel fifth and higher odd-order harmonic components. For example, a fifth harmonic component **815**, a seventh harmonic component **817**, and a ninth harmonic component **819** are cancelled by the LPF.

FIGS. **9**A and **9**B illustrate examples of a unidirectional wireless power transmission and reception system.

Referring to FIG. **9**A, (a) illustrates wireless power charging between a pad **910** and a mobile terminal **911**, (b) illustrates wireless power charging between pads **921** and **922** and hearing aids **923** and **924**, and (c) illustrates wireless power charging between a pad **930** and a smart watch **931**.

In (a), a wireless power transmitter is provided in the pad **910**. A wireless power receiver is provided in the mobile terminal **911**. The pad **910** charges the mobile terminal **911**.

In (b), two wireless power transmitters are provided in the first pad **921** and the second pad **922**, respectively. The hearing aid **923** is a left ear hearing aid, and the hearing aid **924** is a right ear hearing aid. Two wireless power receivers are provided in the hearing aids **923** and **924**, respectively.

In (c), a wireless power transmitter is provided in the pad **930**. A wireless power receiver is provided in the smart watch **931**. The pad **930** charges the smart watch **931**.

In (a) through (c), the wireless power transmitters of the pads include a resonant power generator and a source resonator. The resonant power generator includes a first power amplifier and a second power amplifier. The first power amplifier and the second power amplifier respectively generate a first input signal and a second input signal having a 180 degree phase difference, and differentially input the first input signal and the second input signal to the source resonator, causing even-order harmonic components of an output power of the source resonator to be cancelled. The first power amplifier and the second power amplifier respectively include a first notch filter and a second notch filter. The first notch filter and the second notch filter cancel a third harmonic component of the output power of the source resonator. The wireless power transmitter further includes an LPF, and fifth and higher odd-order harmonic components of the output power are cancelled by the LPF. Accordingly, the wireless power transmitter transmits, to the wireless power receiver, the output power from which the harmonic components have been cancelled.

Referring to FIG. **9**B, (a) illustrates wireless power charging between a pad **941** and mobile terminals **942** and **943**, and (b) illustrates wireless power charging between a power source **951** and mobile terminals **952** and **953** in a three-dimensional (3D) space.

In (a), a wireless power transmitter is provided in the pad **941**. Two wireless power receivers are provided in the mobile terminals **942** and **943**, respectively. The pad **941** charges the mobile terminals **942** and **943**.

In (b), wireless power transmitters are provided in a power source **951**. Two wireless receivers are provided in mobile terminals **952** and **953**, respectively. The power source **951** charges the mobile terminals **952** and **953** in a 3D space.

In (a) and (b), the wireless power transmitters of the pad **941** and the power source **951** include a resonant power generator and a source resonator. The resonant power generator includes a first power amplifier and a second power amplifier. A first input signal and a second input signal having a 180 degree phase difference generated by the first power amplifier and the second power amplifier are differentially input to the source resonator, causing even-order harmonic components of an output power of the source resonator to be cancelled, and a third harmonic component of the output power is cancelled by a first notch filter and a second notch filter included in the first power amplifier and the second power amplifier, respectively. Each of the wireless power transmitters further includes an LPF, which cancels fifth and higher odd-order harmonic components of the output power of the source resonator.

FIGS. **10**A through **10**C illustrate examples of a bidirectional wireless power transmission and reception system.

Referring to FIG. **10**A, mobile terminals **1011** and **1012** each include a wireless power transmitter and a wireless power receiver. The mobile terminal **1011** transmits a power to the mobile terminal **1012**, or receives a power from the mobile terminal **1012**. The mobile terminal **1012** also transmits a power to the mobile terminal **1011**, or receives a power from the mobile terminal **1011**.

The wireless power transmitters of the mobile terminals **1011** and **1012** each include a resonant power generator and a source resonator. The resonant power generator includes a first power amplifier and a second power amplifier. A first input signal and a second input signal having a 180 degree phase difference generated by the first power amplifier and the second power amplifier are differentially input to the source resonator, causing even-order harmonic components of an output power of the source resonator to be cancelled, and a third harmonic component of the output power of the source resonator is cancelled by a first notch filter and a second notch filter included in the first power amplifier and the second power amplifier, respectively. Each of the wireless power transmitters further includes an LPF, which cancels fifth and higher harmonic component of the output power of the source resonator. Accordingly, the mobile terminals **1011** and **1012** transmit and receive the output power from which the harmonic components are cancelled.

Referring to FIG. **10**B, an electric vehicle charging system **1030** includes a source system **1031**, a source resonator **1032**, a target resonator **1033**, a target system **1034**, and an electric vehicle battery **1035**.

The electric vehicle charging system **1030** has a structure similar to a structure of the wireless power transmission and reception system of FIG. **5**. For example, the electric vehicle charging system **1030** includes a source including the source system **1031** and the source resonator **1032**. The electric vehicle charging system **1030** further includes a target including the target resonator **1033** and the target system **1034**. In this example, the source system **1030** includes a signal generator and a resonant power generator like the wireless power transmitter **510** of FIG. **5**. Also, the target system **1034** includes a target resonator, a rectifier, and a DC/DC converter like the wireless power receiver of FIG. **5**.

The resonant power generator of the source system **1031** includes a first power amplifier and a second power amplifier. The first power amplifier and the second power amplifier respectively generate a first input signal and a second input signal having a 180 degree phase difference, and differentially input the first input signal and the second input signal to the source resonator **1032**, which cancels even-order harmonic components of an output power of the source resonator **1032**. The first power amplifier and the second power amplifier respectively include a first notch filter and a second notch filter. The first notch filter and the second notch filter cancel a third harmonic component of the output power of the source resonator **1032**. The source system **1031** further includes an LPF, which cancels fifth and higher odd-order harmonic components of the output power. Accordingly, the source resonator **1032** transmits, to the target resonator **1033**, the output power from which the harmonic components have been cancelled.

The source system **1031** generates a power based on a type of a charging vehicle, a capacity of the electric vehicle battery **1035**, and a charging state of the electric vehicle battery **1035**, and provides the generated power to the target system **1034**.

The source system **1031** controls an alignment of the source resonator **1032** to match an alignment of the target resonator **1033**. For example, a controller of the source system **1031** controls the alignments by transmitting a message to the target resonator **1034** when the alignment of the source resonator **1032** does not match the alignment of the target resonator **1033**.

In this example, the alignments do not match when a position of the target resonator **1033** is not a position at which a maximum magnetic resonance with the source resonator **1032** occurs. For example, when a vehicle is not stopped at a precise position, the source system **1031** instructs the position of the vehicle to be adjusted, and matches the alignment of the source resonator **1032** to the alignment of the target resonator **1033**.

The source system **1031** and the target system **1033** transmit and receive an identifier of the vehicle and various messages by communicating with each other.

The electric vehicle battery **1035** is charged by the target system **1034**.

The electric vehicle charging system **1030** may use a resonant frequency in a band of a few kHz to tens of MHz.

Referring to FIG. **100**, (a) illustrates wireless power charging between an electric device **1041** implanted in a human body and a mobile terminal **1042**, and (b) illustrates wireless power charging between a hearing aid **1051** and a mobile terminal **1052**.

In (a), a wireless power transmitter and a wireless power receiver are provided in the mobile terminal **1042**. A wireless power receiver is provided in the electric device **1041** inserted into the human body. The electric device **1041** implanted in the human body is charged by receiving a power from the mobile terminal **1042**.

In (b), a wireless power transmitter and a wireless power receiver are provided in a mobile terminal **1052**. A wireless power receiver is provided in a hearing aid **1051**. The hearing aid **1051** is charged by receiving a power from the mobile terminal **1052**. Various low-power electric devices, such as a Bluetooth® earphone, in addition to the hearing aid **1051**, may be charged by receiving a power from the mobile terminal **1052**.

The wireless power transmitter in (a) and (b) includes a resonant power generator and a source resonator. The resonant power generator includes a first power amplifier and a second power amplifier. The resonant power generator differentially inputs a first input signal generated in the first power amplifier and a second input signal having a 180 degree phase difference generated in the second power amplifier to the source resonator, which cancels even-order harmonic components of an output power of the source resonator. The first power amplifier and the second power amplifier respectively include a first notch filter and a second notch filter, and the first notch filter and the second notch filter cancel a third harmonic component of the output power of the source resonator. The wireless power transmitter further includes an LPF, and the LPF cancels fifth and higher odd-order harmonic components of the output power of the source resonator.

The source resonator transmits the output power from which the harmonic components have been cancelled to the wireless power receiver by resonating with a target resonator included in the wireless power receiver.

FIG. **11** illustrates an example of a method of wireless power transmission.

Referring to FIG. **11**, in operation **1110**, the method of wireless power transmission includes differentially inputting a first input signal and a second input signal to a source resonator, and cancelling harmonic components of an output power of the source resonator.

In operation **1120**, the method of wireless power transmission includes transmitting the output power from which the harmonic components have been cancelled to a wireless power receiver by resonating with a target resonator of the wireless power receiver.

A detailed description of the method of wireless power transmission of FIG. **11** will be omitted for conciseness because the descriptions provided with respect to FIGS. **1** through **10**C are also applicable to the method of wireless power transmission of FIG. **11**.

The Tx controller **114**, the communication units **115** and **124**, and the Rx controller **125** in FIG. **1** that perform the various operations described with respect to FIGS. **2**A, **2**B, **3**A, **3**B, **4**A, and **4**B may be implemented using one or more hardware components, one or more software components, or a combination of one or more hardware components and one or more software components.

A hardware component may be, for example, a physical device that physically performs one or more operations, but is not limited thereto. Examples of hardware components include resistors, capacitors, inductors, power supplies, frequency generators, operational amplifiers, power amplifiers, low-pass filters, high-pass filters, band-pass filters, analog-to-digital converters, digital-to-analog converters, and processing devices.

A software component may be implemented, for example, by a processing device controlled by software or instructions to perform one or more operations, but is not limited thereto. A computer, controller, or other control device may cause the processing device to run the software or execute the instructions. One software component may be implemented by one processing device, or two or more software components may be implemented by one processing device, or one software component may be implemented by two or more processing devices, or two or more software components may be implemented by two or more processing devices.

A processing device may be implemented using one or more general-purpose or special-purpose computers, such as, for example, a processor, a controller and an arithmetic logic unit, a digital signal processor, a microcomputer, a field-programmable array, a programmable logic unit, a microprocessor, or any other device capable of running software or executing instructions. The processing device may run an operating system (OS), and may run one or more software applications that operate under the OS. The processing device may access, store, manipulate, process, and create data when running the software or executing the instructions. For simplicity, the singular term "processing device" may be used in the description, but one of ordinary skill in the art will appreciate that a processing device may include multiple processing elements and multiple types of processing elements. For example, a processing device may include one or more processors, or one or more processors and one or more controllers. In addition, different processing configurations are possible, such as parallel processors or multi-core processors.

A processing device configured to implement a software component to perform an operation A may include a processor programmed to run software or execute instructions to control the processor to perform operation A. In addition, a processing device configured to implement a software component to perform an operation A, an operation B, and an operation C may have various configurations, such as, for example, a processor configured to implement a software component to perform operations A, B, and C; a first processor configured to implement a software component to perform operation A, and a second processor configured to implement a software component to perform operations B and C; a first processor configured to implement a software component to perform operations A and B, and a second processor configured to implement a software component to perform operation C; a first processor configured to implement a software component to perform operation A, a second processor configured to implement a software component to perform operation B, and a third processor configured to implement a software component to perform operation C; a first processor configured to implement a software component to perform operations A, B, and C, and a second processor configured to implement a software component to perform operations A, B, and C, or any other configuration of one or more processors each implementing one or more of operations A, B, and C. Although these examples refer to three operations A, B, C, the number of operations that may implemented is not limited to three, but may be any number of operations required to achieve a desired result or perform a desired task.

Software or instructions for controlling a processing device to implement a software component may include a computer program, a piece of code, an instruction, or some combination thereof, for independently or collectively instructing or configuring the processing device to perform one or more desired operations. The software or instructions may include machine code that may be directly executed by the processing device, such as machine code produced by a compiler, and/or higher-level code that may be executed by the processing device using an interpreter. The software or instructions and any associated data, data files, and data structures may be embodied permanently or temporarily in any type of machine, component, physical or virtual equipment, computer storage medium or device, or a propagated signal wave capable of providing instructions or data to or being interpreted by the processing device. The software or instructions and any associated data, data files, and data structures also may be distributed over network-coupled computer systems so that the software or instructions and any associated data, data files, and data structures are stored and executed in a distributed fashion.

For example, the software or instructions and any associated data, data files, and data structures may be recorded, stored, or fixed in one or more non-transitory computer-readable storage media. A non-transitory computer-readable storage medium may be any data storage device that is capable of storing the software or instructions and any associated data, data files, and data structures so that they can be read by a computer system or processing device. Examples of a non-transitory computer-readable storage medium include read-only memory (ROM), random-access memory (RAM), flash memory, CD-ROMs, CD-Rs, CD+Rs, CD-RWs, CD+RWs, DVD-ROMs, DVD-Rs, DVD+Rs, DVD-RWs, DVD+RWs, DVD-RAMs, BD-ROMs, BD-Rs, BD-R LTHs, BD-REs, magnetic tapes, floppy disks, magneto-optical data storage devices, optical data storage devices, hard disks, solid-state disks, or any other non-transitory computer-readable storage medium known to one of ordinary skill in the art.

Functional programs, codes, and code segments for implementing the examples disclosed herein can be easily constructed by a programmer skilled in the art to which the examples pertain based on the drawings and their corresponding descriptions as provided herein.

While this disclosure includes specific examples, it will be apparent to one of ordinary skill in the art that various changes in form and details may be made in these examples without departing from the spirit and scope of the claims and their equivalents. Suitable results may be achieved if the described techniques are performed in a different order, and/or if components in a described system, architecture, device, or circuit are combined in a different manner, and/or replaced or supplemented by other components or their equivalents. Therefore, the scope of the disclosure is defined not by the detailed description, but by the claims and their equivalents, and all variations within the scope of the following claims and their equivalents are to be construed as being included in the disclosure.

What is claimed is:

1. A wireless power transmission apparatus comprising:

a resonant power generator comprising a first power amplifier configured to output a first power signal and a second power amplifier configured to output a second power signal, the first amplifier including a first notch filter configured so that a third harmonic of the first power signal is canceled, and the second amplifier including a second notch filter configured so that a third harmonic of the second power signal is canceled,

a low-pass filter (LPF) configured to cancel fifth and higher odd-order harmonic components of the first power signal and the second power signal; and

a source resonator configured to *differentially receive the LPF-filtered first power signal and the LPF-filtered second power signal and wirelessly* transmit [an output] power to a wireless power reception apparatus [by resonating] *based on resonant coupling* with a target resonator of the wireless power reception apparatus, wherein

the transmitted [output] power has a predetermined frequency band[;] and

[a resonant power generator comprising first and second notch filters coupled to a low-pass filter (LPF),

wherein the first and second notch filters are configured to cancel a third harmonic component of the output power, and the LPF is configured to cancel a fifth or higher odd-order harmonic component of the output power,

wherein the resonant power generator is configured to differentially input a first input signal and a second input signal to the source resonator, and]

the first power signal and the second power signal have a phase difference of 180 degrees to cancel an even-order harmonic component of the [output] *transmitted* power[, and

wherein the source resonator is further configured to transmit the output power from which the third harmonic component and the fifth or higher odd-order harmonic component have been cancelled to the wireless power reception apparatus].

[**2**. The apparatus of claim **1**, wherein the resonant power generator comprises:

a first power amplifier configured to generate the first input signal; and

a second power amplifier configured to generate the second input signal.]

3. The apparatus of claim [**2**] *1*, wherein the resonant power generator further comprises:

a first driving circuit coupled to the first power amplifier; and

a second driving circuit coupled to the second power amplifier.

4. The apparatus of claim **3**, wherein the first driving circuit and the second driving circuit are configured to [generate] *supply first and second signals having* a 180 degree phase difference [between] *to* the first [input signal] *amplifier* and the second [input signal] *amplifier respectively*.

[**5**. The apparatus of claim **2**, wherein the first power amplifier comprises the first notch filter;

the second power amplifier comprises the second notch filter; and

the resonant power generator is further configured to cancel the third harmonic component of the output power using the first notch filter and the second notch filter.]

6. The apparatus of claim [**5**] *1*, wherein the first notch filter and the second notch filter are configured to match an output impedance of the wireless power transmission apparatus to an input impedance of the wireless power reception apparatus.

[**7**. The apparatus of claim **5**, wherein the LPF coupled to the first and second notch filters of the resonant power generator is further coupled to the source resonator.]

8. The apparatus of claim [**2**] *1*, wherein the first power amplifier and the second power amplifier are Class-E amplifiers.

9. The apparatus of claim **1**, wherein the source resonator is further configured to receive the *LPF-filtered* first [input] *power* signal and the *LPF-filtered* second [input] *power* signal via a differential input port comprising a separate grounding unit.

10. The apparatus of claim **1**, wherein the predetermined frequency band [is] *of the transmitted power includes a frequency of* 6.78 MHz.

11. The apparatus of claim **1**, wherein the predetermined frequency band is tens of Hz.

12. A wireless power transmission apparatus comprising:

a source resonator configured to *wirelessly* transmit [an output] power to a wireless power reception apparatus [by resonating] *based on resonant coupling* with a target resonator of the wireless power reception apparatus;

a resonant power generator comprising:

a first power amplifier [comprising] *including* a first notch filter and configured to generate a first [input] *power* signal; and

a second power amplifier [comprising] *including* a second notch filter and configured to generate a second [input] *power* signal[;],

a low-pass (LPF) coupled to the source resonator and configured to cancel fifth and higher odd-order harmonic components of the first power signal and the second power signal,

wherein the first notch filter and the second notch filter are coupled to the LPF and are configured so that third harmonic components of the first power signal and the second power signal are canceled,

wherein the [resonant power generator] *source resonator* is configured to [cancel an even-order harmonic component of the output power by] differentially [inputting] *receive* the *LPF-filtered* first [input] *power* signal and the *LPF-filtered* second [input] *power* signal [to the source resonator], and

the first power signal and the second power signal have a phase difference of 180 degrees to cancel [a third harmonic component of the output power using the first notch filter and the second notch filter; and

a low-pass filter (LPF) coupled to the first and second notch filters and configured to cancel a fifth or higher odd-order harmonic component of the output power;

wherein the source resonator is further configured to transmit, to the wireless power reception apparatus, the output power from which the even-order harmonic component, the third harmonic component, and the fifth or higher odd-order harmonic component have been cancelled] *an even-order harmonic component of the transmitted power*.

13. A wireless power transmission method in a wireless power transmission apparatus, the method comprising:

generating, via *a first power amplifier of* a resonant power generator, a first [input] *power* signal [and a second input signal];

generating, via a second power amplifier of the resonant power generator, a second power signal,

canceling, via first and second notch filters, a third harmonic of the first power signal and a third harmonic of the second power signal,

[differentially inputting, via the resonant power generator, the first input signal and the second input signal to a source resonator and cancelling an even-order harmonic component of the output power;]

cancelling, via a low-pass filter (LPF) [and first and second notch filters coupled to the LPF], [a harmonic component comprising a third harmonic component and a] fifth [or] *and* higher odd-order harmonic [component] *components* of [an output] *the first power signal and the second* power [of the source resonator] *signal*; [and]

differentially providing the LPF-filtered first power signal and the LPF-filtered second power signal to a source resonator; and

wirelessly transmitting, [via the source resonator, the output] *by the source resonator,* power [from which the harmonic component including the third harmonic component and the fifth or higher odd-order harmonic component has been cancelled] to a wireless power reception apparatus [by resonating] *based on resonant coupling* with a target resonator of the wireless power reception apparatus,

wherein an even-order harmonic component of the transmitted power is canceled based on the first power signal and the second power signal having a 180 degree phase difference.

[**14**. The method of claim **13**, wherein the cancelling of the harmonic component of the output power comprises:

generating the first input signal using a first power amplifier; and

generating the second input signal using a second power amplifier.]

15. The method of claim [**14**] *13*, [wherein the cancelling of the harmonic component of the output power further comprises] *further comprising*

generating a 180 degree phase difference between the first [input] *power* signal and the second [input] *power* signal using a first driving circuit coupled to the first power amplifier and a second driving circuit coupled to the second power amplifier.

[**16**. The method of claim **14**, wherein the first power amplifier comprises a first notch filter;

the second power amplifier comprises a second notch filter; and

the cancelling of the harmonic component of the output power further comprises cancelling the third harmonic component of the output power using the first notch filter and the second notch filter.]

17. The method of claim [**16**] *13*, wherein the first notch filter and the second notch filter are configured to match an output impedance of the wireless power transmission apparatus to an input impedance of the wireless power reception apparatus.

18. The method of claim [**16**] *13*, wherein the LPF is further coupled to the source resonator.

19. A non-transitory computer-readable storage medium storing instructions [for controlling] *which, when executed, cause* a computer to *control an electronic device to* perform [the method of claim **13**]*:*

generating, via a first power amplifier of a resonant power generator, a first power signal;

generating, via a second power amplifier of a resonant power generator, a second power signal;

canceling, via first and second notch filters, a third harmonic of the first power signal and a third harmonic of the second power signal;

cancelling, via a low-pass filter (LPF) fifth and higher odd-order harmonic components of the first power signal and the second power signal;

differentially providing the filtered first power signal and the filtered second power signal to a source resonator; and

wirelessly transmitting, by the source resonator, the power to a wireless power reception apparatus based on resonant coupling with a target resonator of the wireless power reception apparatus,

wherein an even-order harmonic component of the transmitted power is canceled based on the first power signal and the second power signal having a 180 degree phase difference.

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UNITED STATES PATENT AND TRADEMARK OFFICE

CERTIFICATE OF CORRECTION

PATENT NO. : RE49,564 E
APPLICATION NO. : 17/139943
DATED : June 27, 2023
INVENTOR(S) : Dong Zo Kim

It is certified that error appears in the above-identified patent and that said Letters Patent is hereby corrected as shown below:

On the Title Page

Item (72), Inventors data: change "Bong Chui Kim" to --Bong Chul Kim--.

Signed and Sealed this
Twenty-second Day of August, 2023

Katherine Kelly Vidal

Katherine Kelly Vidal
Director of the United States Patent and Trademark Office