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(54) METHOD AND APPARATUS FOR PRE-ALIGNMENT OF AN AUTOMATICALLY ALIGNING MAGNETIC FIELD SYSTEM

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(21) Appl. No.: **19/169,961**

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Related U.S. Application Data

(63) Continuation of application No. 18/153,991, filed on Jan. 12, 2023, now Pat. No. 12,294,227.

(60) Provisional application No. 63/299,165, filed on Jan. 13, 2022.

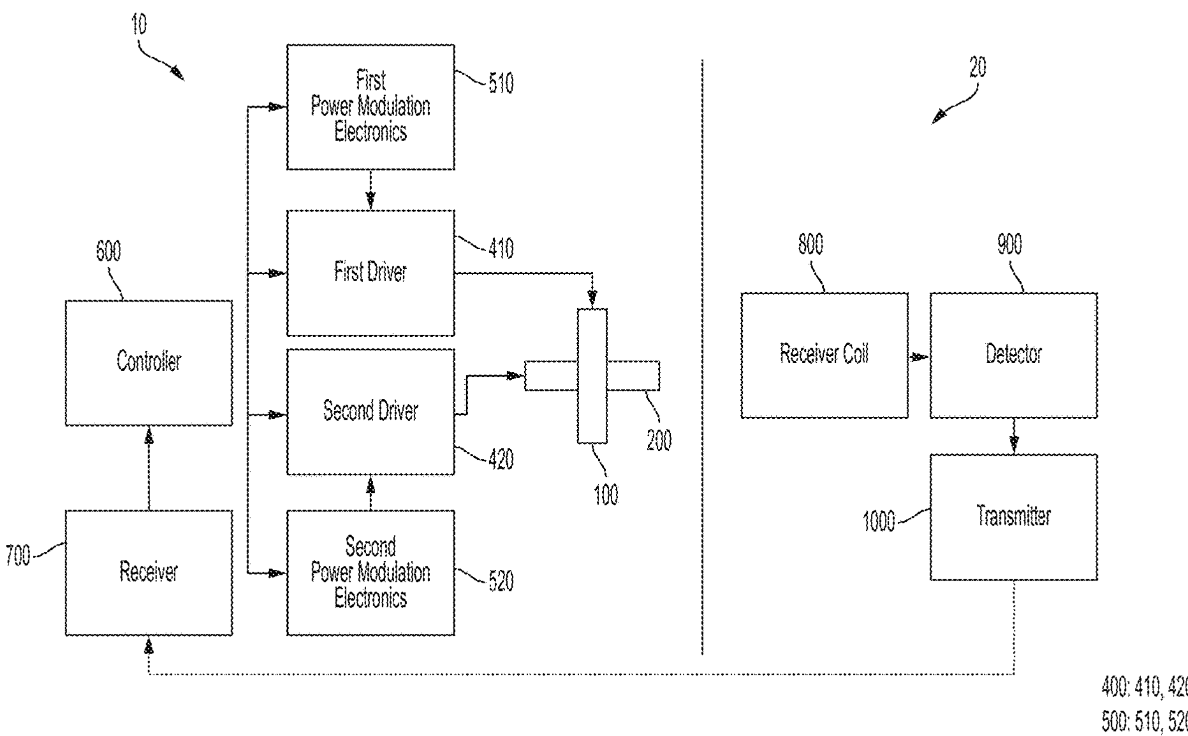
Publication Classification

(51) **Int. Cl.**
H02J 50/40 (2016.01)
G01P 15/02 (2013.01)
G01R 19/00 (2006.01)
H02J 50/12 (2016.01)
H02J 50/80 (2016.01)
H02J 50/90 (2016.01)

(52) **U.S. Cl.**
CPC ***H02J 50/402*** (2020.01); ***G01P 15/02*** (2013.01); ***G01R 19/0092*** (2013.01); ***H02J 50/12*** (2016.02); ***H02J 50/80*** (2016.02); ***H02J 50/90*** (2016.02)

(57) **ABSTRACT**

A wireless power transfer system includes a wireless power transfer device configured to determine a magnetic field, from among a plurality of directionally different potential magnetic fields that the wireless power transfer device is configured to generate, that has, at a receiver coil of an electronic device, a direction aligned with the receiver coil.



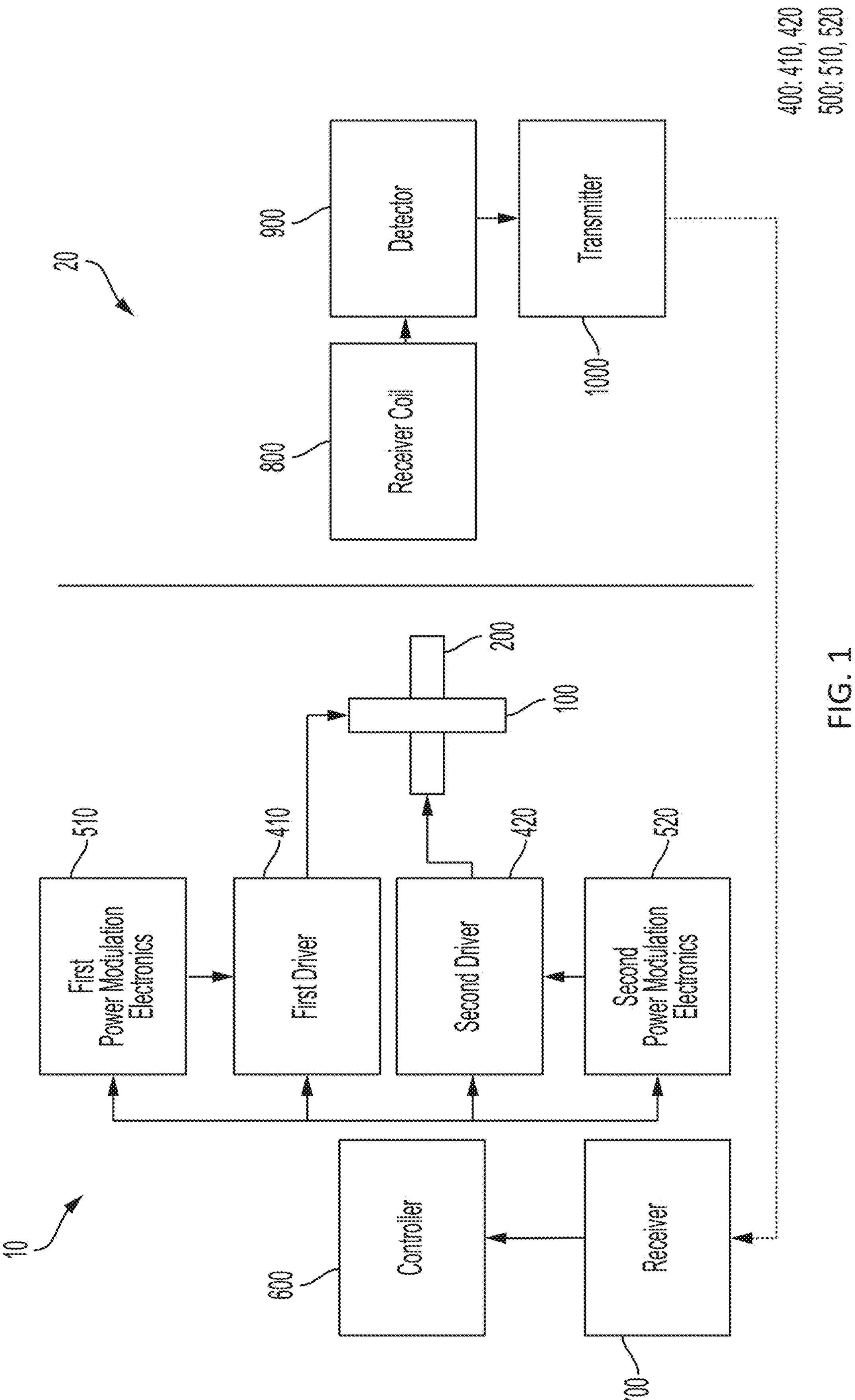

400: 410, 420
500: 510, 520
20
900
Detector
Transmitter
1000
800
Receiver Coil
200
100
510
First Power Modulation Electronics
410
First Driver
420
Second Driver
520
Second Power Modulation Electronics
10
600
Controller
Receiver
700

FIG. 1

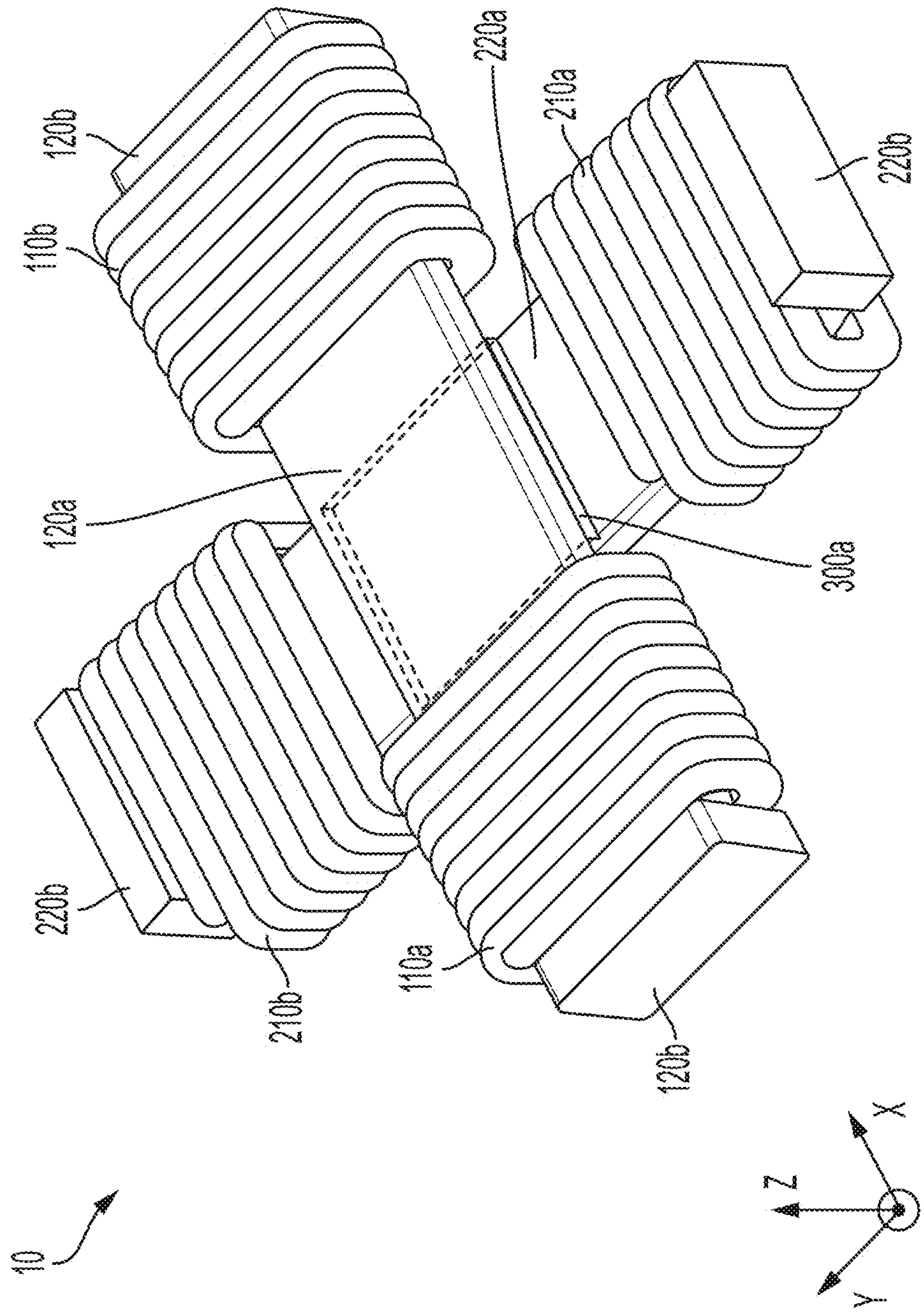


FIG. 2

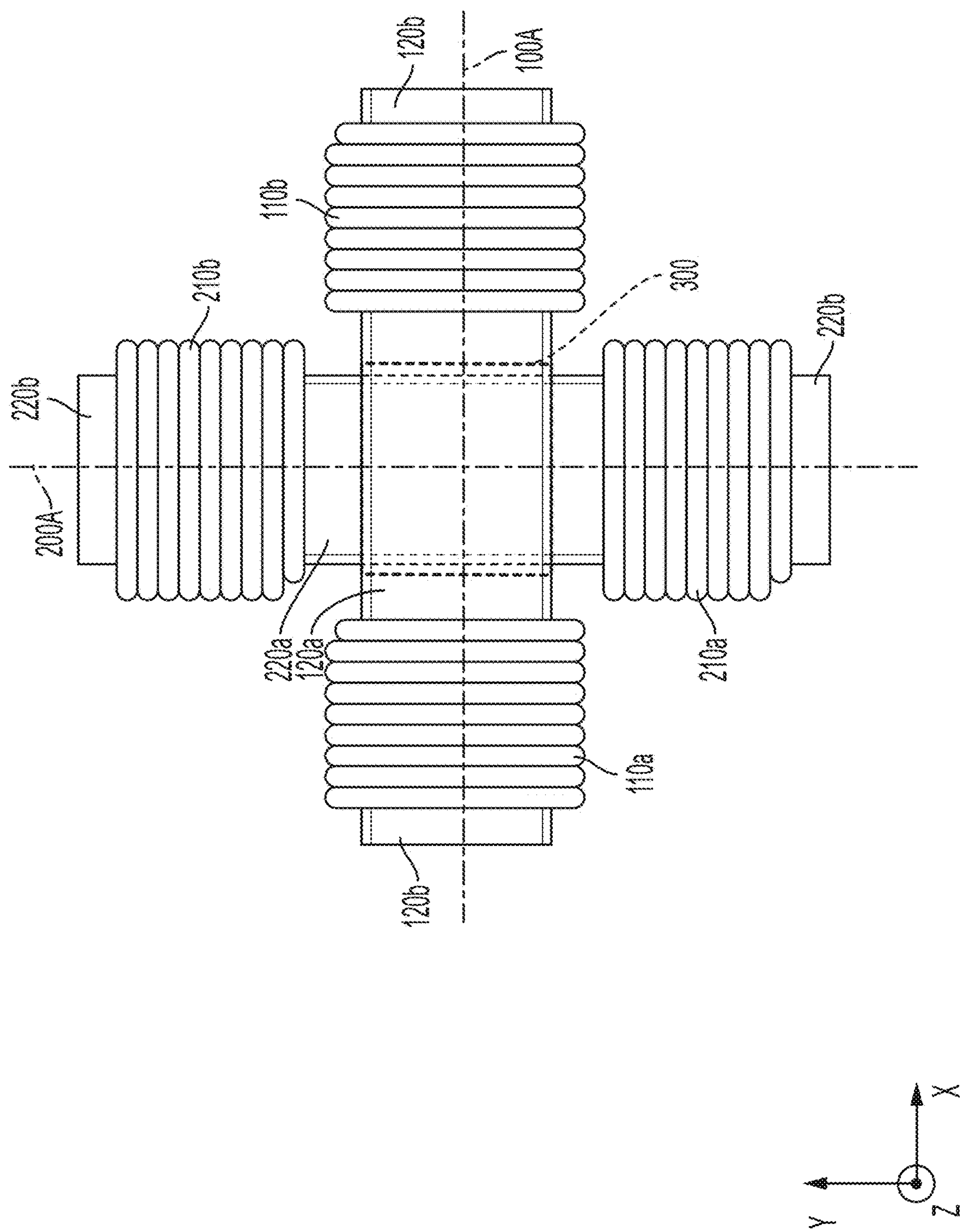

120b
100A
110b
210b
300
220b
220b
200A
220a
120a
210a
110a
120b
X
Y
Z

FIG. 3

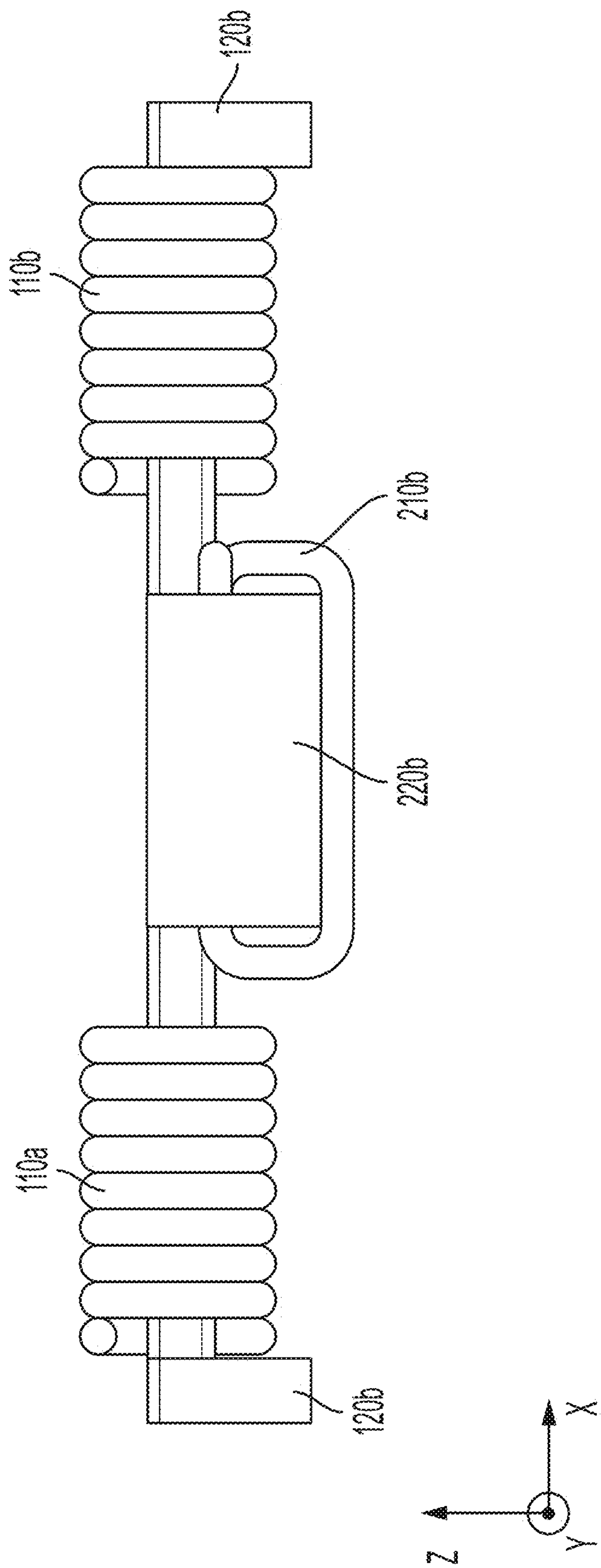


FIG. 4

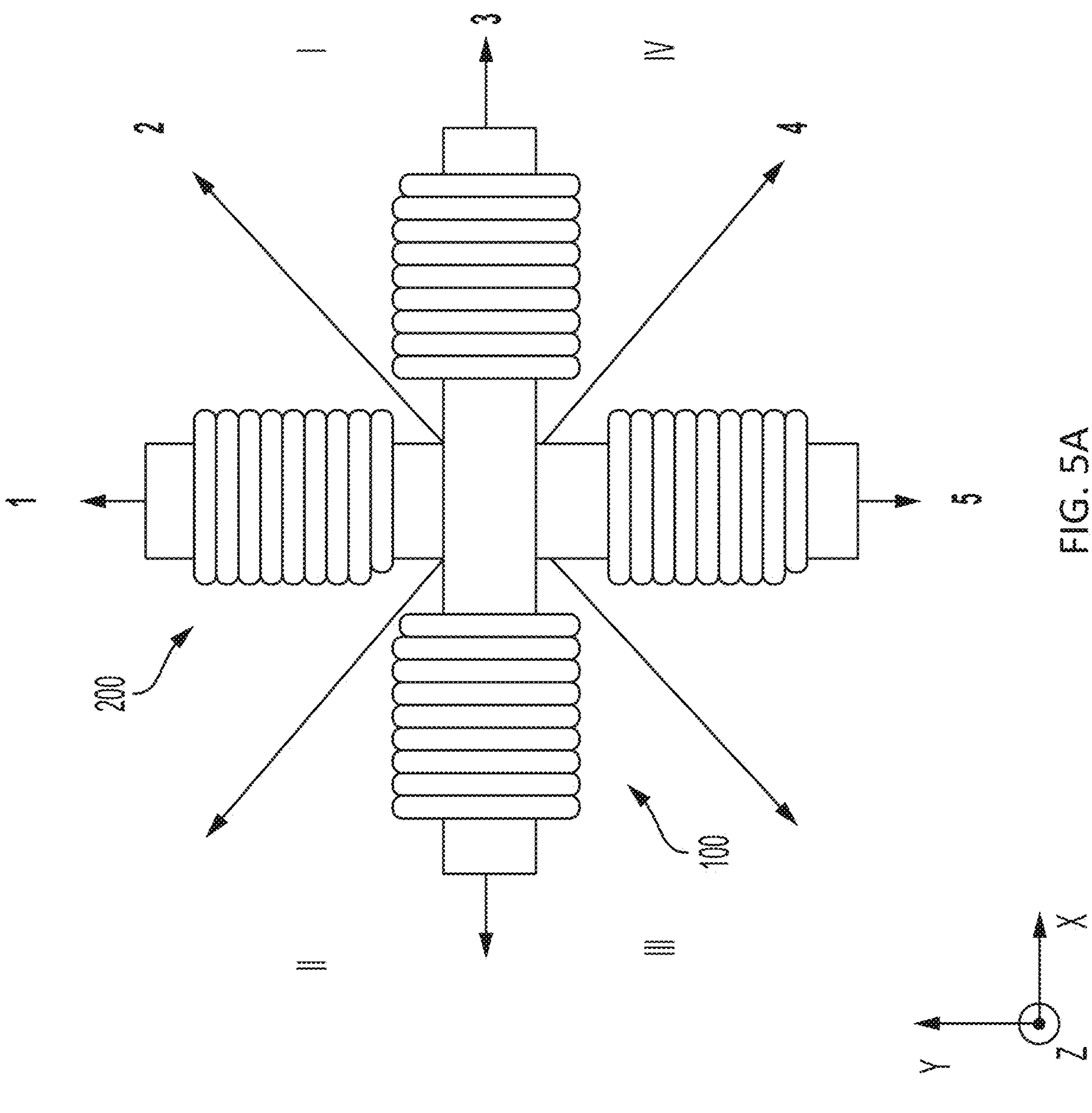
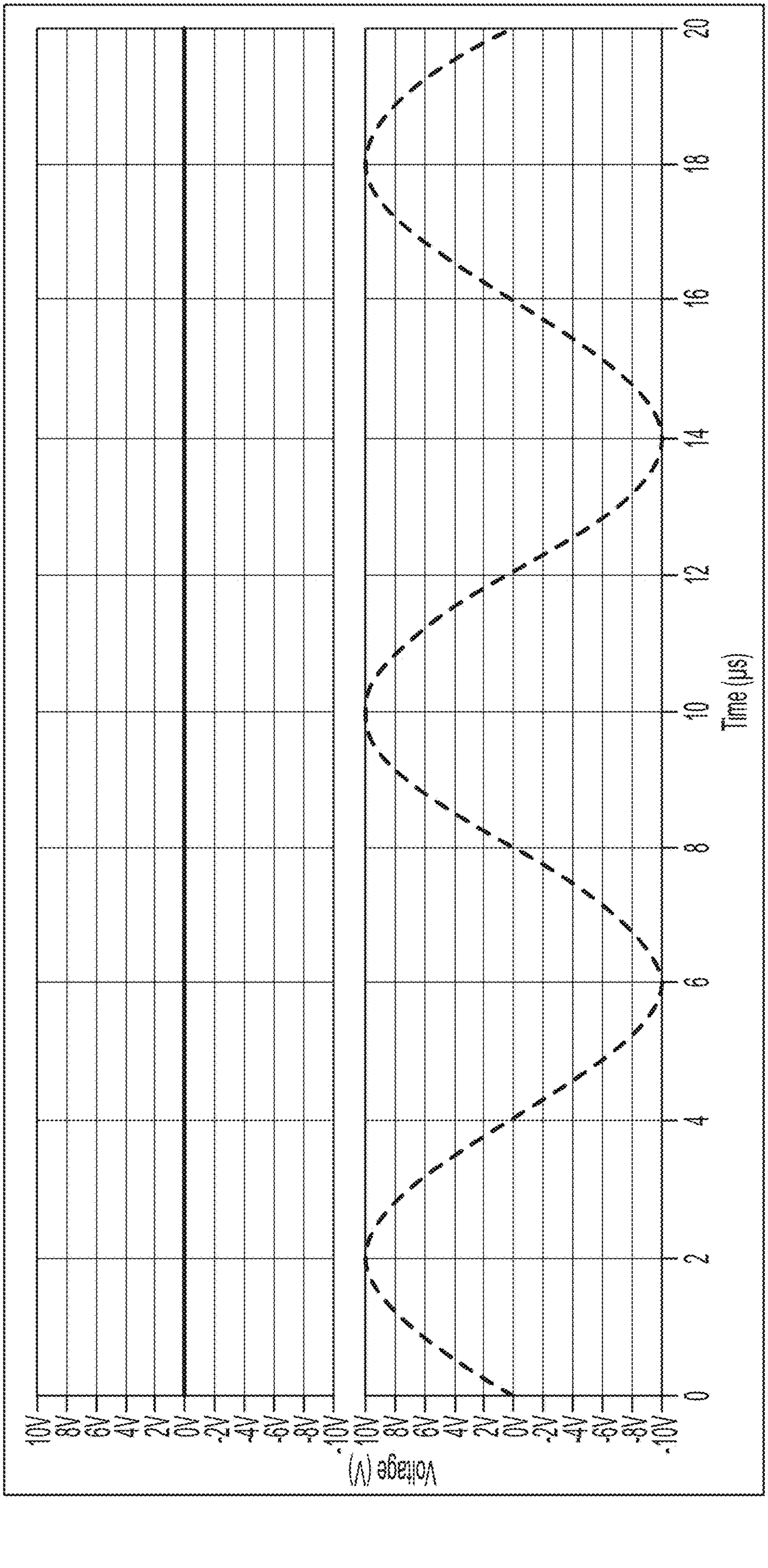
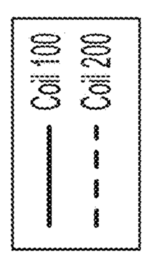


FIG. 5A





(1) Coil 100 = 0% and 0°, Coil 200 = 100% and 0°

FIG. 5B

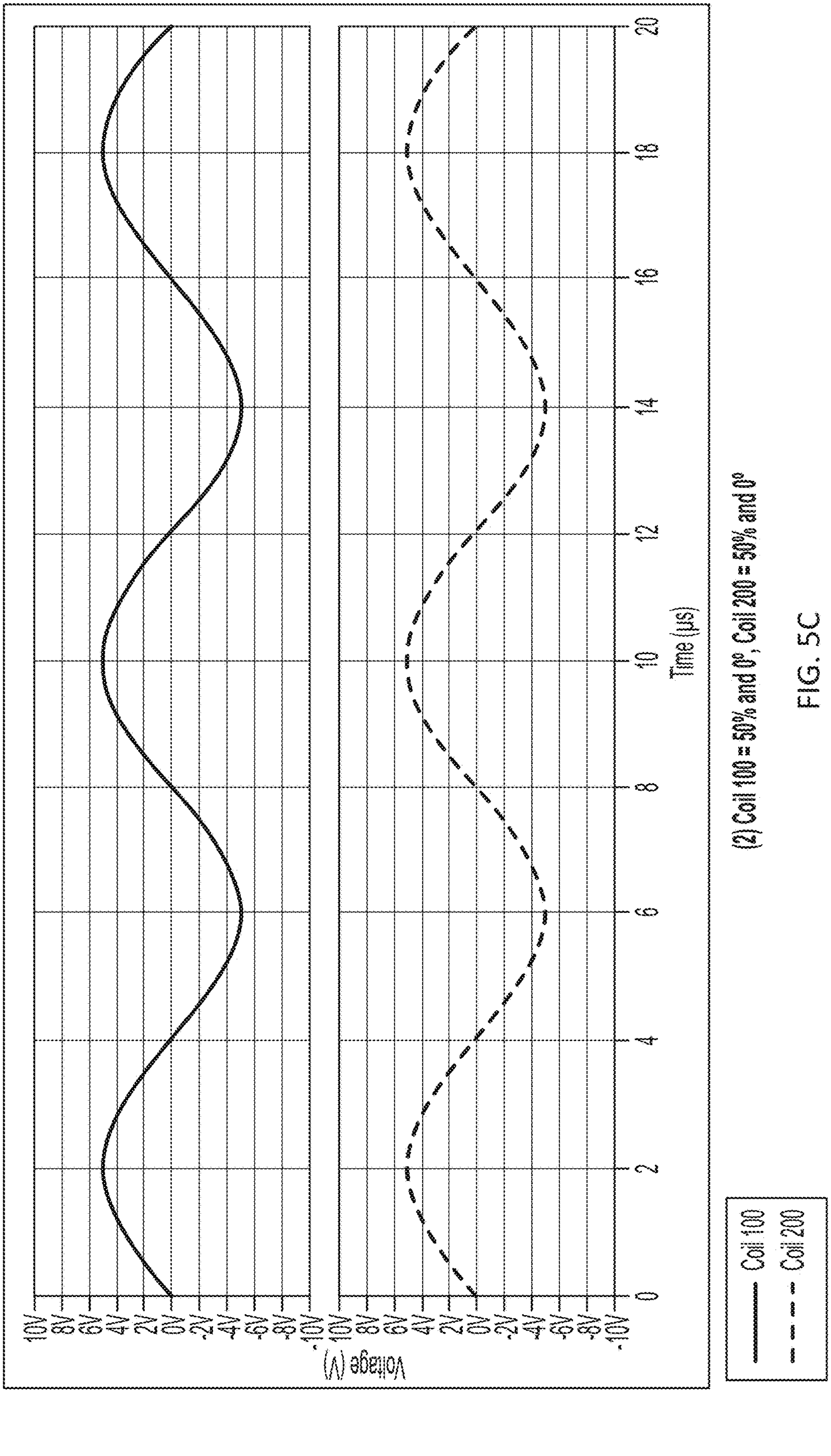
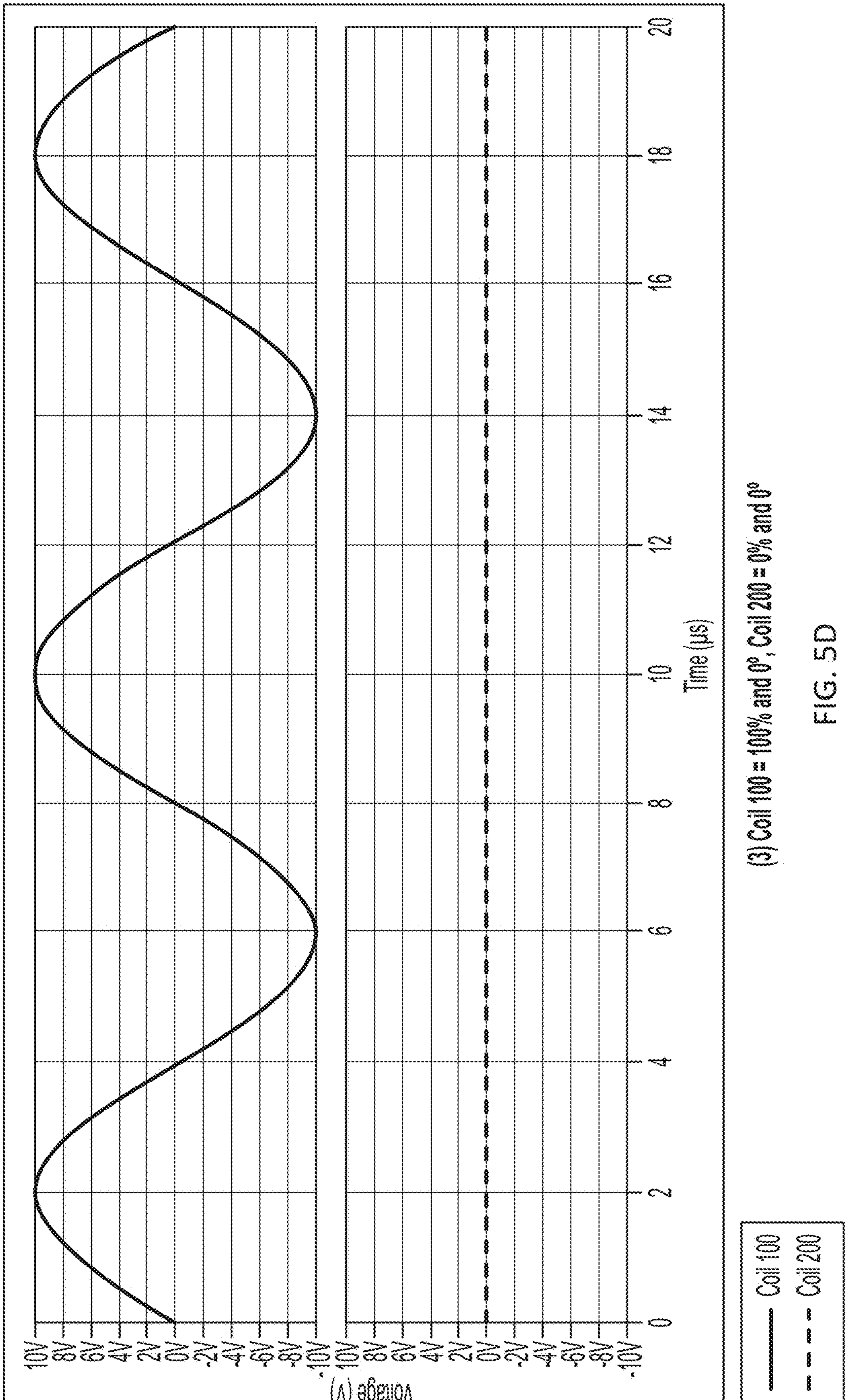
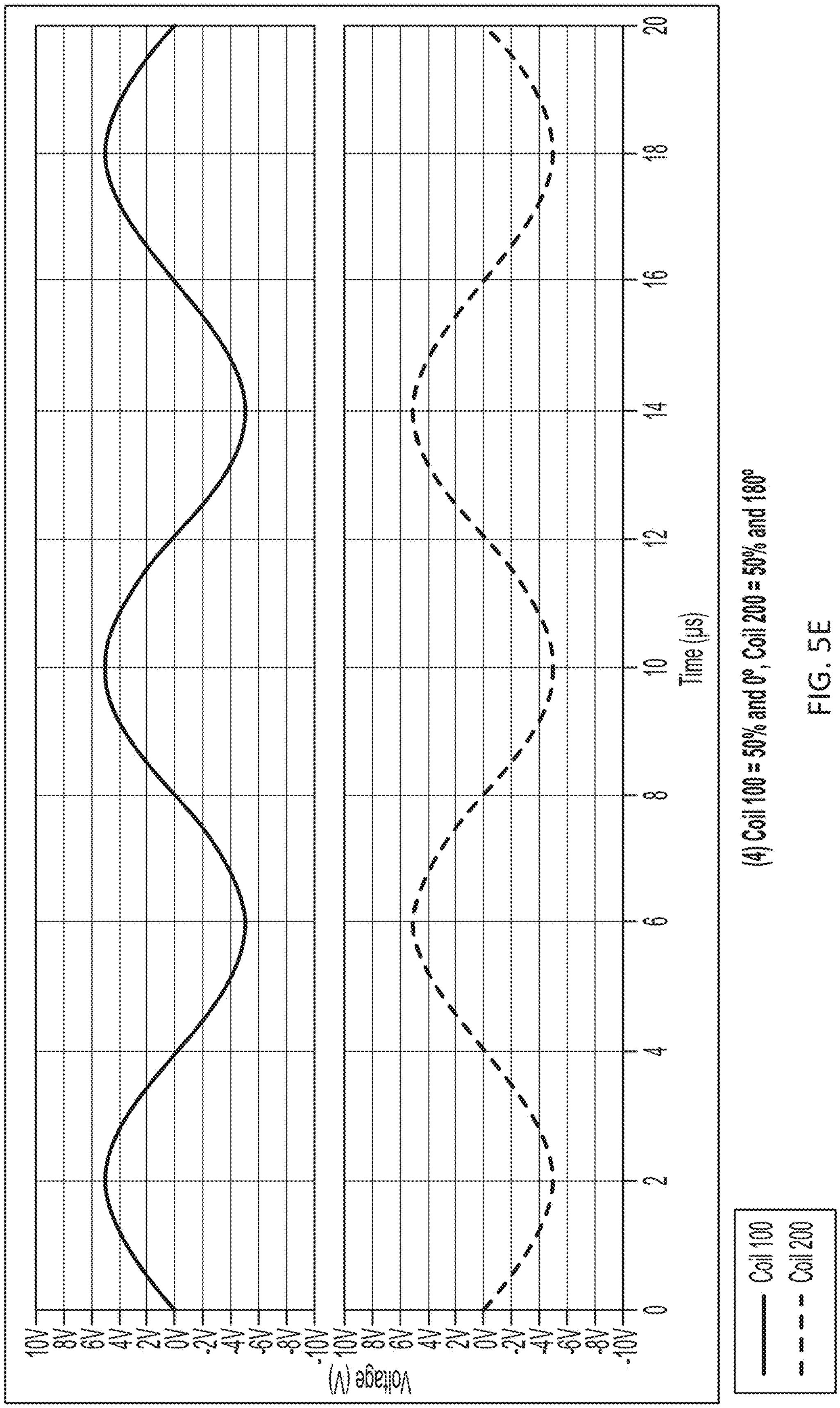

Voltage (V)
10V
8V
6V
4V
2V
0V
-2V
-4V
-6V
-8V
-10V
0
2
4
6
8
10
12
14
16
18
20
Time (μs)
(2) Coil 100 = 50% and 0°, Coil 200 = 50% and 0°
Coil 100
Coil 200

FIG. 5C



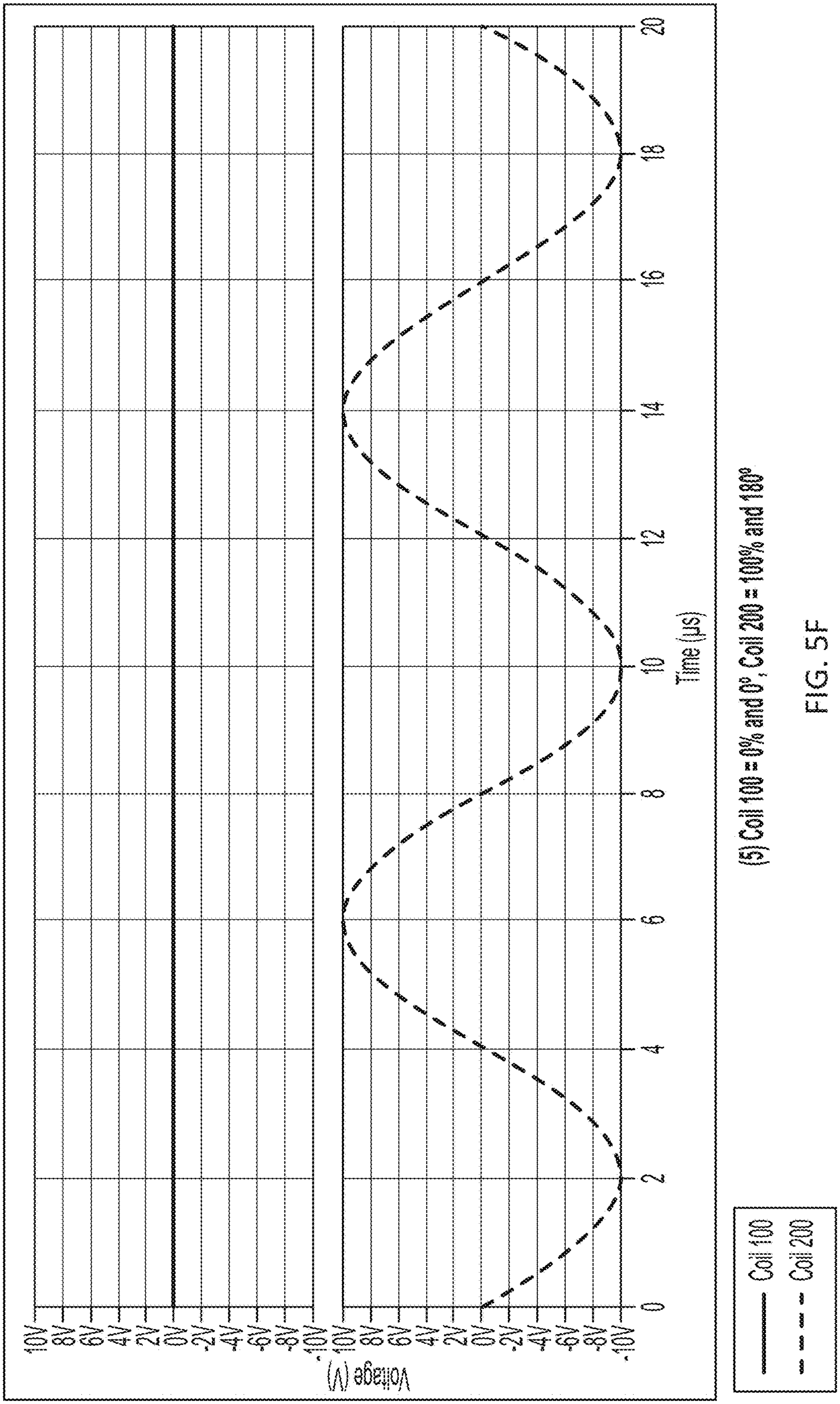
(3) Coil 100 = 100% and 0°, Coil 200 = 0% and 0°

FIG. 5D



Voltage (V)
10V
8V
6V
4V
2V
0V
-2V
-4V
-6V
-8V
-10V
0
2
4
6
8
10
12
14
16
18
20
Time (μs)
(4) Coil 100 = 50% and 0°, Coil 200 = 50% and 180°
Coil 100
Coil 200

FIG. 5E



(5) Coil 100 = 0% and 0°, Coil 200 = 100% and 180°

FIG. 5F

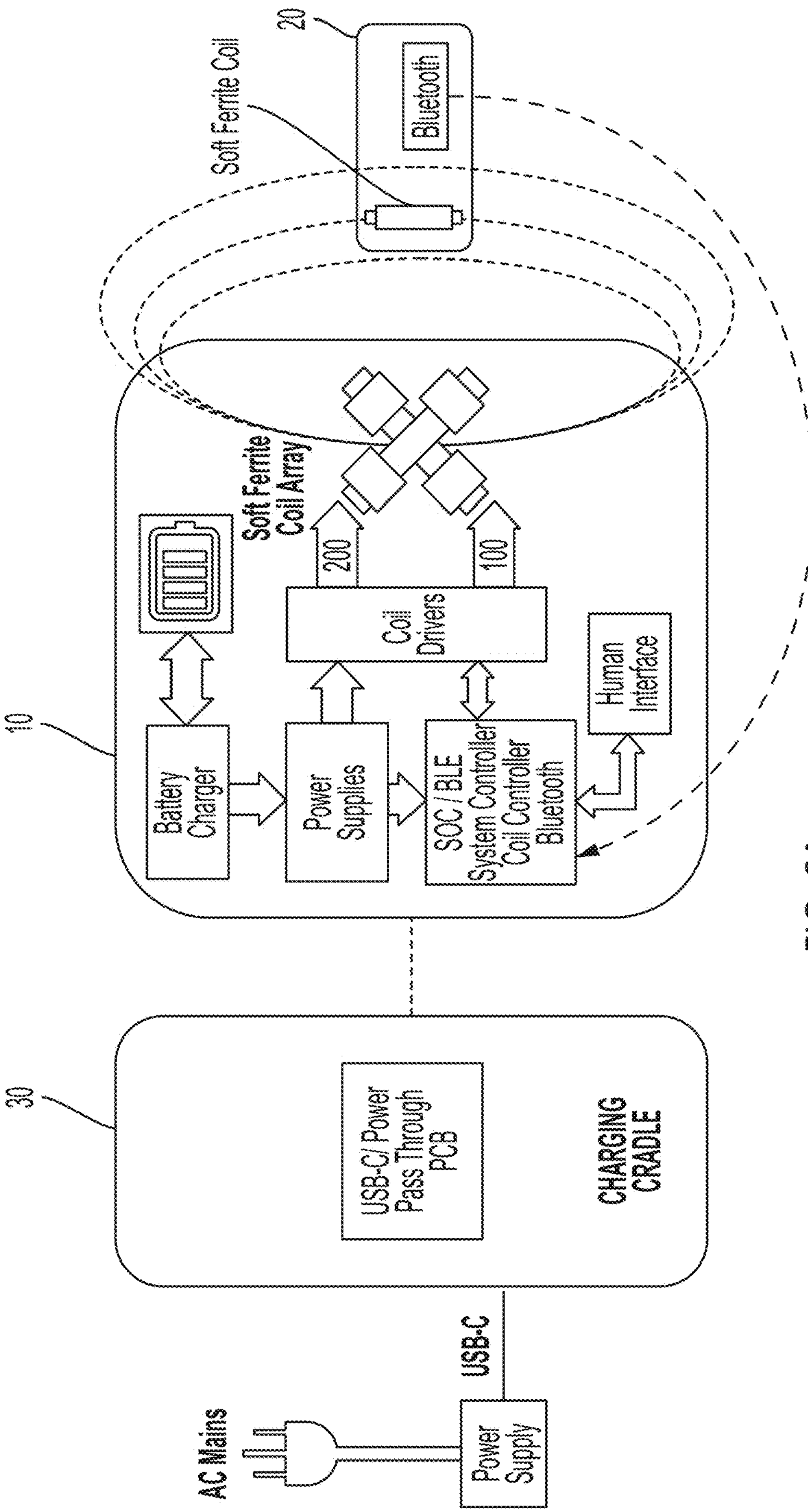

20
Soft Ferrite Coil
Bluetooth
10
Soft Ferrite Coil Array
Battery Charger
Power Supplies
SOC / BLE System Controller Coil Controller Bluetooth
Coil Drivers
200
100
Human Interface
30
USB-C/ Power Pass Through PCB
CHARGING CRADLE
USB-C
AC Mains
Power Supply

FIG. 6A

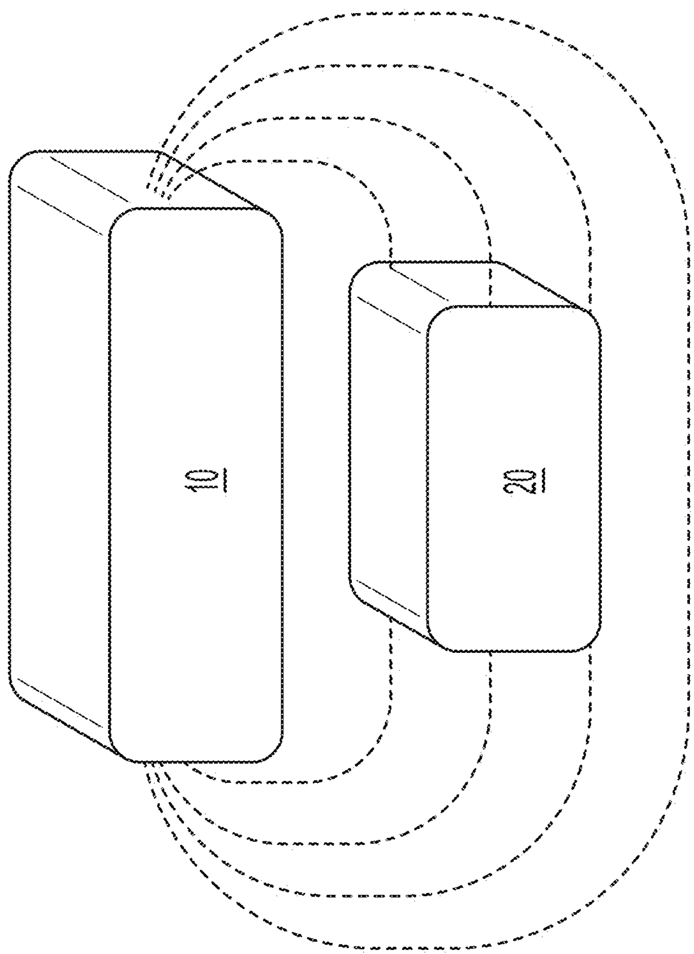


FIG. 6B

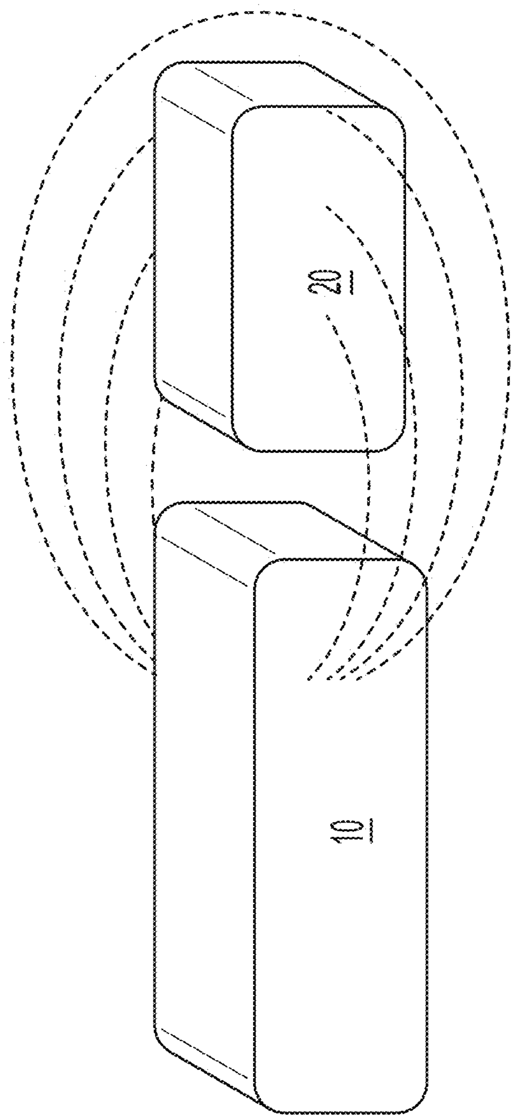


FIG. 6C

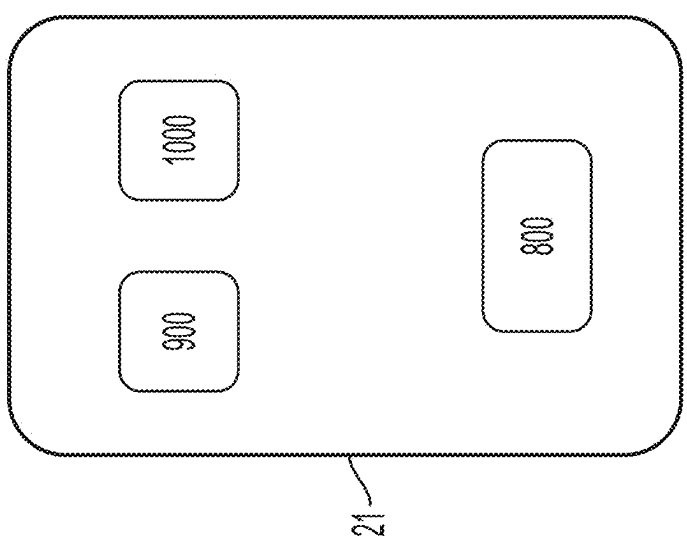


FIG. 7A

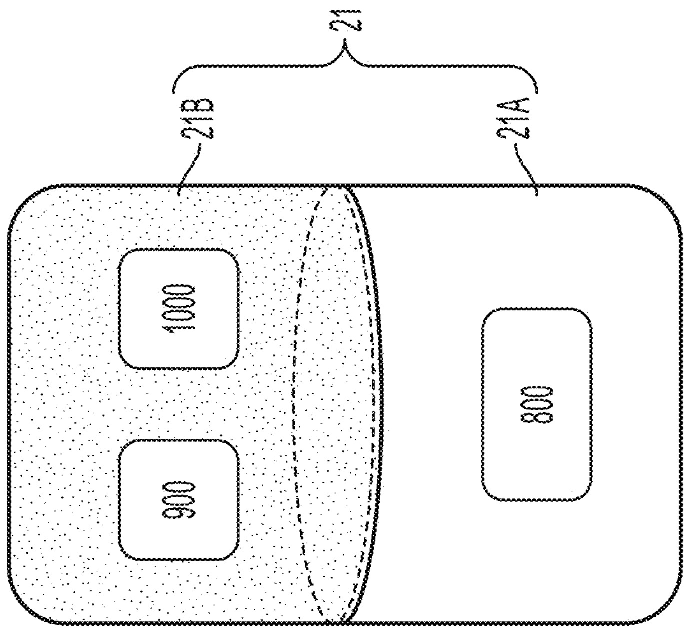


FIG. 7B

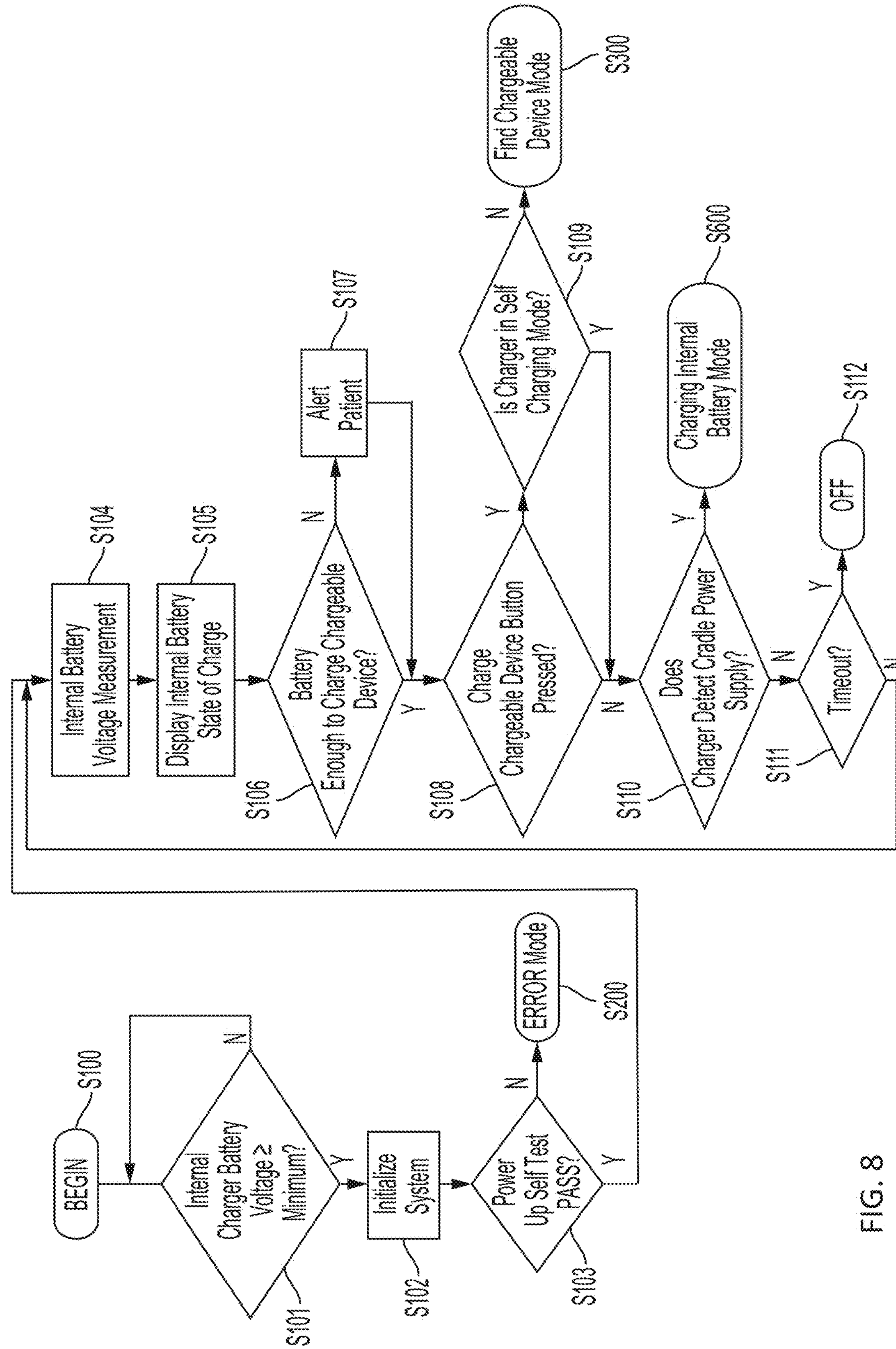

BEGIN
S100
Internal Charger Battery Voltage ≥ Minimum?
S101
N
Y
Initialize System
S102
Power Up Self Test PASS?
S103
N
Y
ERROR Mode
S200
Internal Battery Voltage Measurement
S104
Display Internal Battery State of Charge
S105
Battery Enough to Charge Chargeable Device?
S106
N
Y
Alert Patient
S107
Charge Chargeable Device Button Pressed?
S108
Y
N
Is Charger in Self Charging Mode?
S109
N
Y
Find Chargeable Device Mode
S300
Does Charger Detect Cradle Power Supply?
S110
Y
N
Charging Internal Battery Mode
S600
Timeout?
S111
Y
N
OFF
S112

FIG. 8

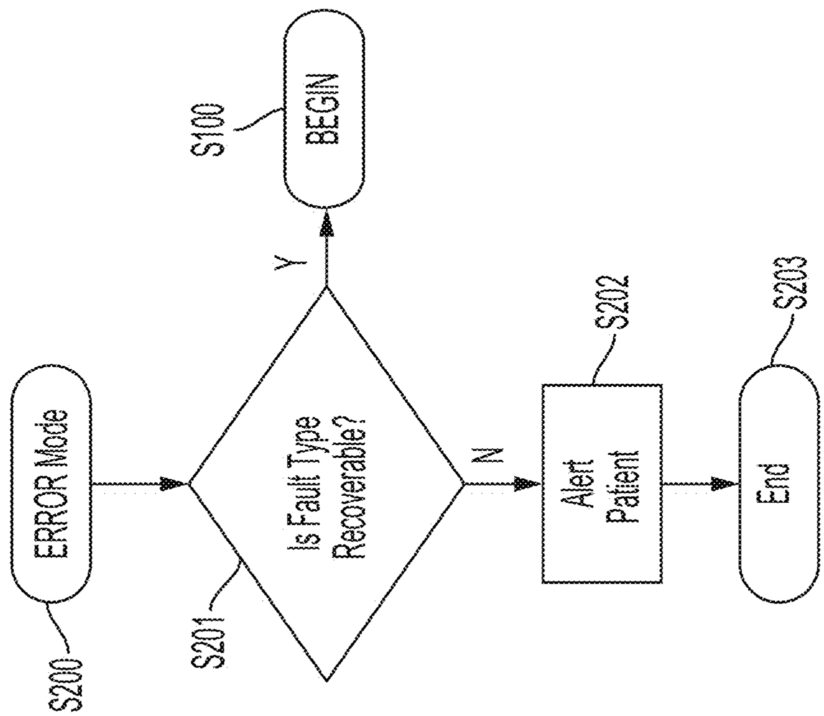

ERROR Mode
S200
Is Fault Type Recoverable?
S201
Y
BEGIN
S100
N
Alert Patient
S202
End
S203

FIG. 9

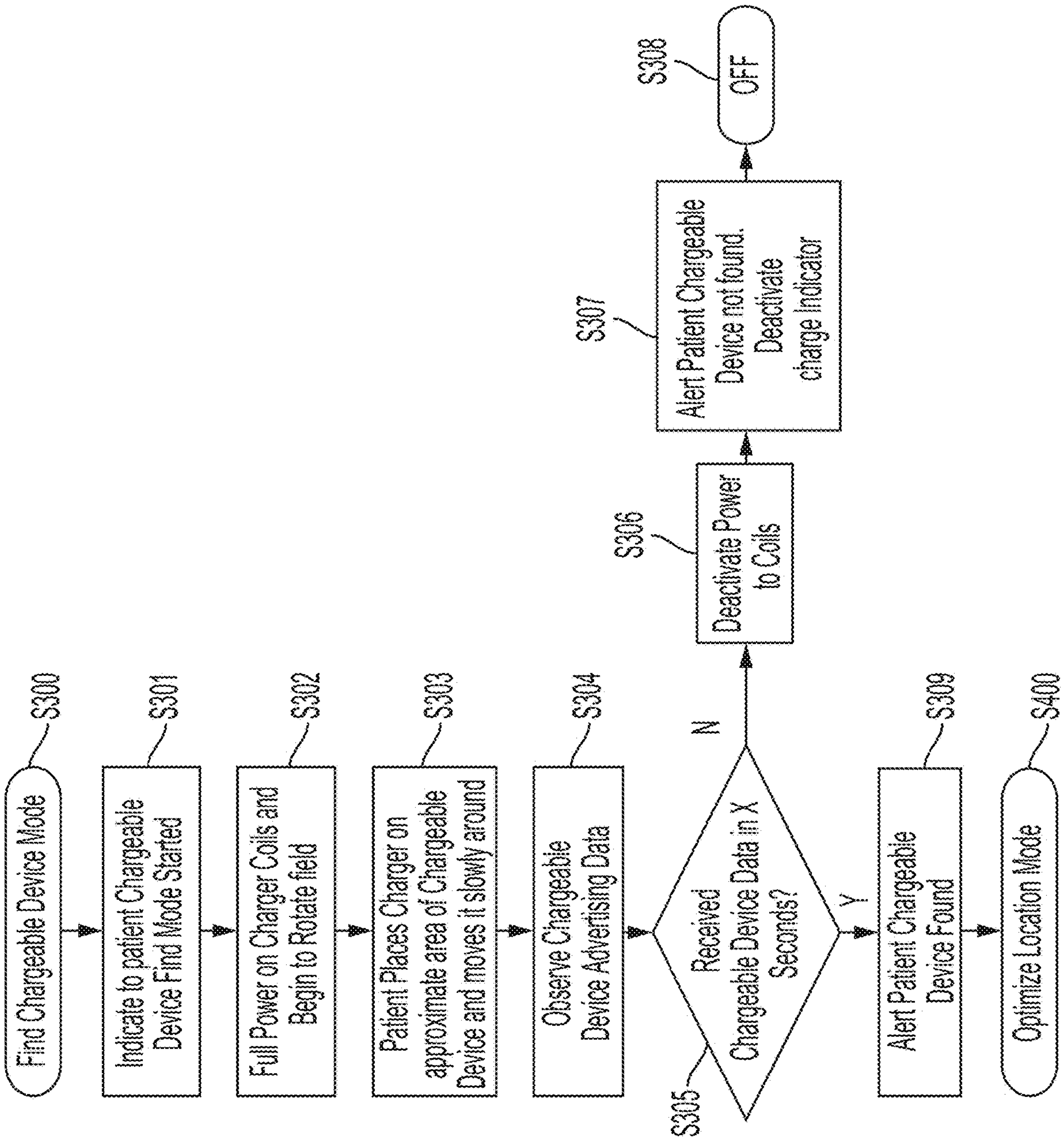

S300
Find Chargeable Device Mode
S301
Indicate to patient Chargeable Device Find Mode Started
S302
Full Power on Charger Coils and Begin to Rotate field
S303
Patient Places Charger on approximate area of Chargeable Device and moves it slowly around
S304
Observe Chargeable Device Advertising Data
S305
Received Chargeable Device Data in X Seconds?
N
Y
S306
Deactivate Power to Coils
S307
Alert Patient Chargeable Device not found. Deactivate charge Indicator
S308
OFF
S309
Alert Patient Chargeable Device Found
S400
Optimize Location Mode

FIG. 10

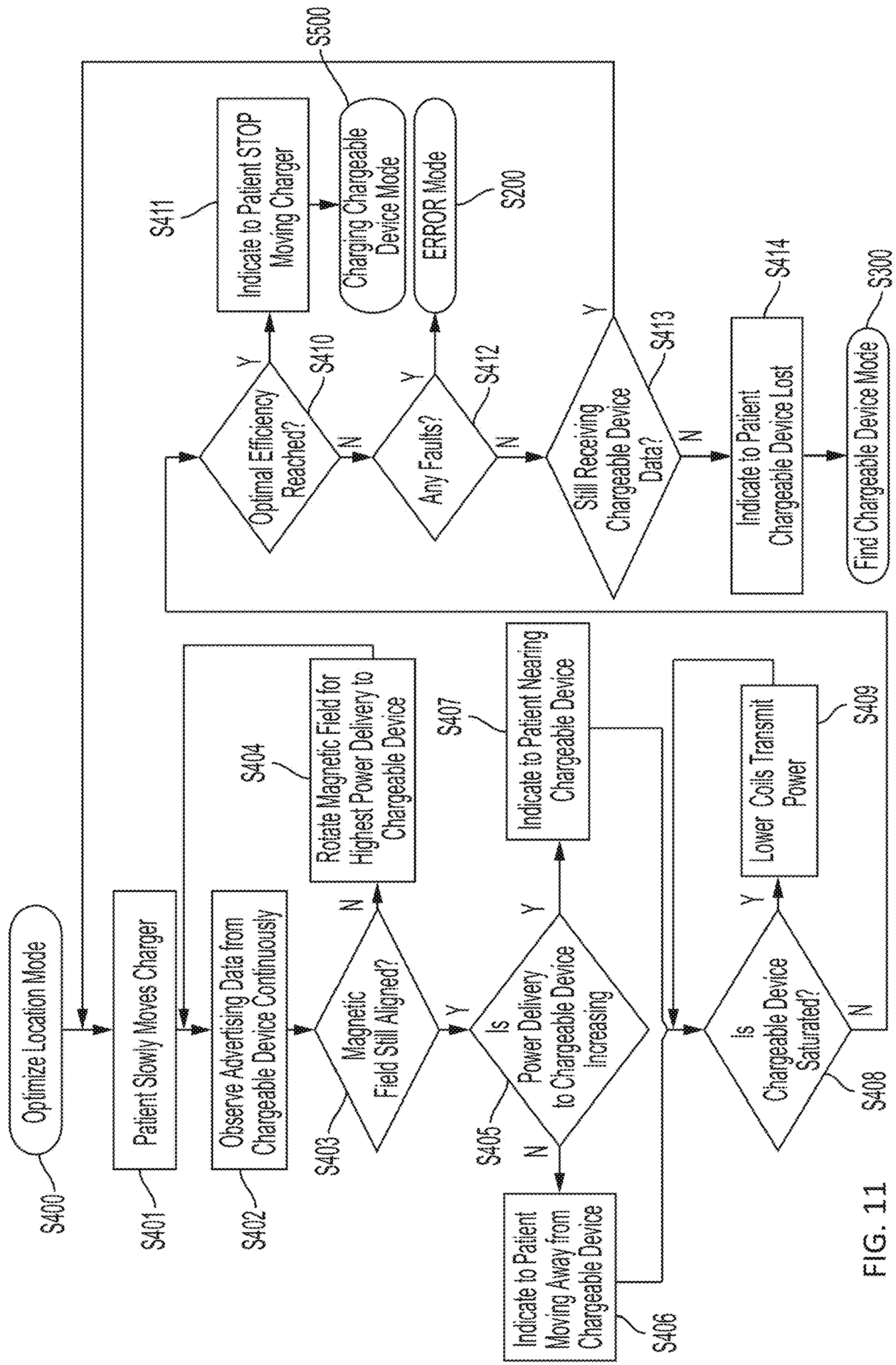

Optimize Location Mode
S400
Patient Slowly Moves Charger
S401
Observe Advertising Data from Chargeable Device Continuously
S402
Magnetic Field Still Aligned?
S403
N
Rotate Magnetic Field for Highest Power Delivery to Chargeable Device
S404
Y
Is Power Delivery to Chargeable Device Increasing
S405
N
Indicate to Patient Moving Away from Chargeable Device
S406
Y
Indicate to Patient Nearing Chargeable Device
S407
Is Chargeable Device Saturated?
S408
Y
Lower Coils Transmit Power
S409
N
Optimal Efficiency Reached?
S410
Y
Indicate to Patient STOP Moving Charger
S411
Charging Chargeable Device Mode
S500
N
Any Faults?
S412
Y
ERROR Mode
S200
N
Still Receiving Chargeable Device Data?
S413
Y
N
Indicate to Patient Chargeable Device Lost
S414
Find Chargeable Device Mode
S300

FIG. 11

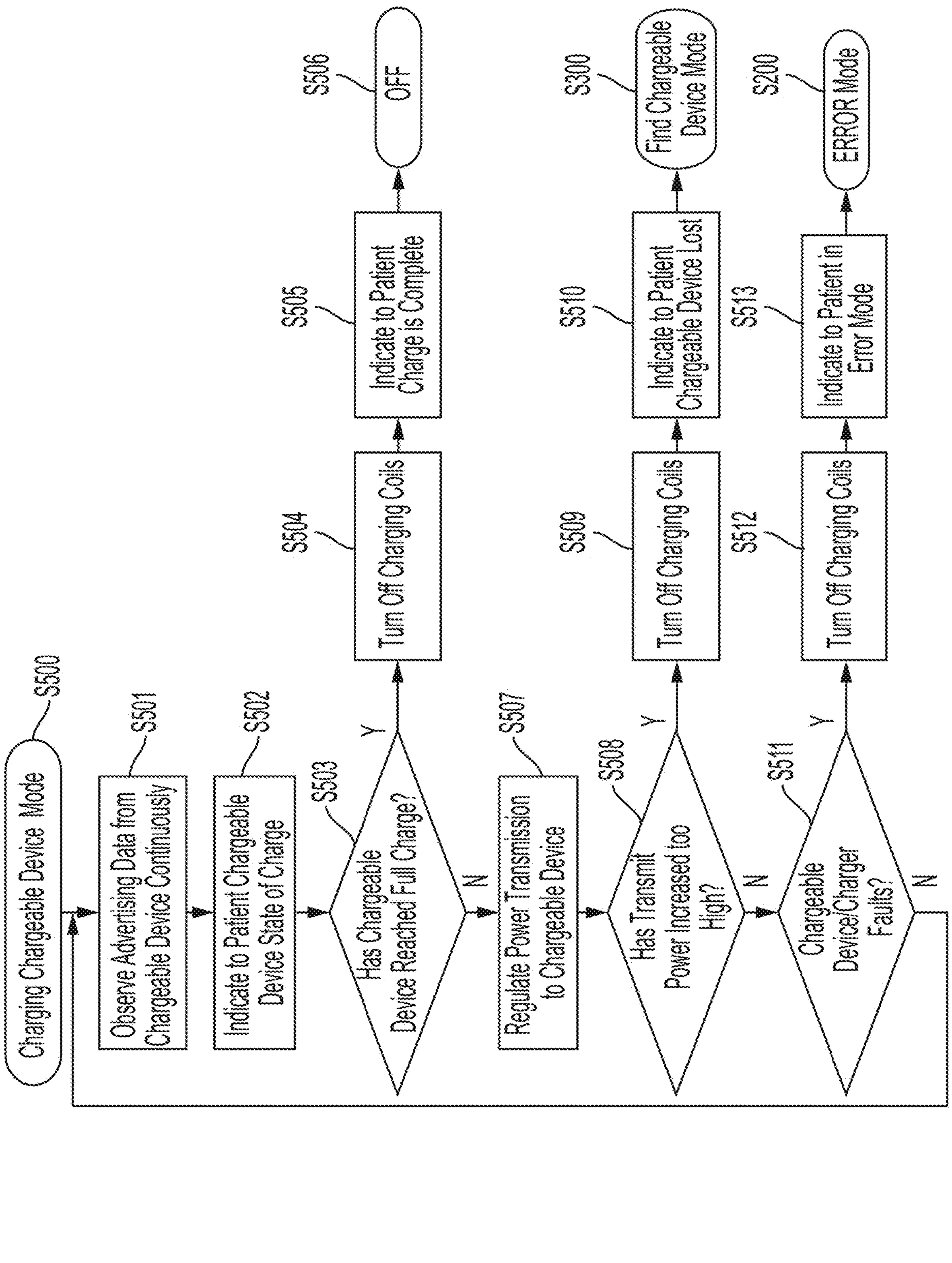

Charging Chargeable Device Mode
S500
Observe Advertising Data from Chargeable Device Continuously
S501
Indicate to Patient Chargeable Device State of Charge
S502
Has Chargeable Device Reached Full Charge?
S503
Y
N
Turn Off Charging Coils
S504
Indicate to Patient Charge is Complete
S505
OFF
S506
Regulate Power Transmission to Chargeable Device
S507
Has Transmit Power Increased too High?
S508
Y
N
Turn Off Charging Coils
S509
Indicate to Patient Chargeable Device Lost
S510
Find Chargeable Device Mode
S300
Chargeable Device/Charger Faults?
S511
Y
N
Turn Off Charging Coils
S512
Indicate to Patient in Error Mode
S513
ERROR Mode
S200

FIG. 12

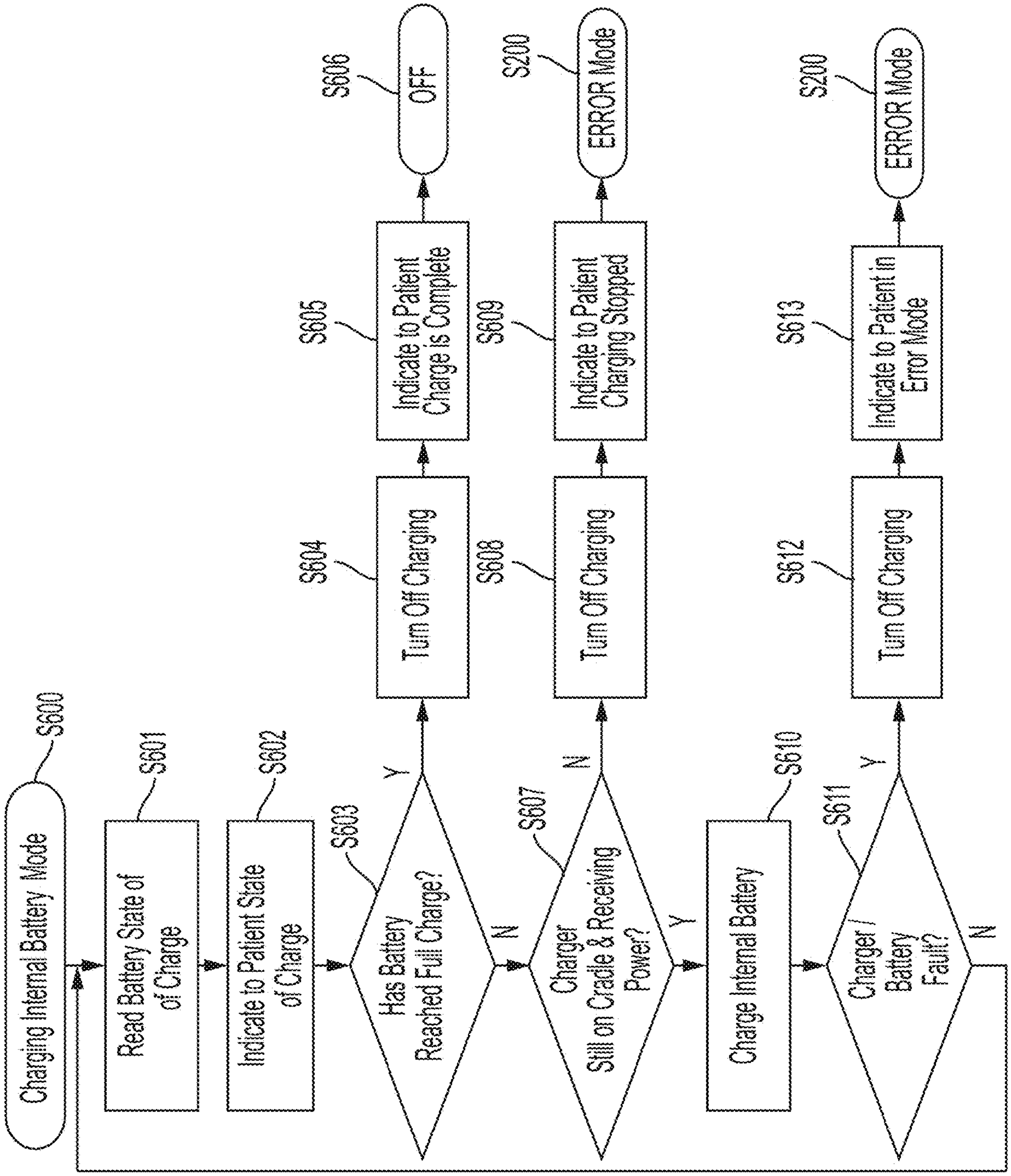

S600
Charging Internal Battery Mode
S601
Read Battery State of Charge
S602
Indicate to Patient State of Charge
S603
Has Battery Reached Full Charge?
Y
N
S604
Turn Off Charging
S605
Indicate to Patient Charge is Complete
S606
OFF
S607
Charger Still on Cradle & Receiving Power?
N
Y
S608
Turn Off Charging
S609
Indicate to Patient Charging Stopped
S200
ERROR Mode
S610
Charge Internal Battery
S611
Charger / Battery Fault?
Y
N
S612
Turn Off Charging
S613
Indicate to Patient in Error Mode
S200
ERROR Mode

FIG. 13

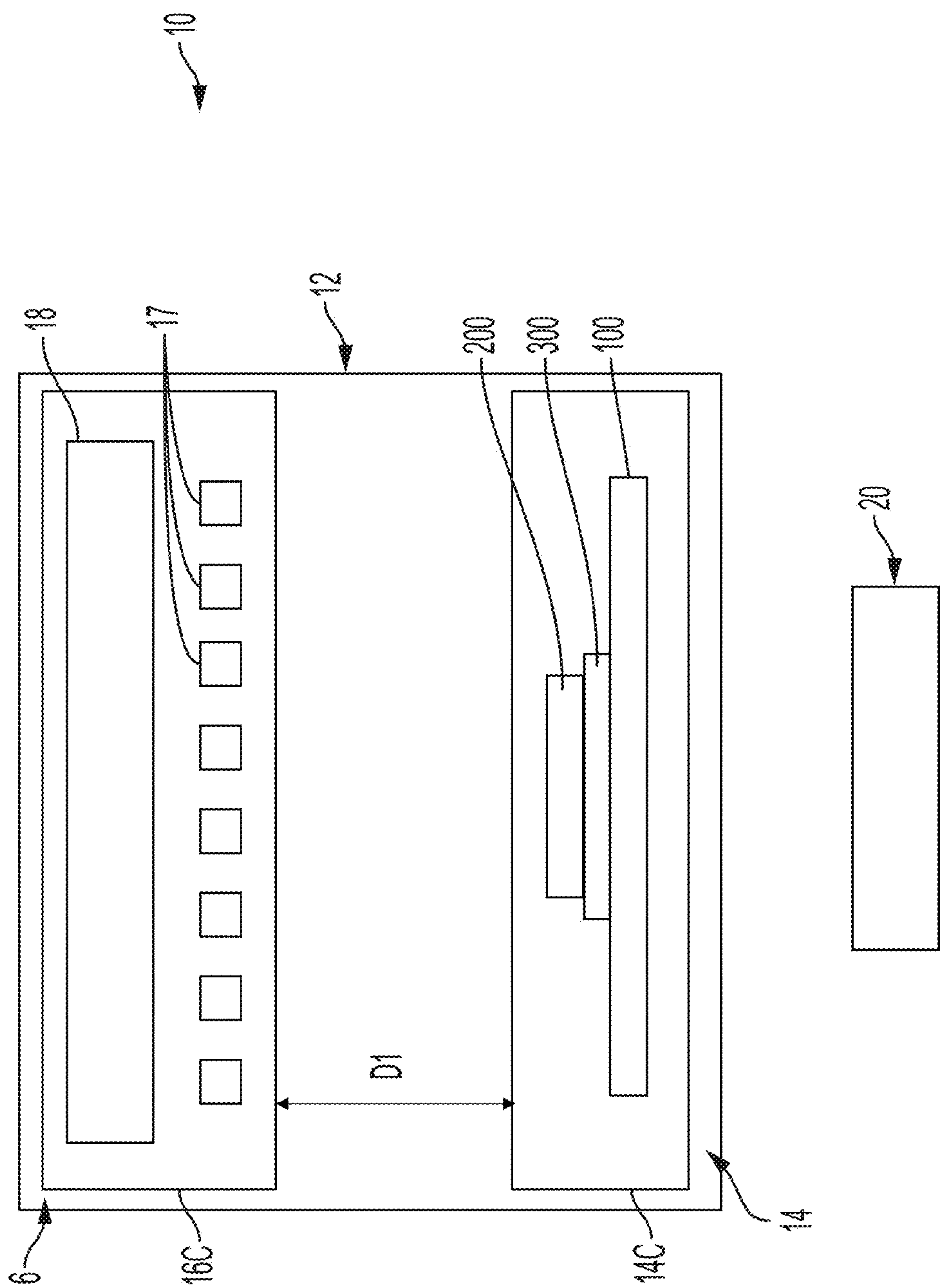


FIG. 14

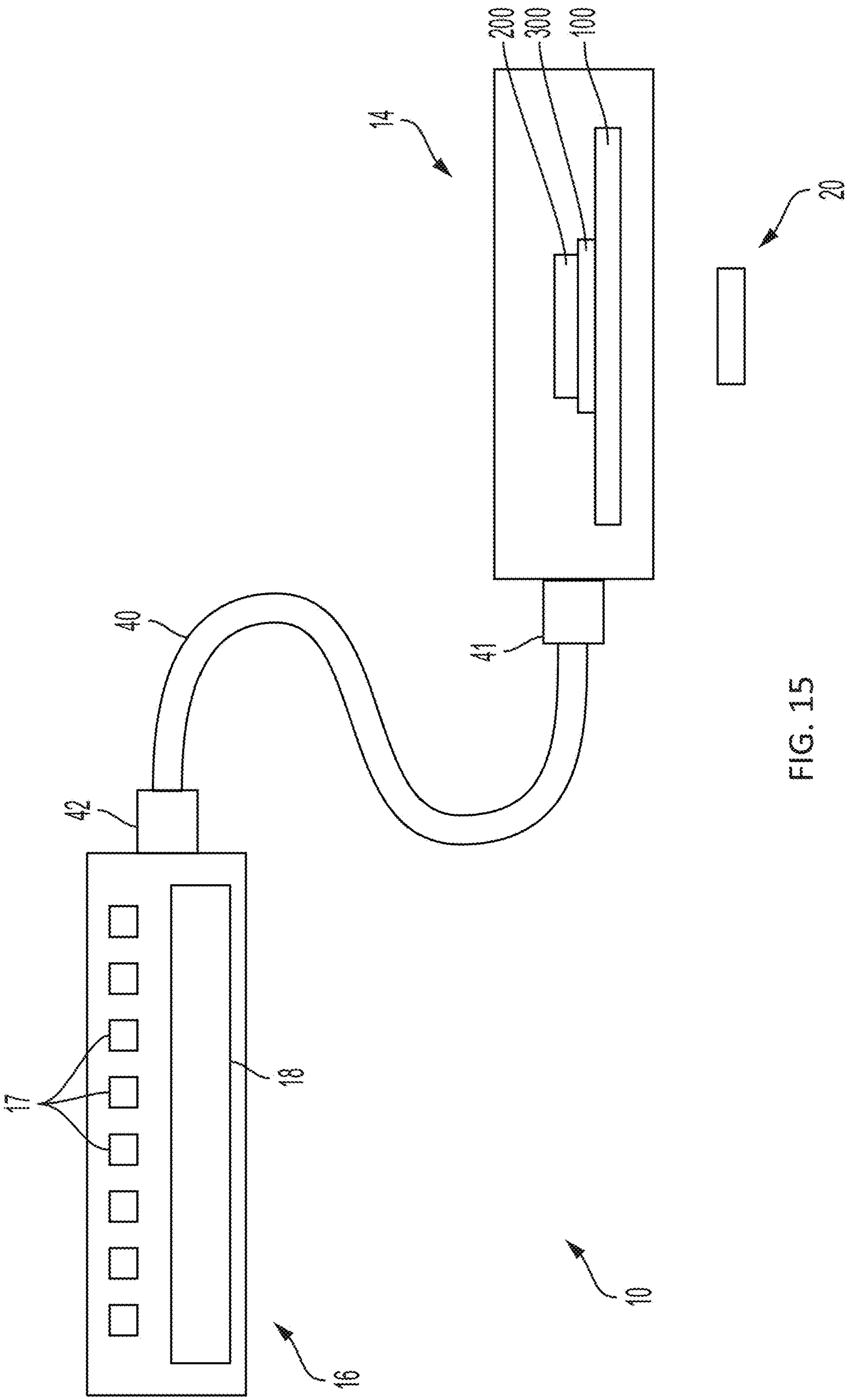


FIG. 15

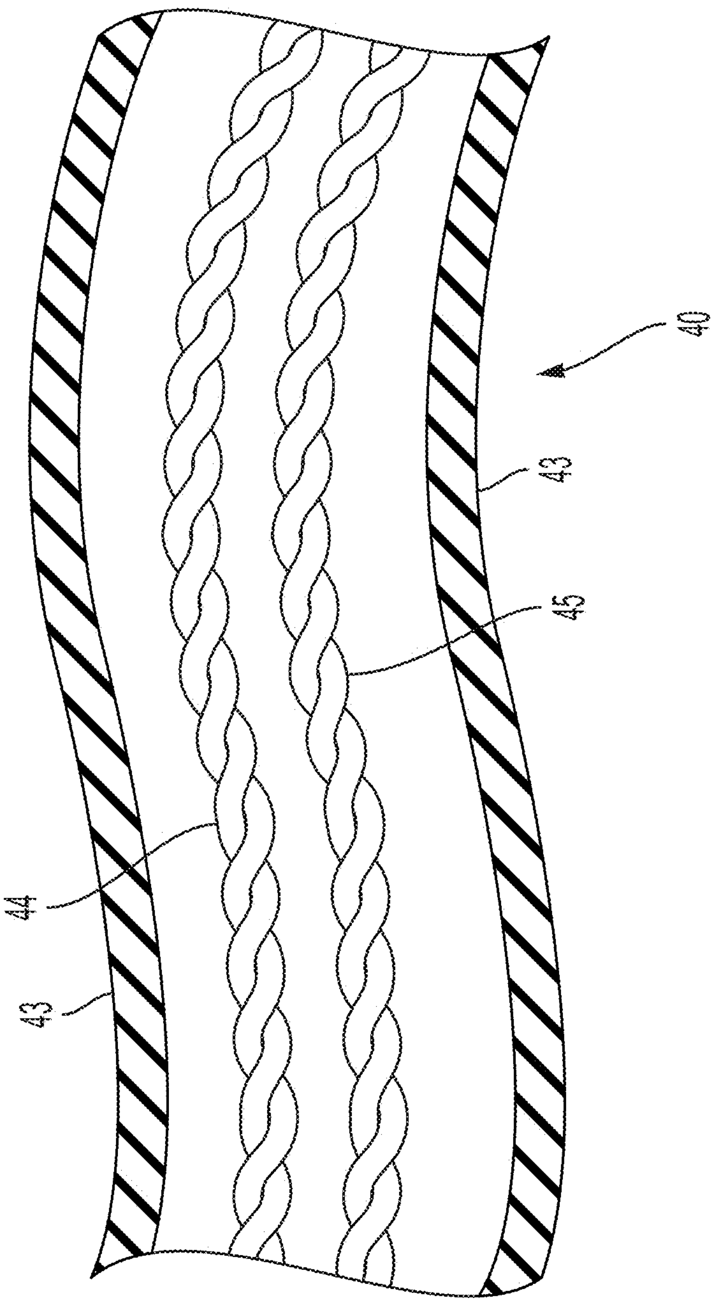


FIG. 16

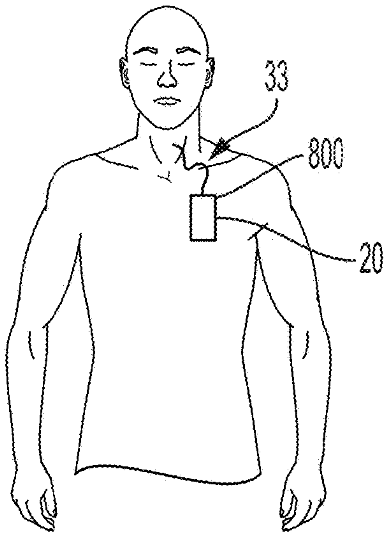


FIG. 17

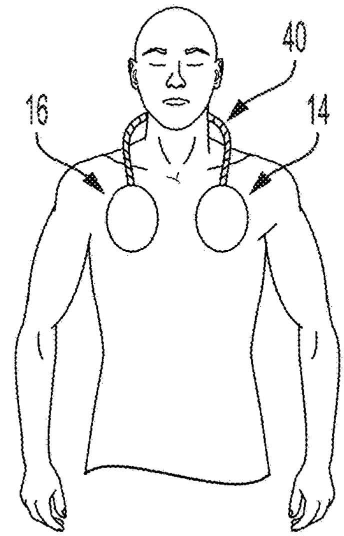


FIG. 18

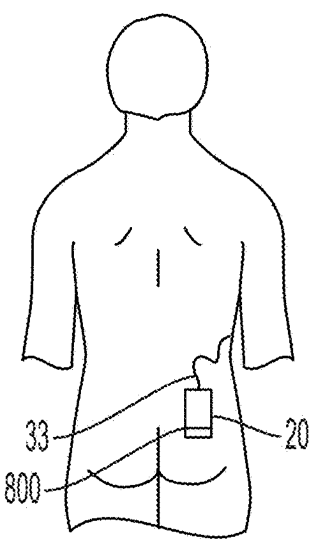


FIG. 19

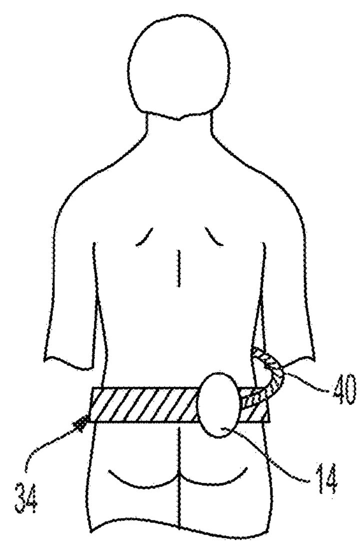


FIG. 20

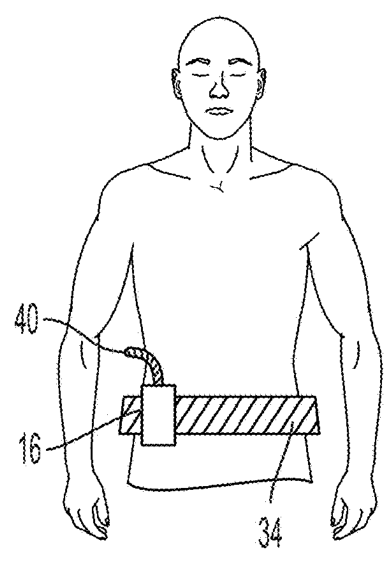


FIG. 21

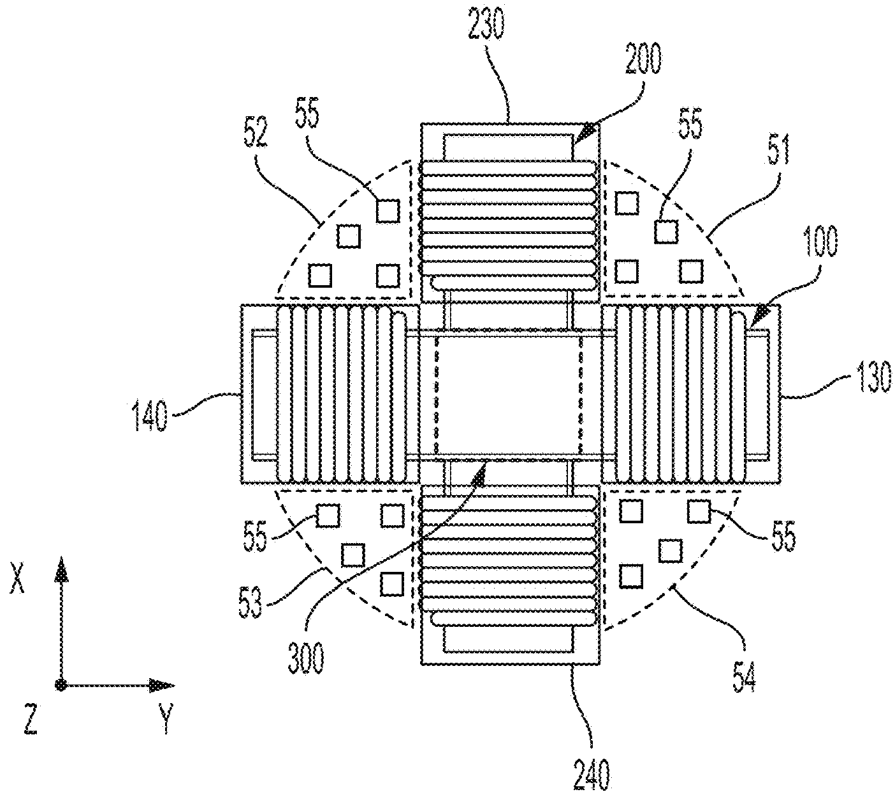


FIG. 22A

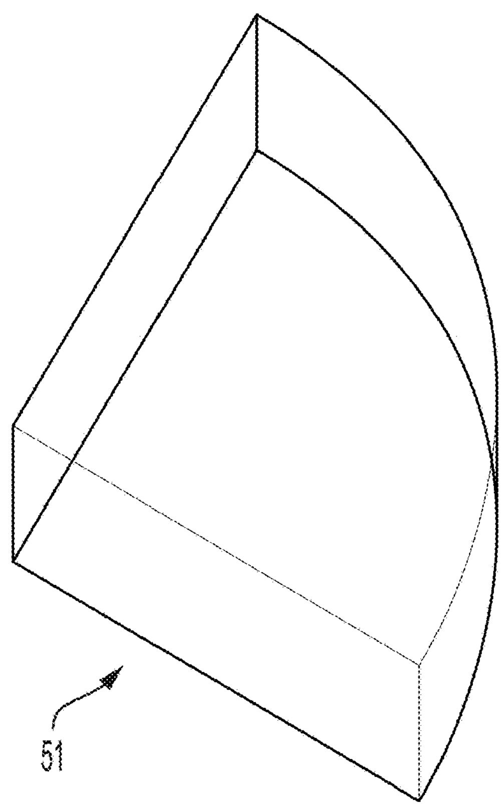


FIG. 22B

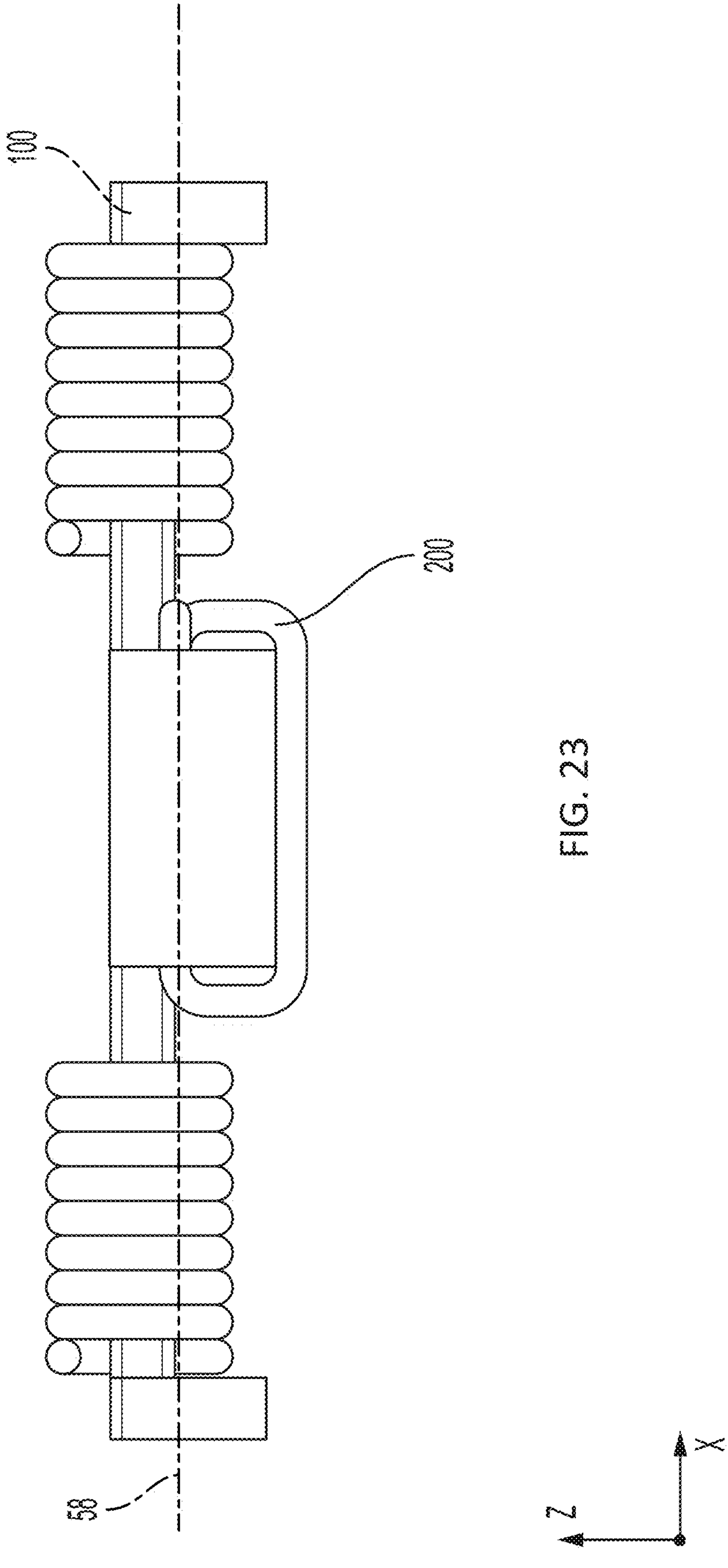


FIG. 23

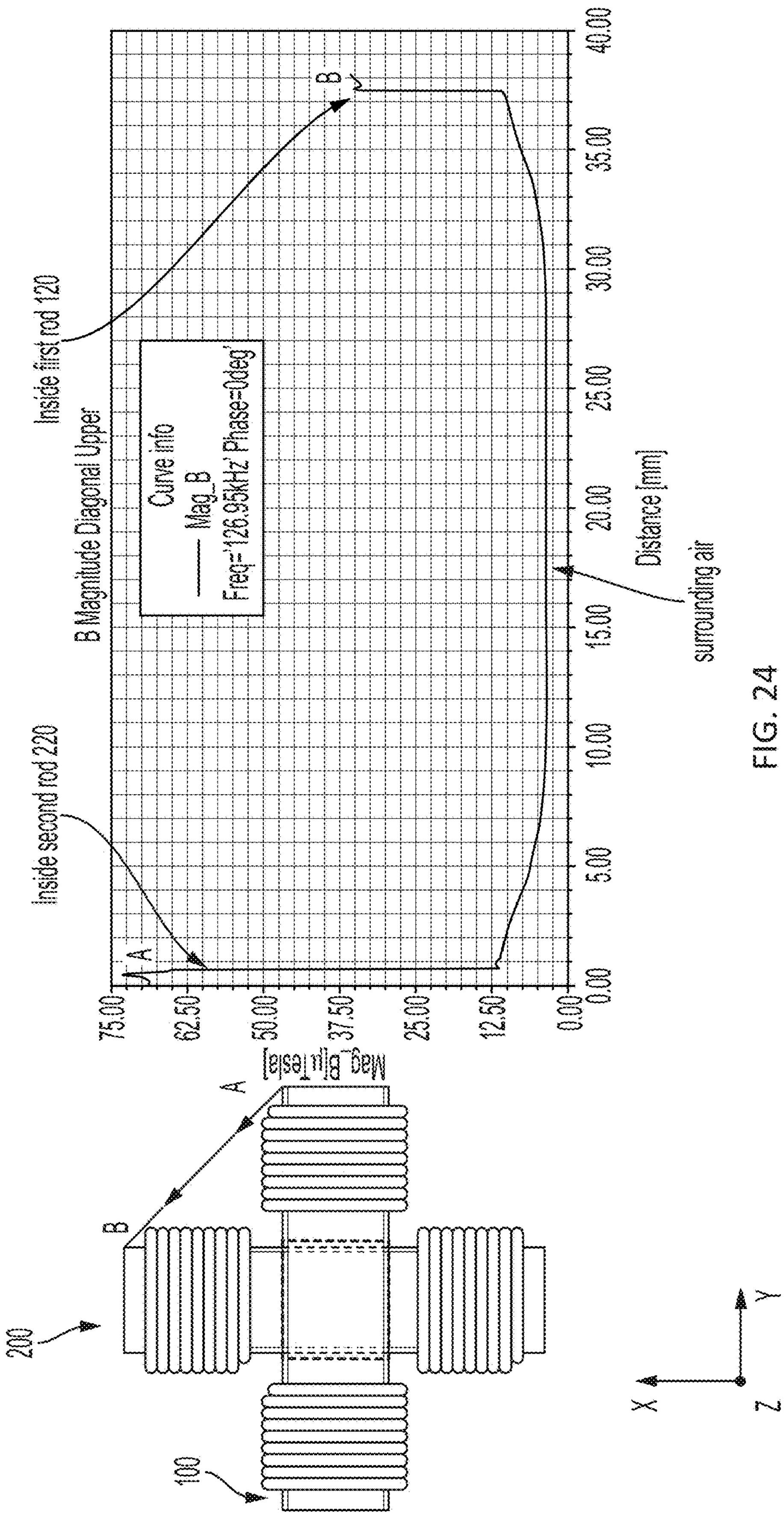

B Magnitude Diagonal Upper
Curve info
Mag_B
Freq='126.95kHz' Phase='0deg'
Inside first rod 120
Inside second rod 220
surrounding air
Distance [mm]
Mag_B[uTesla]
A
B
0.00
5.00
10.00
15.00
20.00
25.00
30.00
35.00
40.00
12.50
25.00
37.50
50.00
62.50
75.00
100
200
X
Y
Z

FIG. 24

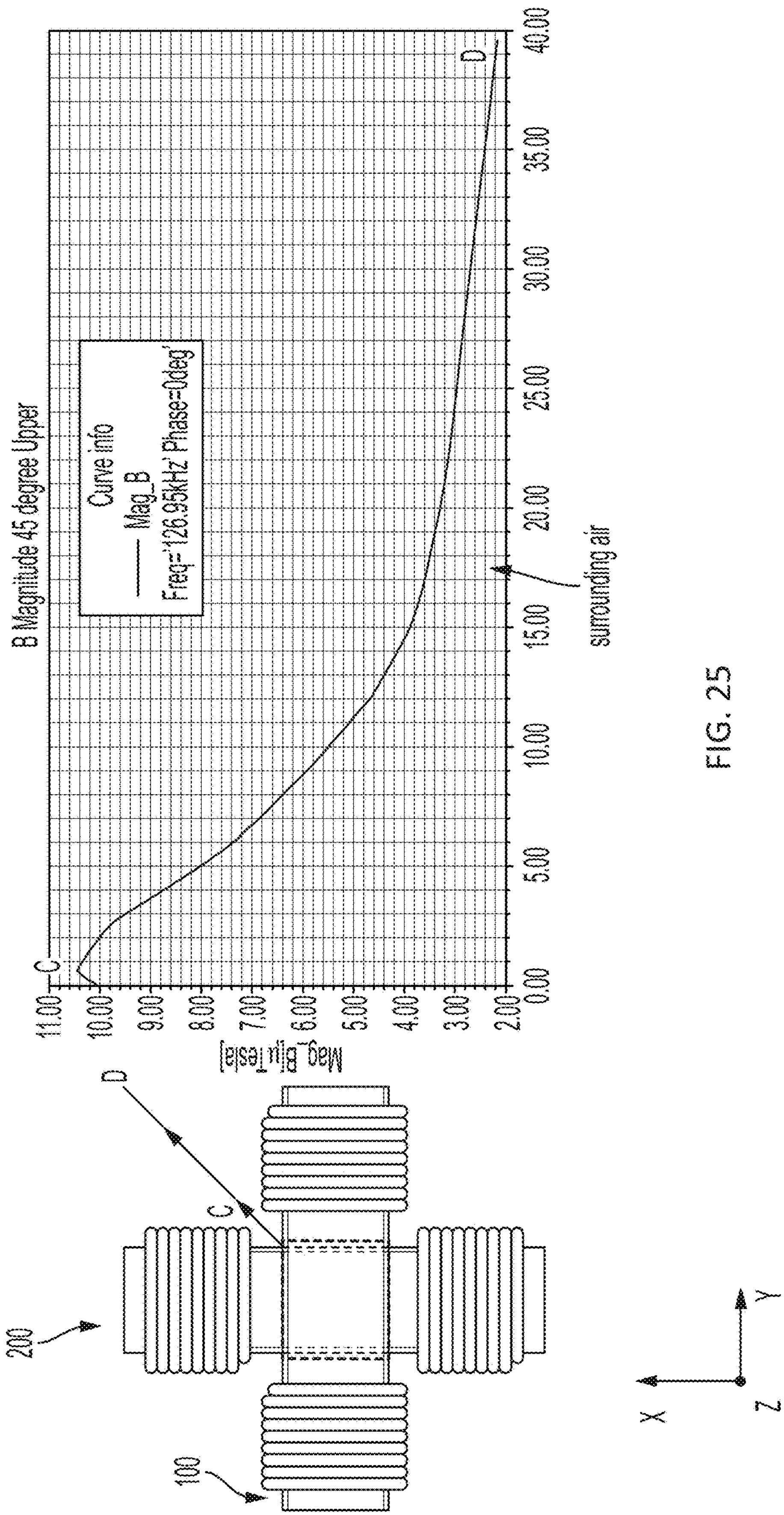

B Magnitude 45 degree Upper
Curve info
Mag_B
Freq='126.95kHz' Phase='0deg'
Mag_B[uTesla]
11.00
10.00
9.00
8.00
7.00
6.00
5.00
4.00
3.00
2.00
0.00
5.00
10.00
15.00
20.00
25.00
30.00
35.00
40.00
surrounding air
C
D
200
100
X
Y
Z

FIG. 25

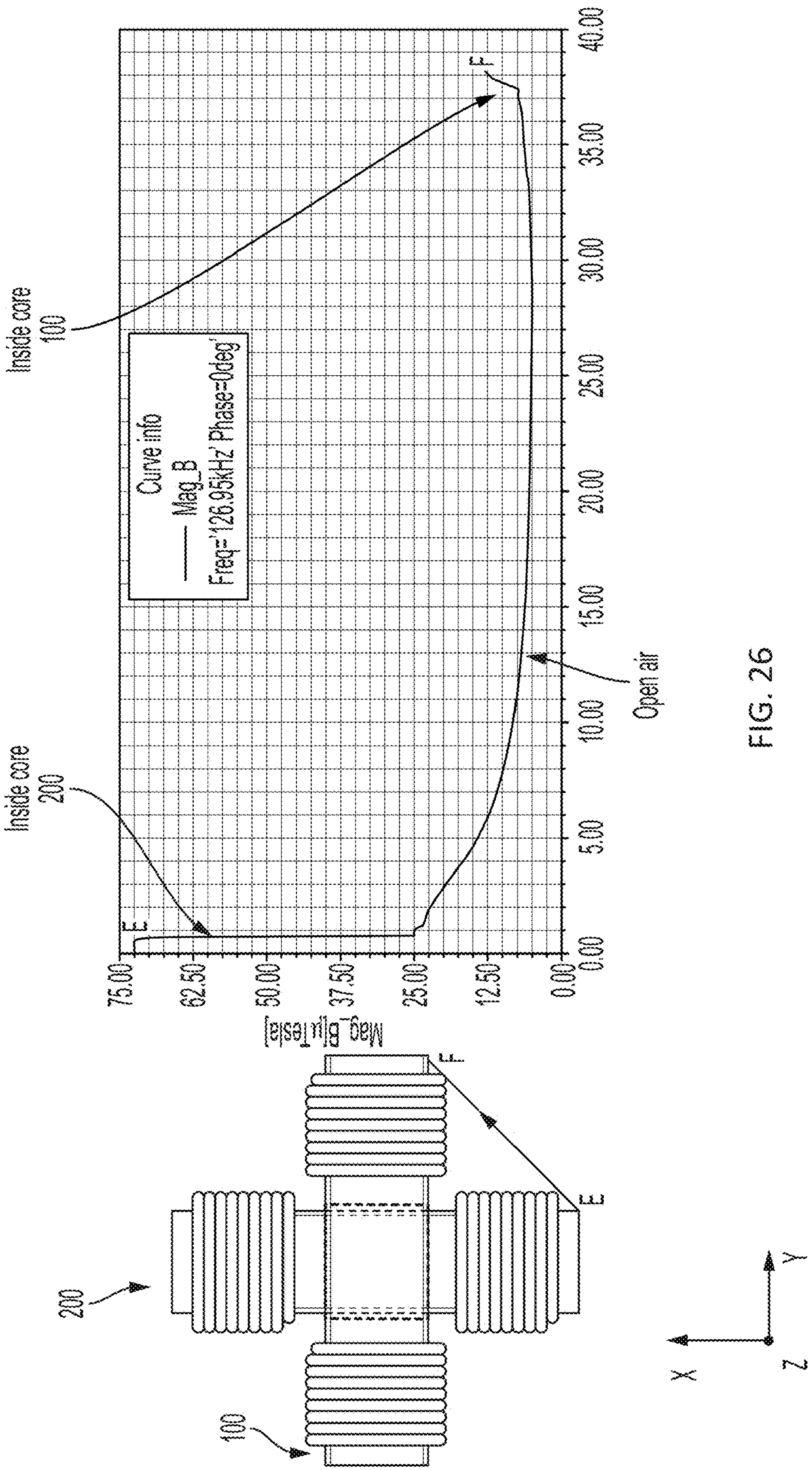

Inside core 100
Inside core 200
Curve info
Mag_B
Freq='126.95kHz' Phase='0deg'
Open air
Mag_B[uTesla]
75.00
62.50
50.00
37.50
25.00
12.50
0.00
0.00
5.00
10.00
15.00
20.00
25.00
30.00
35.00
40.00
E
F
100
200
X
Y
Z

FIG. 26

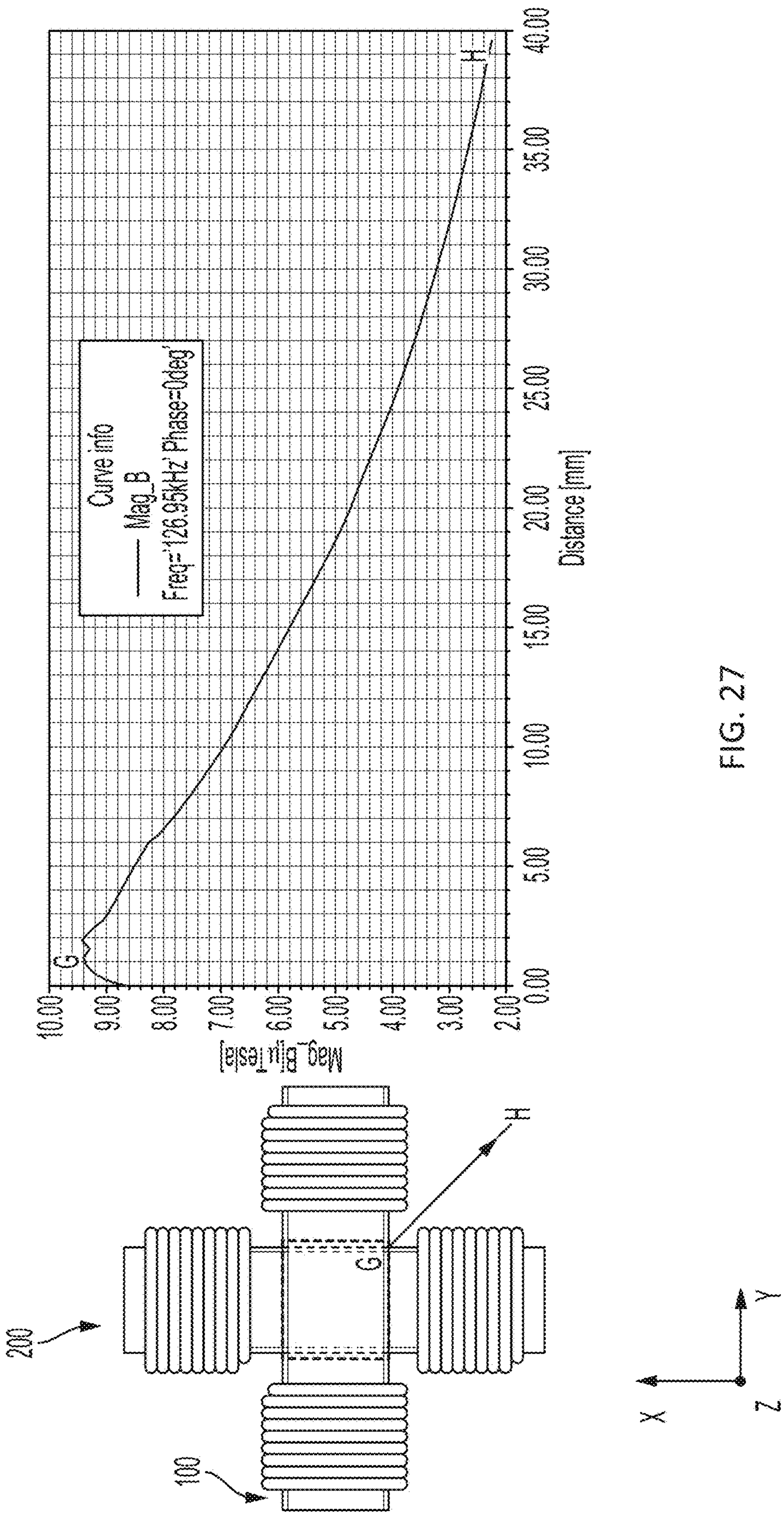

Curve Info
Mag_B
Freq='126.95kHz' Phase='0deg'
Mag_B[uTesla]
Distance [mm]
10.00
9.00
8.00
7.00
6.00
5.00
4.00
3.00
2.00
0.00
5.00
10.00
15.00
20.00
25.00
30.00
35.00
40.00
G
H
100
200
X
Y
Z

FIG. 27

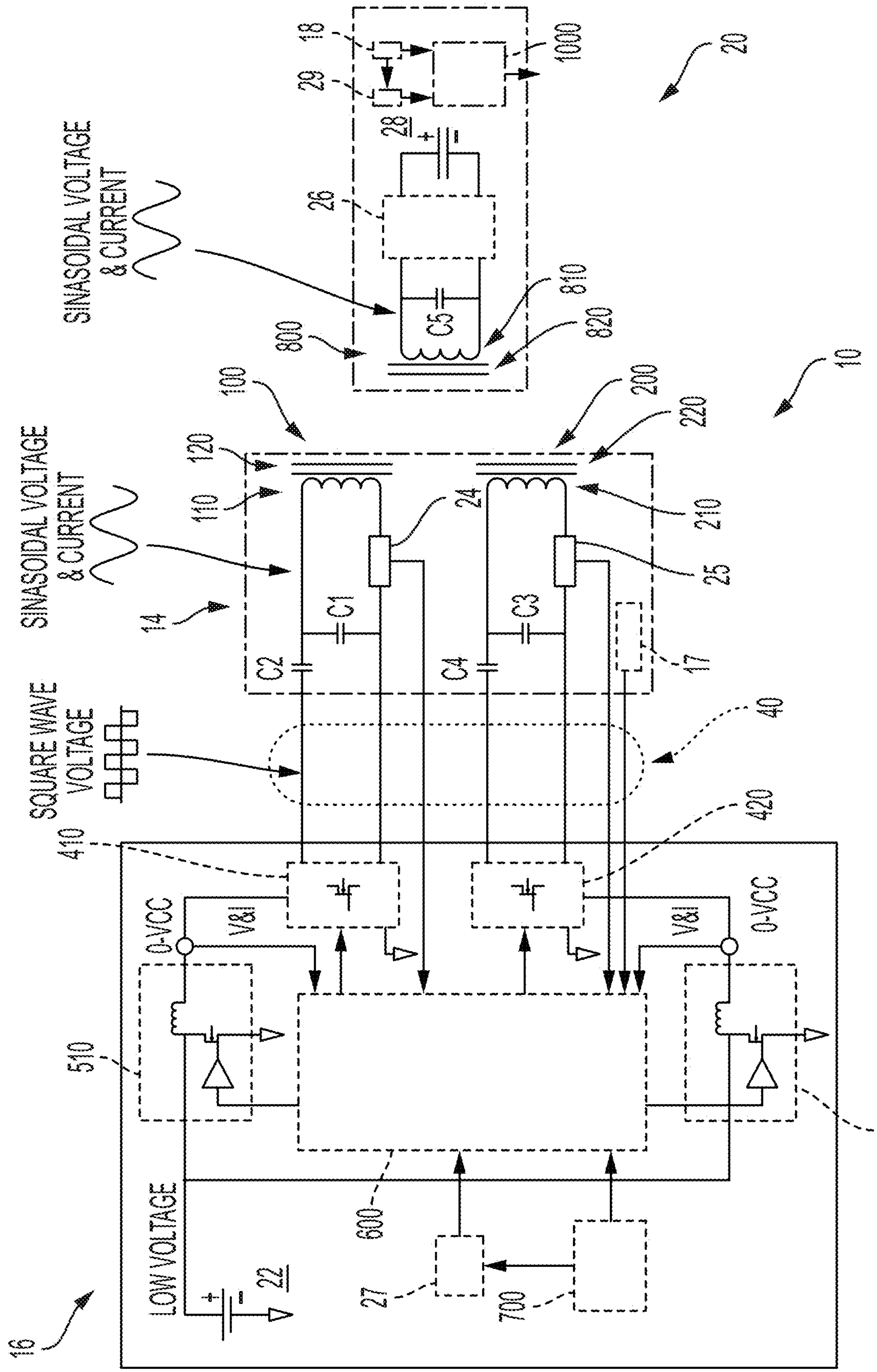
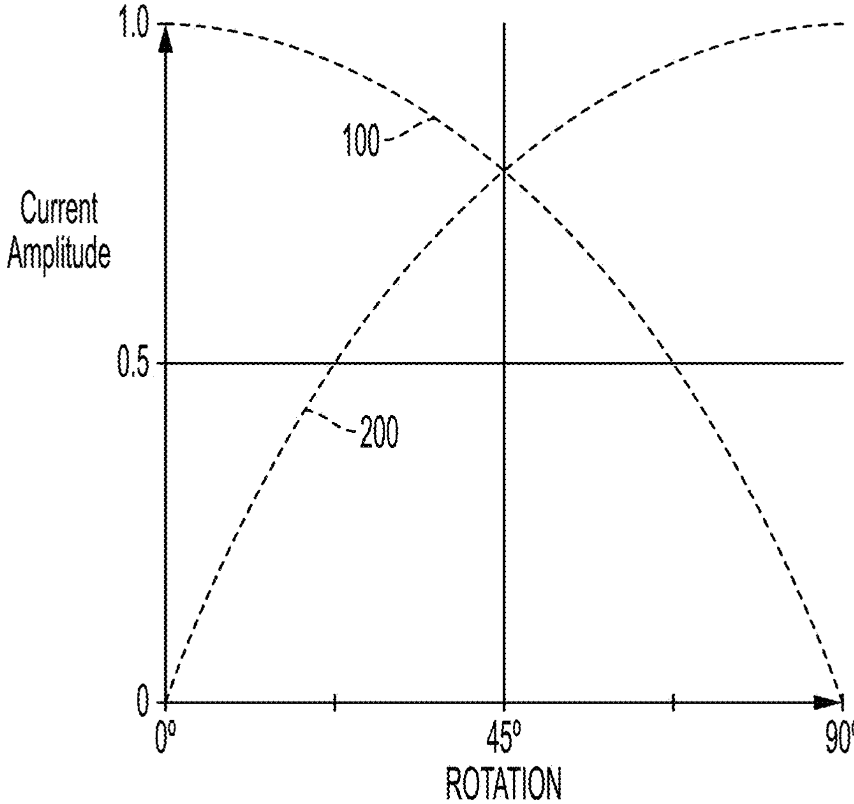
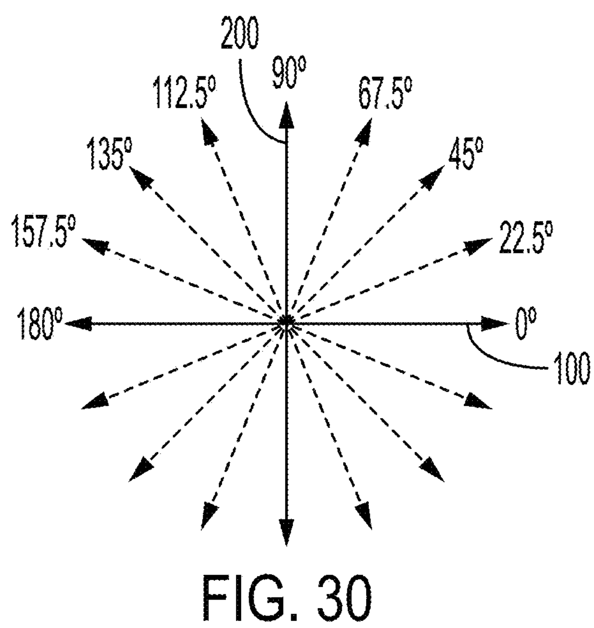

SINASOIDAL VOLTAGE & CURRENT
SINASOIDAL VOLTAGE & CURRENT
SQUARE WAVE VOLTAGE
LOW VOLTAGE
0-VCC
0-VCC
V&I
V&I
C1
C2
C3
C4
C5
10
14
16
17
18
20
22
24
25
26
27
28
29
40
100
110
120
200
210
220
410
420
510
520
600
700
800
810
820
1000

FIG. 28



1.0
100
Current Amplitude
0.5
200
0
0°
45°
90°
ROTATION

FIG. 29



200
90°
112.5°
67.5°
135°
45°
157.5°
22.5°
180°
0°
100

FIG. 30

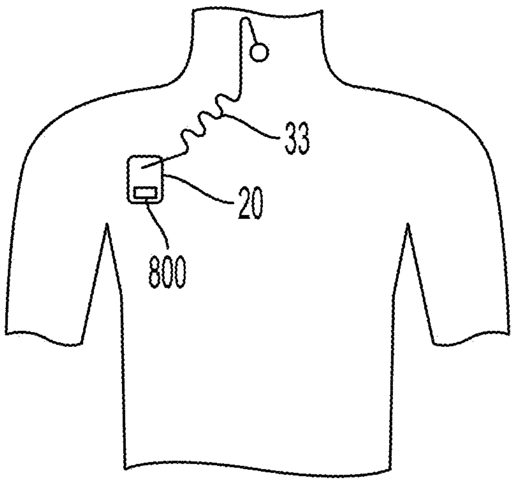


FIG. 31

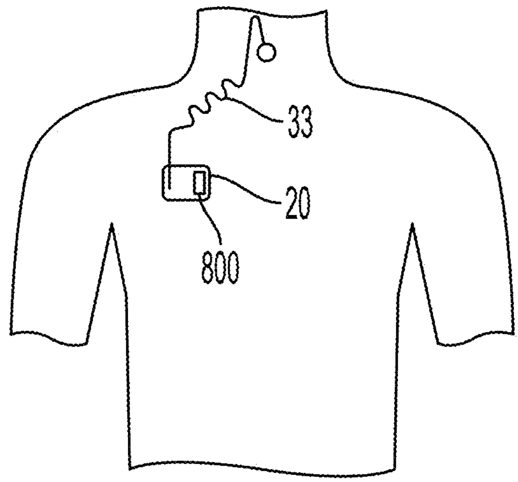


FIG. 32

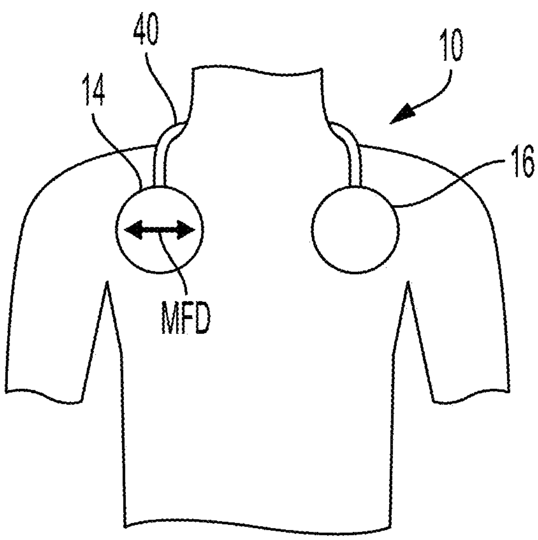


FIG. 33

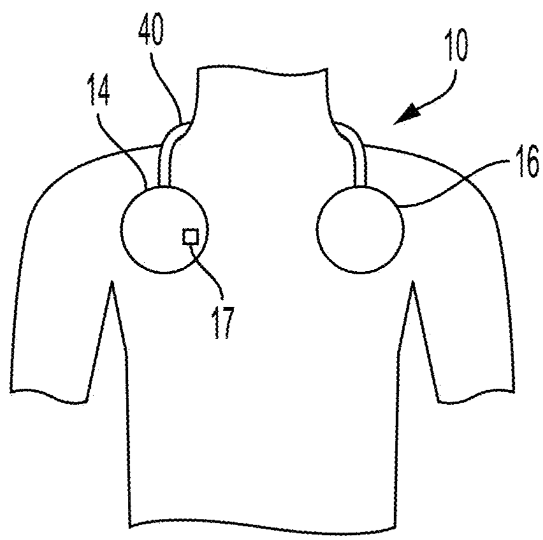


FIG. 34

METHOD AND APPARATUS FOR PRE-ALIGNMENT OF AN AUTOMATICALLY ALIGNING MAGNETIC FIELD SYSTEM

CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] This application is a continuation of U.S. patent application Ser. No. 18/153,991, filed Jan. 12, 2023, which claims priority to and the benefit of U.S. Provisional Application No. 63/299,165, filed Jan. 13, 2022, the entire content of each of which is hereby incorporated by reference.

BACKGROUND

1. Field

[0002] The present disclosure relates to a wireless power transfer device configured to generate a magnetic field and control a direction of the magnetic field.

2. Description of the Related Art

[0003] A primary coil may be driven with AC current to generate an oscillating magnetic field, and the magnetic field can generate a current in a secondary coil in proximity to the primary coil via electromagnetic induction. Electromagnetic induction can be utilized to wirelessly transfer energy and is utilized in one or more suitable industries and devices such as electric vehicles, medical devices, and electronic devices. The magnitude of the current generated in the secondary coil, and thus the effectiveness of the primary coil in transferring energy to the secondary coil, depends on how aligned the magnetic field is with the secondary coil. However, in related art devices, the primary coil cannot control the direction of the magnetic field, and improving alignment between the magnetic field with the secondary coil requires physically moving and/or orientating the primary coil or the secondary coil, which may be inconvenient and cumbersome. Additionally, improving the speed of aligning the magnetic field with the secondary coil is beneficial to improve efficiency, reduce the likelihood of errors during operation, and avoid frustrating a user. The primary coil in related art devices also generates a magnetic field that generates eddy currents in electronic components in the proximity of the primary coil, thereby reducing the efficiency of the primary coil to transfer energy to the secondary coil.

SUMMARY

[0004] The present disclosure relates to one or more suitable embodiments of a wireless power transfer system including a wireless power transfer device. In one embodiment, the wireless power transfer system includes: a wireless power transfer device, the wireless power transfer device including: a first transmitting coil oriented along a first axis, a second transmitting coil on the first transmitting coil, oriented along a second axis different from the first axis, and magnetically decoupled from the first transmitting coil in an area of overlap between the first and second transmitting coils, and a controller configured to differentially control driving of the first and second transmitting coils, wherein the controller is configured to determine an amplitude ratio such that, in response to the first transmitting coil being driven with a first current having a first amplitude, the second transmitting coil being driven with a second current having a second amplitude, and a ratio of the first amplitude to the second amplitude is the amplitude ratio, the wireless power transfer device generates a magnetic field having a direction, at a receiver coil of an electronic device, that is aligned with the receiver coil.

[0005] The present disclosure relates to one or more suitable embodiments of a wireless power transfer system include a wireless power transfer device. In one embodiment, the wireless power transfer system, includes: a wireless power transfer device configured: to determine a magnetic field, from among a plurality of directionally different potential magnetic fields that the wireless power transfer device is configured to generate, that has, at a receiver coil of an electronic device, a direction aligned with the receiver coil, and to selectively generate the magnetic field.

[0006] The present disclosure relates to one or more suitable embodiments method of transferring power from a wireless power transfer device to an electronic device. In one embodiment, the method includes: determining, by a wireless power transfer device, a magnetic field from among a plurality of directionally different potential magnetic fields that the wireless power transfer device is configured to generate that has, at a receiver coil of an electronic device, a direction aligned with the receiver coil; and selectively generating, by the wireless power transfer device, the magnetic field to wirelessly transfer power to the electronic device via the magnetic field.

[0007] This summary is provided to introduce a selection of features and concepts of embodiments of the present disclosure that are further described below in the detailed description. This summary is not intended to identify key or essential features of the claimed subject matter, nor is it intended to be utilized in limiting the scope of the claimed subject matter.

BRIEF DESCRIPTION OF THE DRAWINGS

[0008] The accompanying drawings, together with the specification, illustrate example embodiments of the present disclosure. These drawings, together with the description, serve to better explain aspects and principles of the present disclosure.

[0009] FIG. **1** shows a schematic view of a wireless power transfer system according to some embodiments.

[0010] FIG. **2** shows a perspective view of first and second transmitting coils of a wireless power transfer device according to some embodiments.

[0011] FIG. **3** shows a plan view of the first and second transmitting coils of FIG. **2**.

[0012] FIG. **4** shows a side view of the first and second transmitting coils of FIG. **2**.

[0013] FIG. **5**A shows a plan view of first and second transmitting coils of a wireless power transfer device according to some embodiments and the direction of a magnetic field generated by the first and second transmitting coils pursuant to five states in which the first and second transmitting coils may be driven.

[0014] FIGS. **5**B-**5**F show graphs of the voltages applied to the first and second transmitting coils as a function of time for the five states of FIG. **5**A.

[0015] FIG. **6**A shows a schematic view of a wireless power transfer system according to some embodiments.

[0016] FIG. **6**B shows a schematic side view of the wireless power transfer system of FIG. **6**A with the wireless power transfer device above the electronic device.

[0017] FIG. **6**C shows a schematic side view of the wireless power transfer system of FIG. **6**A with the electronic device at the side of the wireless power transfer device.

[0018] FIG. **7**A shows a schematic view of an electronic device according to some embodiments.

[0019] FIG. **7**B shows a schematic view of an electronic device according to some embodiments.

[0020] FIG. **8** shows a method flow chart for an initialization mode according to some embodiments.

[0021] FIG. **9** shows a method flow chart for an error mode according to some embodiments.

[0022] FIG. **10** shows a method flow chart for a find electronic device mode according to some embodiments.

[0023] FIG. **11** shows a method flow chart for an optimize location mode according to some embodiments.

[0024] FIG. **12** shows a method flow chart for an electronic device charging mode according to some embodiments.

[0025] FIG. **13** shows a method flow chart for a wireless power transfer device charging mode according to some embodiments.

[0026] FIG. **14** shows a schematic view of a wireless power transfer system according to some embodiments.

[0027] FIG. **15** shows a schematic view of a wireless power transfer system according to some embodiments.

[0028] FIG. **16** shows a cross-sectional partial view of the cable illustrated in FIG. **15**.

[0029] FIG. **17** shows a possible placement of an electronic device in a user.

[0030] FIG. **18** shows a possible placement of a wireless power transfer device on the user of FIG. **17**.

[0031] FIG. **19** shows another possible placement of an electronics device in a user.

[0032] FIGS. **20** and **21** show a possible placement of the wireless power transfer device on the user of FIG. **19**.

[0033] FIG. **22**A shows a plan view of a coil assembly according to some embodiments.

[0034] FIG. **22**B shows a perspective view of a magnetic field shallow zone of FIG. **22**A according to some embodiments.

[0035] FIG. **23** shows a side view of the first and second transmitting coils according to some embodiments.

[0036] FIG. **24** shows a plan view of first and second transmitting coils and a graph of a magnitude of the magnetic field along line A-B generated by the first and second transmitting coils when the first and second transmitting coils are driven with AC currents that are in-phase and of a same amplitude, according to some embodiments.

[0037] FIG. **25** shows a plan view of first and second transmitting coils and a graph of a magnitude of the magnetic field along line C-D generated by the first and second transmitting coils when the first and second transmitting coils are driven with AC currents that are in-phase and of a same amplitude, according to some embodiments.

[0038] FIG. **26** shows a plan view of first and second transmitting coils and a graph of a magnitude of the magnetic field along line E-F generated by the first and second transmitting coils when the first transmitting coil is driven with AC current and the second transmitting coil is not driven, according to some embodiments.

[0039] FIG. **27** shows a plan view of first and second transmitting coils and a graph of a magnitude of the magnetic field along line G-H generated by the first and second transmitting coils when the first transmitting coil is driven with AC current and the second transmitting coil is not driven, according to some embodiments.

[0040] FIG. **28** shows a schematic view of a circuit diagram of the wireless power transfer system according to some embodiments.

[0041] FIG. **29** shows a graph displaying current magnitude versus a direction of a magnetic field generated by a wireless power transfer device according to an embodiment.

[0042] FIG. **30** shows a graph displaying various directions of a magnetic field generated by a wireless power transfer device according to an embodiment.

[0043] FIG. **31** shows an electronic device implanted in a body according to an embodiment.

[0044] FIG. **32** shows an electronic device implanted in a body according to another embodiment.

[0045] FIG. **33** shows a wireless power transfer device coupled to a body according to an embodiment.

[0046] FIG. **34** shows a wireless power transfer device coupled to a body according to another embodiment.

DETAILED DESCRIPTION

[0047] The terminology utilized herein is for the purpose of describing particular embodiments only and is not intended to be limiting of the present disclosure. As utilized herein, the singular forms "a", "an" and "the" are intended to include the plural forms as well, unless the context clearly indicates otherwise. As utilized herein, the term "and/or" includes any and all combinations of one or more of the associated listed items.

[0048] It will be understood that, although the terms "first", "second", "third", etc., may be utilized herein to describe various elements, components, regions, layers and/or sections, these elements, components, regions, layers and/or sections should not be limited by these terms. These terms are only utilized to distinguish one element, component, region, layer or section from another element, component, region, layer or section. Thus, a first element, component, region, layer or section discussed below could be termed a second element, component, region, layer or section, without departing from the spirit and scope of the present disclosure.

[0049] It will be understood that when an element or layer is referred to as being "on", "connected to", "coupled to", or "adjacent to" another element or layer, it can be directly on, connected to, coupled to, or adjacent to the other element or layer, or one or more intervening element(s) or layer(s) may be present. In contrast, when an element or layer is referred to as being "directly on," "directly connected to", "directly coupled to", or "immediately adjacent to" another element or layer, there are no intervening elements or layers present.

[0050] As utilized herein, the term "substantially" and similar terms are utilized as terms of approximation and not as terms of degree, and are intended to account for the inherent deviations in measured or calculated values that would be recognized by those of ordinary skill in the art. Also, the terms "about," "approximately," and similar terms, when utilized herein in connection with a numerical value or a numerical range, are inclusive of the stated value and mean within an acceptable range of deviation for the particular value as determined by one of ordinary skill in the art, considering the measurement in question and the error associated with measurement of the particular quantity (e.g., the limitations of the measurement system). For example, "about" may mean within one or more standard deviations, or within +30%, 20%, 10%, 5% of the stated value.

[0051] Also, any numerical range recited herein is intended to include all sub-ranges of the same numerical precision subsumed within the recited range. For example, a range of "1.0 to 10.0" is intended to include all subranges between (and including) the recited minimum value of 1.0 and the recited maximum value of 10.0, that is, having a minimum value equal to or greater than 1.0 and a maximum value equal to or less than 10.0, such as, for example, 2.4 to 7.6. Any maximum numerical limitation recited herein is intended to include all lower numerical limitations subsumed therein and any minimum numerical limitation recited in this specification is intended to include all higher numerical limitations subsumed therein. Accordingly, Applicant reserves the right to amend this specification, including the claims, to expressly recite any sub-range subsumed within the ranges expressly recited herein.

[0052] Example embodiments of the present disclosure will now be described with reference to the accompanying drawings. In the drawings, the same or similar reference numerals refer to the same or similar elements throughout. As utilized herein, the use of the term "may," when describing embodiments of the present disclosure, refers to "one or more embodiments of the present disclosure."

[0053] FIG. **1** schematically illustrates a wireless power transfer system according to some embodiments. The wireless power transfer system may include a wireless power transfer device **10** and an electronic device **20**.

[0054] The wireless power transfer device **10** may include a first transmitting coil **100**, a second transmitting coil **200** on (e.g., positioned on) the first transmitting coil **100**, a driver **400** configured to drive the first transmitting coil **100** with a first AC current and the second transmitting coil **200** with a second AC current, power modulation electronics **500** configured to modulate the first and second AC currents provided by the driver **400**, a controller **600** (e.g., a micro-controller) configured to control the operations of the driver **400** and the power modulation electronics **500**, and a receiver **700** for receiving information (e.g., information transmitted by the electronic device **20**).

[0055] The electronic device **20** may include a receiver coil **800**, a detector **900** configured to detect information about power received in the receiver coil **800**, and a transmitter **1000** configured to transmit information (e.g., transmit information to the wireless power transfer device **10**). In some embodiments, the transmitter **1000** may be a radio or an RF transmitter.

[0056] The wireless power transfer device **10** may be configured to generate an oscillating magnetic field by driving the first and second transmitting coils **100** and **200** with the first and second AC currents, respectively, and to rotate the direction of the magnetic field by controlling (e.g., setting or adjusting) a first magnitude of the first AC current, a second magnitude of the second AC current, and a phase difference between the first and second AC currents (e.g., the wireless power transfer device **10** is configured to rotate the direction of the magnetic field by differentially driving the first and second transmitting coils **100** and **200**). When the wireless power transfer device **10** generates the magnetic field and the electronic device **20** is in the proximity to the wireless power transfer device **10**, a current may be generated in the receiver coil **800** by electromagnetic induction (e.g., wireless resonant induction). The detector **900** may be configured to detect information (e.g., power, amplitude, etc.) about the current generated in the receiver coil **800**, and the transmitter **1000** may be to transmit (e.g., wirelessly transmit) the detected information to outside of the electronic device **20**, for example, to the receiver **700** of the wireless power transfer device **10**. The controller **600** may control the driver **400** and the power modulation electronics **500** based on the information received by the receiver **700** to control the direction of the magnetic field at the receiver coil **800**.

[0057] The first and second transmitting coils **100** and **200** will now be described in more detail with reference to FIGS. **2-4**. FIG. **2** shows a perspective view of the first and second transmitting coils **100** and **200** according to some embodiments, FIG. **3** shows a plan view of the first and second transmitting coils **100** and **200** of FIG. **2**, and FIG. **4** shows a side view of the first and second transmitting coils **100** and **200** of FIG. **2**.

[0058] The first transmitting coil **100** may include a first rod **120** and a first wire **110** wound around the first rod **120**, and the second transmitting coil **200** may include a second rod **220** and a second wire **210** wound around the second rod **220**.

[0059] The first transmitting coil **100** may be aligned along a first axis **100**A, and the second transmitting coil **200** may be aligned along a second axis **200**A different from the first axis **100**A. In some embodiments, the second axis **200**A is perpendicular (or substantially perpendicular) to the first axis **100**A. For example, an angle between the second axis **200**A and the first axis **100**A may be approximately (about) 90°. When the first and second axes **100**A and **200**A are perpendicular, coupling between the first and second transmitting coils **100** and **200** may be reduced or substantially prevented. Coupling between the first and second transmitting coils **100** and **200** may be at a maximum when the first and second axes **100**A and **200**A are parallel, and coupling between the first and second transmitting coils **100** and **200** may decrease as an angle between the first and second axes **100**A and **200**A increases towards 90°, at which point coupling is at a minimum. However, the angle between the first axis **100**A and the second axis **200**A may be any suitable angle, for example, within the range of about 45° to about 90°. In FIGS. **2-4**, the first axis **100**A is shown as being aligned along an X-axis, and the second axis **200**A is shown as being aligned along a Y-axis.

[0060] The second transmitting coil **200** may be on (e.g., above) the first transmitting coil **100** and may overlap the first transmitting coil **100** in a plan view (shown in FIG. **3**) at an area of overlap **300**. In some embodiments, the area of overlap **300** corresponds to a center region of the first transmitting coil **100** and a center region of the second transmitting coil **200**. The second transmitting coil **200** may be spaced apart (e.g., separated) from the first transmitting coil **100** in a thickness direction (e.g., a Z-axis direction) at the area of overlap **300**.

[0061] An intermediate space **300***a* between the first and second transmitting coils **100** and **200** in the area of overlap **300** may include (e.g., be filled or at least partially filled with) a nonmagnetic material having a low permeability, for example, air, plastic, foam, one or more non-ferrimagnetic materials, one or more low permeability metals (e.g., aluminum and/or copper), etc. In some embodiments, when the intermediate space **300***a* is filled with air, a frame or housing may be utilized to hold the first and second transmitting coils

100 and **200** and/or to maintain the relative positions of the first and second transmitting coils **100** and **200** with respect to each other. In some embodiments, the material in the intermediate space **300***a* has a relative permeability of equal to or less than about 5, for example, in the range of about 1 to about 1.5. In some embodiments, the material in the intermediate space **300***a* may be diamagnetic (e.g., a material having a relative permeability in the range of about 0 to about 1). Therefore, in some embodiments, the second transmitting coil **200** does not contact the first transmitting coil **100**, and the first and second transmitting coils **100** and **200** are magnetically independent (e.g., magnetically decoupled and/or magnetically isolated from each other) and/or electrically independent (e.g., electrically decoupled and/or electrically isolated) from each other. Because the first and second transmitting coils **100** and **200** are not in contact, coupling between the first and second transmitting coils **100** and **200** may be reduced or substantially prevented. For example, the first transmitting coil **100** may generate a first magnetic field without being significantly influenced by the presence of the second transmitting coil **200**, and the second transmitting coil **200** may generate a second magnetic field without being significantly influenced by the presence of the first transmitting coil **100**. A magnetic field generated by the wireless power transfer device **10** may be a superposition of the first and second magnetic fields generated by the first and second transmitting coils **100** and **200**, respectively.

[0062] The first rod **120** may include a magnetic material having a high permeability, such as a ferrimagnetic material (e.g., soft ferrite material), such as nickel- or manganese-based ferrites (e.g., MnZn, NiZn, and/or the like). The magnetic material may increase the intensity of a magnetic field generated by the first transmitting coil **100** compared to an otherwise comparable coil without the magnetic rod. In some embodiments, the material of the first rod **120** may have a relative permeability equal to or greater than about 5, for example, in the range of about 10 to about 10,000. The second rod **220** may include any material that the first rod **120** may include, and the second rod **220** may include a material that is the same as, or different from, a material included in the first rod **120**. In some embodiments, a ratio of the permeability of a material in the first rod **120** to the permeability of the material in the intermediate space **300***a* may be equal to or greater than approximately (about) **5**. When the permeability of the materials of the first and second rods **120** and **220** are significantly larger than the permeability of the material in the intermediate space **300***a*, coupling between the first and second transmitting coils **100** and **200** may be reduced or substantially prevented. For example, a magnetic field flowing through the first rod **120** may be blocked (by the material in the intermediate space **300***a*) from permeating through the intermediate space **300***a* and into the magnetic material of the second rod **220**. Thus, the presence of the second transmitting coil **200** may not substantially affect the first magnetic field generated by the first transmitting coil **100**, and vice versa.

[0063] The first rod **120** may include a material based on a frequency of an AC current to be driven through the first wire **110** (e.g., the designed or intended operational frequency of the first and/or second coils **100** and **200**). In some embodiments, the first rod **120** may include a material (e.g., MnZn ferrite) having a relative permeability within the range of about 1000 to about 4000 when the frequency of the AC current to be driven through the first wire **110** is within the range of about 100 kHz to about 1 MHz. In some embodiments, the first rod **120** may include a material (e.g., NiZn ferrite) having a relative permeability within the range of about 10 to about 200 when the frequency of the AC current to be driven through the first wire **110** is above about 1 MHz.

[0064] In some embodiments, the first rod **120** may include a material having a relative permeability within the range of about 2300 to about 4000. In some embodiments, the first rod **120** may include a material having low resistive, low eddy currents, low hysteresis, and/or low flux losses at the operation frequency.

[0065] In some embodiments, the wireless power transfer device **10** is to be operated (e.g., operated at normal operating conditions) so that the flux density within the first and second rods **120** and **220** is operated or controlled (e.g., set) to be within the substantially linear region of a BH curve of the material included in the first rod **120** and/or the second rod **220**. When the wireless power transfer device **10** is operated above this region, losses may increase, system efficiency may be reduced, and a desired intensity of the magnetic field may not be generated due to nonlinear increases in losses in the first rod **120** and/or the second rod **220** lowering the first coil **100** and/or the second coil's **200** quality factor. This will distort the directionality of the combined magnetic field of the first and second coils **100** and **200**.

[0066] Because the first and second rods **120** and **220**, and a rod of the receiver coil **800**, may be rods rather than closed magnetic cores, such as in transformers, the effective permeability of the rods may be far lower than the manufacturer specified initial permeability of the material(s) of the rods. A rod with a low length to width (e.g., diameter) ratio may have a very low effective permeability. In some embodiments, the first rod **120** and/or the second rod **220** may have an effective permeability (e.g., relative effective permeability) between about 20 and about 50. However, the present disclosure is not limited thereto.

[0067] The first rod **120** may include a first main rod **120***a* and first thick portion (e.g., a tab or a flange) **120***b* at an end (e.g., both ends) of the first main rod **120***a*, and the second rod **220** may include a second main rod **220***a* and a second thick portion (e.g., a tab or a flange) **220***b* at an end (e.g., both ends) of the second main rod **220***a*. The first main rod **120***a* may have any suitable shape. The second main rod **220***a* may have any shape that the first main rod **120***a* may have, and the shape of the second main rod **220***a* may be the same as, or different from, the shape of the first main rod **120***a*. In some embodiments, the first main rod **120***a* has a cylindrical shape. In other embodiments, the first main rod **120***a* has a rectangular shape having a length along the X-axis, a width along the Y-axis, and a thickness along the Z-axis. The width of the first main rod **120***a* may be less than the length of the first main rod **120***a*, and the thickness of the first main rod **120***a* may be less than the width of the first main rod **120***a*, but the present disclosure is not limited thereto.

[0068] A thickness of the intermediate space **300***a* may be relatively small compared to the dimensions of the first and second transmitting coils **100** and **200**. For example, the thickness of the intermediate space **300***a* may be less than the length, the width, and/or the thickness of the first main rod **120***a*. Because the first and second magnetic fields generated by the first and second transmitting coils **100** and **200** will each generally decrease in magnitude as respective distances from the first and second transmitting coils **100** and **200** increase, it is advantageous for the thickness of the intermediate space **300***a* to be small in order to minimize or at least reduce a disparity between a distance between the electronic device **20** and the first transmitting coil **100** and a distance between the electronic device **20** and the second transmitting coil **200**. When the disparity is large, one of the first and second transmitting coils **100** and **200** may have an unintended disproportionate effect on the electronic device **20** compared to the other one of the first and second transmitting coils **100** and **200**. Accordingly, in one or more embodiments, the thickness of the intermediate space **300***a* may be sufficiently small such that the first and second transmitting coils **100** and **200** are substantially coplanar to advantageously minimize or at least reduce the disproportionate effect of one of the first and second transmitting coils **100** and **200** on the electronic device **20**.

[0069] In some embodiments, a thickness of the first main rod **120***a* at the area of overlap **300** is less than a thickness of the first main rod **120***a* at an area outside of the area of overlap **300**. For example, the first main rod **120***a* may have an indent or recess (e.g., a step) at the area of overlap **300** that faces the second main rod **220***a*. When one or both of the first and second main rods **120***a* and **220***a* have such an indent or recess, the distance between the first and second transmitting coils **100** and **200** may be reduced. In some embodiments, the indent or recess in one or both of the first and second main rods **120***a* and **220***a* may allow the first and second wires **110** and **210** to be coplanar (or substantially coplanar).

[0070] The first thick portion **120***b* may be at an end (or end portion) of the first main rod **120***a*, and a thickness of the first thick portion **120***b* may be greater than a thickness of the first main rod **120***a*. For example, as shown in FIG. **3**, the first thick portion **120***b* may protrude toward the second transmitting coil **200** (e.g., in the negative Z-axis direction). Similarly, the second thick portion **220***b* may be at an end (or end portion) of the second main rod **220***a*, and a thickness of the second thick portion **220***b* may be greater than a thickness of the second main rod **220***a*. For example, the second thick portion **220***b* may protrude toward the first transmitting coil **100** (e.g., in the Z-axis direction). For example, the second thick portion **220***b* of the second transmitting coil **200** may protrude in a direction opposite to a protruding direction of the first thick portion **120***b* of the first transmitting coil **100**. Because the first and second thick portions **120***b* and **220***b* of the first and second transmitting coils **100** and **200** may protrude toward the second and first transmitting coils **200** and **100**, respectively, the distance along the Z-axis direction between the ends of the first rod **120** and the ends of the second rod **220** may be reduced or eliminated, and thus, the ends of the first and second rods **120** and **220** may be substantially coplanar.

[0071] The first wire **110** may be wound around the first rod **120** in any suitable configuration. The second wire **210** may be wound around the second rod **220** in any configuration that the first wire **110** may be wound around the first rod **120**. In some embodiments, the first wire **110** is wound around the first main rod **120***a* and is not wound around the first thick portion **120***b*. The first wire **110** may be wound around substantially the entire length of the first main rod **120***a*. For example, the first wire **110** and the first main rod **120***a* may form a solenoid. In some embodiments, the first wire **110** is wound around two ends (or two end portions) of the first main rod **120***a* to form first and second sub-coils **110***a* and **110***b* at the two ends (or two end portions) of the first main rod **120***a*, and the first wire **110** exposes, and is not wound around, a portion (e.g., an exposed intermediate or central portion) of the first main rod **120***a* between the first and second sub-coils **110***a* and **110***b*. The exposed portion of the first main rod **120***a* may include a portion of the first main rod **120***a* corresponding to the area of overlap **300** between the first and second transmitting coils **100** and **200**. When the first wire **110** is not wound around the first main rod **120***a* at the area of overlap **300**, the thickness of the first transmitting coil **100** at the area of overlap **300** may be reduced.

[0072] The first sub-coil **110***a* may be electrically coupled (e.g., electrically connected) to the second sub-coil **110***b* in series or in parallel. When the first sub-coil **110***a* is electrically coupled (e.g., electrically connected) to the second sub-coil **110***b* in series, the first wire **110** may electrically couple (e.g., electrically connect) the first sub-coil **110***a* to the second sub-coil **110***b* by extending across the area of overlap **300** on the first main rod **120***a* and on a side of the first main rod **120***a* facing away from the second transmitting coil **200**.

[0073] In some embodiments, the first sub-coil **110***a* is not electrically coupled (e.g., electrically connected) to the second sub-coil **110***b*, and the first and second sub-coils **110***a* and **110***b* are separately driven. In such embodiments, the first and second sub-coils **110***a* and **110***b* may be synchronously driven so that the magnetic fields generated by the first and second sub-coils coils **110***a* and **110***b* oscillate in phase.

[0074] The wireless power transfer device **10** may generate a magnetic field by driving the first AC current through the first wire **110** and/or driving the second AC current through the second wire **210**. The first and second AC currents may be driven in phase (i.e., with about 0° phase difference between the first and second AC currents) or about 180° out of phase. A direction of the magnetic field generated by the wireless power transfer device **10** may be controlled or selected by controlling (e.g., setting or changing) a first amplitude of the first AC current, a second amplitude of the second AC current, and a phase difference between the first and second AC currents (e.g., the wireless power transfer device **10** is configured to rotate the direction of the magnetic field by differentially driving the first and second transmitting coils **100** and **200**). Accordingly, the direction of the magnetic field can be rotated by changing these parameters.

[0075] FIG. **5**A shows how the direction of a magnetic field generated by the wireless power transfer device **10** can be rotated according to a non-limiting example. FIGS. **5**B-**5**F show graphs of the voltages applied to the first and second transmitting coils **100** and **200** as a function of time for five states shown in FIG. **5**A. The numerical values shown in the graphs of FIGS. **5**B-**5**F represent non-limiting examples. Beginning with a first state (1) as shown in FIGS. **5**A and **5**B, the first amplitude of the first AC current of the first wire **110** is at 0, the second amplitude of the second AC of the second wire **210** current is at 10, and the direction of the magnetic field at a point above the area of overlap **300** may oscillate between the Y-axis direction and the negative Y-axis direction.

[0076] To rotate the magnetic field clockwise to a second position corresponding to a second state (2) as shown in FIGS. **5**A and **5**C, the first and second AC currents are driven in phase, the first amplitude is increased while the second amplitude is decreased until they are the same (each at an amplitude of 5), and the direction of the magnetic field at the point will oscillate between 45° between the X-axis direction and the Y-axis direction and 45° between the negative X-axis direction and the negative Y-axis direction.

[0077] To rotate the magnetic field clockwise to a third position corresponding to a third state (3) as shown in FIGS. **5**A and **5**D, the first and second AC currents are driven in phase, the first amplitude is increased while the second amplitude is decreased until the first amplitude is at 10 and the second amplitude is at 0, and the direction of the magnetic field at the point will oscillate between the X-axis direction and the negative X-axis direction.

[0078] To rotate the magnetic field to a fourth position corresponding to a fourth state (4) as shown in FIGS. **5**A and **5**E, the first and second AC currents are driven 180° out of phase, the first amplitude is decreased while the second amplitude is increased until the first and second amplitudes are the same (each at **5**), and the direction of the magnetic field at the point will oscillate between 45° between the X-axis direction and the negative Y-axis direction and 45° between the negative X-axis direction and the Y-axis direction.

[0079] To rotate the magnetic field to a fifth position corresponding to a fifth state (5) as shown in FIGS. **5**A and **5**F, the first and second AC currents are driven 180° out of phase, the first amplitude is decreased while the second amplitude is increased until the first amplitude is at 0 and the second amplitude is at 10, and the direction of the magnetic field at the point may oscillate between the negative Y-axis direction and the Y-axis direction, similar to the first state (1). As utilized herein, the terms "first amplitude" and "second amplitude" refer to the peak amplitude.

[0080] Accordingly, the direction of the magnetic field at a point above the area of overlap **300** may be rotated to have any direction in the X-Y plane (any of quadrants I-IV of the X-Y plane in FIG. **5**) by gradually adjusting the first amplitude of the first AC current and the second amplitude of the second AC current, and by shifting the first and second AC currents between being in-phase and being 180° out of phase. For example, when the first and second AC currents are in phase, the magnetic field at the point may have any direction in the first and third quadrants I and III of the X-Y plane by suitably setting the first and second amplitudes. Furthermore, when the first and second AC currents are 180° out of phase, the magnetic field at the point may have any direction in the second and fourth quadrants II and IV of the X-Y plane by suitably setting the first and second amplitudes.

[0081] Although a direction of the magnetic field generated by the wireless power transfer device **10** at a point above the area of overlap **300** has been described with respect to FIG. **5**, it will be understood that the direction of the magnetic field at any point around the wireless power transfer device **10** may be controlled (e.g., rotated) or selected as described above by controlling the first and second amplitudes and/or by controlling the phase difference between the first and second AC currents. The direction of the magnetic field at points away from regions above or below the area of overlap **300** may have a directional component along the Z-axis direction, whereas a direction of the magnetic field at regions above or below the area of overlap **300** may have substantially no Z-axis component.

[0082] The wireless power transfer device **10** may also include a power source, such as a rechargeable battery (e.g., a lithium-ion battery pack) or non-rechargeable battery (e.g., a replaceable battery), or the wireless power transfer device **10** may be configured to couple to (e.g., connect to), and be powered from, an external power source, such an electrical outlet. In some embodiments, the wireless power transfer device **10** includes a rechargeable battery and a power management system. A charger profile of the rechargeable battery may be set to not perform trickle charging, and the rechargeable battery may be allowed to charge to a set percentage of battery state of charge (SoC) of the rechargeable battery, for example, a percentage within a range of about 80% to about 90% of the SoC. The SoC of the rechargeable battery may refer to the maximum charge that the rechargeable battery is able to store.

[0083] Referring to FIG. **6**A, which illustrates a wireless power transfer system according to some embodiments, the rechargeable battery of the wireless power transfer device **10** may be recharged through a power port or connector of the wireless power transfer device **10** that interfaces with a charging cradle **30**. The wireless power transfer device **10** may be configured to be placed in or fixed to the charging cradle **30**, and the wireless power transfer device **10** may be configured to detect the presence of a voltage at the power port or connector when it is placed in or fixed to the charging cradle **30**. In some embodiments, the wireless power transfer device **10** is configured to allow the rechargeable battery to charge when the detected voltage value is equal to a set value or within a set range.

[0084] Referring again to FIG. **1**, the driver **400** may include a first driver **410** to drive the first transmitting coil **100** and a second driver **420** to drive the second transmitting coil **200**. In some embodiments, each of the first and second drivers **410** and **420** include a class D MOSFET bridge module, and the first and second drivers **410** and **420** may be respectively coupled (e.g., connected) in series to the first and second wires **110** and **210** through a capacitor to create a series resonant tank circuit, which may be tuned to 125 KHz. At the tuned frequency, the circuit may have the lowest impedance and highest quality factor. In some embodiments, each of the first and second drivers **410** and **420** may include a half or full bridge MOSFET switch.

[0085] Each of the first and second drivers **410** and **420** may receive an independent digital output signal from a digital port of the controller **600**. Each of the digital output signals may be a driver signal, for example, a 125 KHz frequency, 50% duty cycle square wave. The two independent digital output signals may allow phase shifting between the first and second AC currents. However, the present disclosure is not limited thereto, and these quantities are provided as an example. In some embodiments, the first and second coils **100** and **200** may be driven with AC frequency within a range of about 1 kHz to 100 MHz (e.g., within a range of about 120 KHz to about 130 kHz). As the frequency at which the first and second coils **100** and **200** are operated increases, the efficiency of wireless charging of the electronic device **200** may increase because the quality factor increases when the frequency increases. The frequencies at which the first and second coils **100** and **200** are to be operated at may be limited by secondary effects, such as losses in the first and second cores **120** and **220** and the first and second wires **110** and **210** caused by skin and proximity effects. The frequencies at which the first and second coils **100** and **200** are to be operated at may be limited by regulations from governments and authorities, such as regulations from the Federal Communications Commission (FCC) and the international electrotechnical commission (IEC) regarding EM field strength and energy levels vs. frequency that create effective bands for operating for wireless charging systems.

[0086] Each of the first and second drivers **410** and **420** may include an isolation current sensor respectively coupled (e.g., connected) in series with the first and second wires **110** and **210**. The isolation current sensors may be configured to convert a current passing through the first and second drivers **410** and **420** into a proportional voltage which is rectified and signal conditioned. The signal may then be routed to an analog port of the controller **600** to be utilized as current feedback.

[0087] In some embodiments, the power modulation electronics **500** includes first power modulation electronics **510** and second power modulation electronics **520**. The first and second power modulation electronics **510** and **520** may be respectively configured to provide power to the first and second drivers **410** and **420**. The first and second power modulation electronics **510** and **520** may be independently controlled by respective analog output control signals received from the controller **600**. In some embodiments, each of the first and second power modulation electronics **510** and **520** includes a single-ended primary-inductor converter (SEPIC) DC-to-DC converter that is configured to step-up or step-down a system bus voltage received at an input and to output the stepped-up or stepped-down voltage.

[0088] Each of the first and second power modulation electronics **510** and **520** may be configured to monitor their respective output voltages and provide overcurrent protection. In some embodiments, the first and second power modulation electronics **510** and **520** are configured to attenuate their respective output voltages, filter their output voltages via a capacitor, and couple (e.g., connect) their output voltages to respective analog inputs of the controller **600**. For example, the first and second power modulation electronics **510** and **520** may be configured to provide their respective output voltages to the controller **600** as analog voltage feedback signals. The controller **600** may be configured to then provide respective digital signals to the first and second power modulation electronics **510** and **520** to enable or disable the first and second power modulation electronics **510** and **520** from providing power to the first and second drivers **410** and **420**.

[0089] In some embodiments, the controller **600** is a Bluetooth™ low energy system on chip controller (BLE SOC). The controller **600** may be programmed via a JTAG or USB-C connector. In some embodiments, the controller **600** is configured to provide two analog output control signals to the first and second power modulation electronics **510** and **520**, and the controller **600** is configured to receive two analog voltage feedback signals from the first and second power modulation electronics **510** and **520**, which are utilized to monitor and adjust output power and to detect supply faults. Furthermore, the controller **600** may be configured to provide two digital output signals to the first and second drivers **410** and **420** to drive the first and second transmitting coils **100** and **200**, and the controller **600** may be configured to provide two digital output signals to enable or disable the first and second power modulation electronics **510** and **520**. The two digital output signals may be wave pulses having a frequency and duty cycle, such as 125 kHz and 50% duty cycle.

[0090] The controller **600** may be configured to control the power output from each of the first and second drivers **410** and **420** by controlling the respective bus voltages of the first and second power modulation electronics **510** and **520**. The controller **600** may also be configured to control the phase difference between the first and second AC currents by changing a phase difference between the digital output signal pulse signals it provides to the first and second drivers **410** and **420**. Accordingly, by controlling the power of the first and second AC currents and the phase difference between the first and second AC currents, the controller **600** may control the direction and magnitude of the magnetic fields generated by the first and second transmitting coils **100** and **200**.

[0091] The wireless power transfer device **10** may be configured (e.g., via the controller **600**) to communicate various suitable information to the user. Such information may include information about charging of the wireless power transfer device **10**, information about charging of the electronic device **20**, and various faults (e.g., defects, overheating, etc.). More details regarding what information the wireless power transfer device **10** may communicate to the user will be described below with reference to FIGS. **17-22**. The wireless power transfer device **10** may communicate the information via any suitable means, for example, auditory signals, visual signals, and/or haptic feedback signals (e.g., vibrational signals). For example, referring to FIG. **6**A, the charger **10** may include a human interface circuit that includes a piezoelectric based speaker, a vibration motor, and/or an LED light configured to communicate information.

[0092] The electronic device **20** may be an implantable device (e.g., a device that is configured to be inserted in vivo). In some embodiments where the electronic device **20** is an implantable medical device, the electronic device **20** may include a casing **21** that encases the components of the electronic device **20**. In some embodiments, as shown in FIG. **7**A, the entire casing **21** may include a metallic material. In some other embodiments, as shown in FIG. **7**B, a first portion **21**A of the casing **21** may include a ceramic material and a second portion of **21**B of the casing **21** may include a metallic material. The first portion **21**A may cover the receiver coil **800**, and the second portion **21**B may cover the other components of the electronic device **20** (e.g., the detector **900** and the transmitter **1000**). The size and configuration of the first and second portions **21**A and **21**B may depend, for example, on the sizes, shapes, and relative positions of the receiver coil **800** and the other components of the electronic device **20**. In some embodiments, a portion of the casing **21** may include a plastic, an epoxy, and/or a polymer material.

[0093] The electronic device **20** is not limited to implantable devices or medical devices, and the electronic device **20** may be any suitable device configured to receive power and/or generate an electrical current via electromagnetic induction. In some embodiments, the electronic device **20** may be configured to store energy of the current generated in the receiver coil **800**, for example, in a capacitor. However, the present disclosure is not limited thereto, and the electronic device **20** may be configured in some embodiments to utilize the current without storing the energy of the current. For example, energy of the current generated in the receiver coil **800** may be utilized to drive or power other components in the electronic device **20**.

[0094] When the electronic device **20** is in the proximity of the wireless power transfer device **10**, and the wireless power transfer device **10** generates an oscillating magnetic field, a current may be generated in the receiver coil **800** by electromagnetic induction via the oscillating magnetic field. The receiver coil **800** may be, for example, a solenoid with a ferrimagnetic (e.g., soft ferrite) core.

[0095] The detector **900** may be electrically coupled (e.g., electrically connected) to the receiver coil **800** and configured to detect information about the current (e.g., the power or amplitude of the current) generated in the receiver coil **800**.

[0096] The transmitter **1000** may be to transmit the information detected by the detector **900** to the receiver **700** of the wireless power transfer device **10**, but the present disclosure is not limited thereto. The transmitter **1000** may be configured to transmit the information to any suitable receiver outside of the electronic device **20** that is able to receive the information transmitted by the transmitter **1000**. In some embodiments, the transmitter **1000** transmits information wirelessly, for example, via Bluetooth™ low energy (BLE).

[0097] Aligning the orientation of magnetic field at the receiver coil **800** with the receiver coil **800** increases the efficiency at which the wireless power transfer device **10** transfers power to the electronic device **20** compared to otherwise comparable wireless power transfer devices and receiver coils in which the magnetic field is misaligned. Accordingly, the wireless power transfer device **10** may rotate the magnetic field in order to align (e.g., optimally align) the magnetic field with the receiver coil **800**.

[0098] A feedback system that monitors (e.g., directly or indirectly monitors) the relative direction of the magnetic field at the receiver coil **800** may be utilized to align (or to enable an operator to align) the magnetic field with the receiver coil **800**. The feedback system may allow the wireless power transfer device **10** to automatically align the magnetic field with, or to create a magnetic field that is aligned with, the receiver coil **800** at the receiver coil **800** without requiring a user to manually adjust the position and/or orientation of the wireless power transfer device **10** after placing the wireless power transfer device **10** in proximity with the electronic device **20**. Two example feedback systems will now be described in more detail.

[0099] In a first feedback system, the wireless power transfer device **10** generates an initial magnetic field and rotates the initial magnetic field (e.g., in the manner described above with reference to FIG. **5**). For example, the initial magnetic field may be continuously rotated through a range of angles, or rotated through the range of angles via a plurality of steps changes in angle (e.g., 10 degrees). As the initial magnetic field is rotated, the detector **900** detects information (e.g., power or amplitude) of the current generated in the receiver coil **800**. The power received in the receiver coil **800** (e.g., the power of the current generated in the receiver coil **800**) may correlate with how aligned the initial magnetic field is with the receiver coil **800**. Accordingly, a maximum detected power may correspond to alignment (e.g., optimal alignment) between the initial magnetic field and the receiver coil **800**. The maximum detected power also indicates what values of the first amplitude, the second amplitude, and the relative phase between the first and second AC currents generate a magnetic field that will be aligned with the receiver coil **800**. After this information is obtained, the wireless power transfer device **10** may generate a magnetic field aligned with the receiver coil **800** to charge (or drive) the electronic device **20**.

[0100] In a second feedback system, load modulation may be utilized. Load modulation is described in Griffith, U.S. Pat. No. 9,962,085 and Finkenzeller, "Battery Powered Tags for ISO/IEC 14443, Actively Emulating Load Modulation," *RFID SysTech* 2011 *7th European Workshop on Smart Objects: Systems, Technologies and Applications* (2011), the entire content of each of which is incorporated herein by reference.

[0101] In the second feedback system, the wireless power transfer device **10** may generate an initial magnetic field and rotate the initial magnetic field (e.g., in the manner described above with reference to FIG. **5**). For example, the initial magnetic field may be continuously rotated through a range of angles, or rotated through the range of angles via a plurality of steps changes in angle (e.g., 10 degrees). The electronic device **20** may include a modulation resistance coupled (e.g., connected in parallel) to the receiver coil **800**, and the modulation resistance can be turned on and off to cause the receiver coil **800** to transmit a signal back to the wireless power transfer device **10** while the electronic device **20** receives power from the wireless power transfer device **10**. Information in the signal may be controlled or selected, for example, by the clock rate at which the modulation resistance is turned on and off. The signal may include information about how aligned (i.e., the degree or extent of alignment) the initial magnetic field is with the receiver coil **800**. The signal may be measured by a demodulator in the wireless power transfer device **10** that is coupled to one or both of the first and second transmitting coils **100** and **200**. The information in the signal may be utilized to determine what values of the first amplitude, the second amplitude, and the relative phase between the first and second AC currents generate a magnetic field that will be aligned with the receiver coil **800**. After this information is obtained, the wireless power transfer device **10** may generate a magnetic field that is aligned with the receiver coil **800** to charge (or drive) the electronic device **20**.

[0102] In some embodiments, the values of the first amplitude, the second amplitude, and the phase difference between the first and second AC currents that can generate a magnetic field that is aligned with the receiver coil **800** may be determined after the wireless power transfer device **10** rotates the magnetic field through a range of degrees (e.g., the wireless power transfer device **10** sweeps the magnetic field through a range of orientations), for example, a full 180° sweep (360° when taking into account the oscillating nature of the magnetic field), but the present disclosure is not limited thereto. For example, information regarding how aligned the initial magnetic field is with the receiver coil **800** may be continuously monitored, and the wireless power transfer device **10** (e.g., the controller **600** of the wireless power transfer device **10**) may stop the rotation when alignment (e.g., optimal alignment) between the initial magnetic field and the receiver coil **800** has been detected. The wireless power transfer device **10** may then charge (or drive) the electronic device **20**.

[0103] The wireless power transfer device **10** may be configured to transfer power to the electronic device **20** regardless of where the electronic device **20** is positioned relative to the wireless power transfer device **10**. For example, FIGS. **6**B and **6**C show schematic side views of the wireless power transfer device **10** and electronic device **20** of the wireless power transfer system of FIG. **6**A with the electronic device **20** in two different positions relative to the wireless power transfer device **10**. For example, FIGS. **6**B and **6**C show side views of a plane substantially defined by the first and second transmitting coils **100** and **200**. FIG. **6**B shows a non-limiting example where the wireless power transfer device **10** transfers power to the electronic device **20** while being positioned above (e.g., while an area of overlap between the first and second transmitting coils **100** and **200** is positioned above) the electronic device **20**. FIG. **6**C shows a non-limiting example where the wireless power transfer device **10** transfers power to the electronic device while the electronic device **20** is positioned at the side of the wireless power transfer device **10** (e.g., at the side of the first and second transmitting coils **100** and **200**).

[0104] Various modes of operating a wireless power transfer system will now be described in more detail with reference to FIGS. **8-13**. FIG. **8** illustrates an initialization mode; FIG. **9** illustrates an error mode; FIG. **10** illustrates a find the electronic device mode; FIG. **11** illustrates an optimize location mode; FIG. **12** illustrates an electronic device charging mode; and FIG. **13** illustrates a wireless power transfer device charging mode.

[0105] Referring to FIG. **8**, an Initialization mode may begin at stage S**100**. The initialization mode may begin, for example, when the wireless power transfer device **10** is placed in the charging cradle **30**, when a charge button is pressed, or when the wireless power transfer device **10** is trying to recover from a recoverable error. The charge button may be a button on the wireless power transfer device **10** that allows a user to initialize the wireless power transfer device **10** for charging the electronic device **20**.

[0106] At stage S**101**, the wireless power transfer device **10** may determine whether a voltage of an internal battery (e.g., a rechargeable battery) of the wireless power transfer device **10** is greater than or equal to a minimum voltage. When the voltage of the internal battery is less than the minimum voltage, then the wireless power transfer device **10** may repeat stage S**101**. However, when the voltage of the internal battery is greater than or equal to the minimum voltage, the wireless power transfer device **10** may initialize the system of the wireless power transfer device **10** at stage S**102**.

[0107] After the wireless power transfer device **10** is initialized at stage S**102**, the wireless power transfer device **10** may perform a power up self-test at stage S**103**. For example, the wireless power transfer device **10** may test for internal faults (e.g., defects) or errors during stage S**103**, and the wireless power transfer device **10** may begin an error mode at stage S**200** when the wireless power transfer device **10** detects an error such that the power up self-test fails. However, when at stage S**103** the power up self-test is passed, the wireless power transfer device **10** may measure a voltage of the internal battery at stage S**104** and communicate to the user the SoC of the internal battery at stage S**105**.

[0108] At stage S**106**, the wireless power transfer device **10** may determine whether the SoC of the internal battery is sufficient to charge (or drive) the electronic device **20**. When the SoC of the internal battery is insufficiently low, the wireless power transfer device **10** may alert the user at S**107** and proceed to stage S**108**. However, when at stage S**106** the SoC is determined to be sufficient, the wireless power transfer device **10** may determine whether the charge button has been pressed at stage S**108**.

[0109] When the charge button has been pressed, the wireless power transfer device **10** may determine whether it is in a self-charging mode at stage S**109**. When the wireless power transfer device **10** is not in the self-charging mode, then the wireless power transfer device **10** may begin the find electronic device mode at stage S**300**. However, when at stage S**109** the wireless power transfer device **10** is in the self-charging mode, the wireless power transfer device **10** may proceed to stage S**110**. Furthermore, when at stage S**108** it is determined that the charge button has not been pressed, the wireless power transfer device **10** may detect whether a power supply from the charging cradle **30** is available.

[0110] When the wireless power transfer device **10** detects the power supply from the charger cradle **30**, the wireless power transfer device **10** may begin the wireless power transfer device charging mode at stage S**600**. However, when at stage S**110** the wireless power transfer device **10** does not detect the power supply from the charger cradle **30**, the wireless power transfer device **10** may determine at stage S**111** whether a set (e.g., predetermined) amount of time has passed since a previous stage, for example, stage S**102** or stage S**103**.

[0111] When the wireless power transfer device **10** determines that the set amount of time has not elapsed, then the wireless power transfer device **10** may proceed to stage S**104**. However, when the set amount of time has elapsed, then the wireless power transfer device **10** may turn off at stage S**112**.

[0112] Referring to FIG. **9**, after the error mode begins at stage S**200**, the wireless power transfer device **10** may determine at stage S**201** whether it is able to recover from (e.g., resolve or remedy) the fault. When the wireless power transfer device **10** is able to recover from the fault, the wireless power transfer device **10** may begin the initialization mode at stage S**100**. However, when the wireless power transfer device **10** is unable to recover from the fault, the wireless power transfer device **10** may alert the user at stage S**202** that the wireless power transfer device **10** is unable to recover. The wireless power transfer device **10** may then end the error mode at stage S**203**. In some embodiments, the wireless power transfer device **10** may turn off at stage S**203**.

[0113] Referring to FIG. **10**, after the find electronic device mode begins at stage S**300**, the wireless power transfer device **10** may communicate to the user that the find electronic device mode has started. The wireless power transfer device **10** may drive the first and second transmitting coils **100** and **200** to generate and rotate an initial magnetic field at stage S**302**. At stage S**303**, the wireless power transfer device **10** may be placed at an initial position in approximate or estimated proximity to the electronic device **20**, and the wireless power transfer device **10** may be moved slowly around the initial position. At stage S**304**, the wireless power transfer device **10** may communicate information to the user regarding whether the electronic device **20** has been located, for example, by receiving a signal from the electronic device **20**, while the wireless power transfer device **10** is moved around the initial position.

[0114] The wireless power transfer device **10** may determine at stage S**305** whether the electronic device **20** has been located within a set amount of time, for example, from a previous stage such as S**303**. When the electronic device **20** has not been located when the set amount of time elapses, the wireless power transfer device **10** may stop driving the first and second transmitting coils **100** and **200** to terminate the initial magnetic field at stage S**306**. The wireless power transfer device **10** may then communicate to the user that the electronic device **20** was not found at stage S**307**, and the wireless power transfer device **10** may turn off at stage S**308**. However, when at stage S**305** the wireless power transfer device **10** determines within the set amount of time that the electronic device **20** has been found, then the wireless power transfer device **10** may communicate to the user that the electronic device **20** has been found at stage S**309**. The wireless power transfer device **10** may then begin an optimize location mode at stage S**400**.

[0115] Referring to FIG. **11**, after the optimize location mode begins at stage S**400** and at stage S**401**, the wireless power transfer device **10** may be slowly moved, for example, from a second position where the wireless power transfer device **10** was located when the electronic device **20** was found. The wireless power transfer device **10** may continuously communicate information to the user at stage S**402** while the wireless power transfer device **10** is being moved. The information communicated at stage S**402** may include whether the initial magnetic field is aligned with the receiver coil **800** and whether power delivered to the electronic device **20** is increasing or decreasing. The wireless power transfer device **10** may determine whether the initial magnetic field is aligned with the receiver coil **800** by utilizing a feedback system as described above.

[0116] At stage S**403**, the wireless power transfer device **10** may determine whether the initial magnetic field is aligned with the receiver coil **800**. When the initial magnetic field is not aligned, the wireless power transfer device **10** may rotate the initial magnetic field as needed (e.g., by utilizing a feedback system as described above) at stage S**404** to automatically align the initial magnetic field with the receiver coil **800**. However, when at stage S**403** the wireless power transfer device **10** determines that the initial magnetic field is aligned with the receiver coil **800**, then the wireless power transfer device **10** may determine at stage S**405** whether power delivered to the electronic device **20** is increasing as the wireless power transfer device **10** is moved. The wireless power transfer device **10** may then communicate to the user whether the wireless power transfer device **10** is being moved away from the electronic device **20** (stage S**406**) or toward the electronic device **20** (stage S**407**).

[0117] At stage S**408**, the wireless power transfer device **10** may determine whether the receiver coil **800** is saturated. Saturation of the receiver coil **800** may occur when an increase in magnitude of the initial magnetic field at the receiver coil **800** does not significantly increase the magnetization of the core material (e.g., ferrimagnetic material) of the receiver coil **800**. When it is determined that the receiver coil **800** is saturated, the first and second amplitudes of the first and second currents utilized to generate the initial magnetic field may be reduced at stage S**409**, and the wireless power transfer device **10** may again determine whether the receiver coil **800** is saturated at stage S**408**. However, when at stage S**408** it is determined that the receiver coil **800** is not saturated, the wireless power transfer device **10** may determine whether the wireless power transfer device **10** is at an optimal position and/or orientation at stage S**410**. The optimal position and/or orientation may correspond to a position and/or orientation of the wireless power transfer device **10** that results in a maximum power received in the receiver coil at set amplitudes of the first and second AC currents that do not saturate the receiver coil **800**.

[0118] When it is determined that the wireless power transfer device **10** is at an optimal position and/or orientation, the wireless power transfer device **10** may communicate to the user to stop moving the wireless power transfer device **10** at stage S**411**, and the wireless power transfer device **10** may begin the electronic device charging mode at stage S**500**. However, when at stage S**410** it is determined that the wireless power transfer device **10** is not at an optimal position and/or orientation, the wireless power transfer device **10** may conduct a test to detect faults at stage S**412**. When a fault is detected, the wireless power transfer device **10** may begin the error mode at stage S**200**. However, when no faults are detected, the wireless power transfer device **10** may determine whether information from the electronic device **20** is still being received at stage S**413**.

[0119] When information from the electronic device **20** is still being received, the user may continue to move the wireless power transfer device **10** at stage S**401**. For example, the wireless power transfer device **10** may prompt the user to continue to move the wireless power transfer device **10**. However, when at stage S**413** the wireless power transfer device **10** determines that information is not being received from the electronic device **20**, the wireless power transfer device **10** may communicate to the user at stage S**414** that the electronic device **20** has been lost, and the wireless power transfer device **10** may begin the find electronic device mode at stage S**300**.

[0120] Referring to FIG. **12**, after the electronic device charging mode begins at stage S**500**, information from the electronic device **20** may be continuously received and monitored at stage S**501**, and the wireless power transfer device **10** may communicate information about the electronic device **20** (e.g., SoC of a battery or of an energy storage in the electronic device **20**) to the user at stage S**502**.

[0121] At stage S**503**, the wireless power transfer device **10** may determine whether the electronic device **20** has reached a set SoC of the electronic device **20**. For example, the wireless power transfer device **10** may determine whether the electronic device **20** has reached a fully charged state. When the electronic device **20** has reached the set SoC, the wireless power transfer device **10** may stop driving the first and second transmitting coils **100** and **200** at stage S**504** to terminate the magnetic field generated by the wireless power transfer device **10**. The wireless power transfer device **10** may then communicate to the user that the charge is complete at stage S**505** before turning off at stage S**506**.

[0122] However, when at stage S**503** the wireless power transfer device **10** determines that the set SoC of the electronic device **20** has not been reached, it may regulate power transmission to the electronic device **20** at stage S**507**. For example, the wireless power transfer device **10** may change the amplitudes of the first and second AC currents to reduce or increase the power provided to the electronic device **20**.

[0123] At stage S**508**, the wireless power transfer device **10** may determine whether transmission power is at or above a set or predetermined threshold. When the transmission power is at or above the set or predetermined threshold, the wireless power transfer device **10** may turn off the first and second transmitting coils **100** and **200** at stage S**509** to terminate the magnetic field. The wireless power transfer device **10** may then communicate to the user that the electronic device **20** has been lost at stage S**510** and begin the find electronic device mode at stage S**300**.

[0124] However, when at stage S**508** the wireless power transfer device **10** determines that the transmission power is below the set or predetermined threshold, then the wireless power transfer device **10** may determine whether any faults have occurred in the wireless power transfer device **10** and/or in the electronic device **20** at stage S**511**. When a fault is detected, the wireless power transfer device **10** may turn off the first and second transmitting coils **100** and **200** at stage S**512**. The wireless power transfer device **10** may then communicate to the user that a fault has been found and begin the error mode at stage S**200**.

[0125] However, when at stage S**511** the wireless power transfer device **10** does not detect any faults, the wireless power transfer device **10** may proceed to stage S**501** and continue to receive and monitor information received from the electronic device **20**.

[0126] Referring to FIG. **13**, the wireless power transfer device **10** may begin charging an internal battery via a power supply provided by the charging cradle **30** at stage S**600** of the wireless power transfer device charging mode. The wireless power transfer device **10** may determine a SoC of the internal battery at stage S**601** and communicate the SoC to the user at stage S**602**. At stage S**603**, the wireless power transfer device **10** may determine whether a set SoC of the internal battery has been reached. For example, the wireless power transfer device **10** may determine whether the internal battery has been fully charged.

[0127] When the wireless power transfer device **10** determines that the set SoC of the internal battery has been reached, the wireless power transfer device **10** may stop charging the internal battery at stage S**604**, communicate to the user that the charging process is complete at stage S**605**, and turn off at stage S**606**.

[0128] However, when at stage S**603** the wireless power transfer device **10** determines that the internal battery has not reached the set SoC, the wireless power transfer device **10** may determine whether the wireless power transfer device **10** is still coupled to (e.g., on or in) the charger cradle **30** and receiving power from the charger cradle **30**. When the wireless power transfer device **10** is not coupled to the charger cradle **30** or not receiving power from the charger cradle **30**, the wireless power transfer device **10** may stop charging the internal battery at stage S**608**, communicate to the user that the charging process has stopped at stage S**609**, and begin the error mode at stage S**200**.

[0129] However, when at stage S**607** the wireless power transfer device **10** determines that the wireless power transfer device **10** is coupled to the charger cradle **30** and is receiving power from the charger cradle **30**, the wireless power transfer device **10** may continue to charge the internal battery at stage S**610**. At stage S**611**, the wireless power transfer device **10** may determine whether faults have occurred in the wireless power transfer device **10** and/or in the internal battery at stage S**611**. When a fault is detected, the wireless power transfer device **10** may stop the charging process at stage S**612**, communicate to the client that the charging process has stopped at stage S**613**, and begin the error mode at stage S**200**.

[0130] However, when at stage S**611** the wireless power transfer device **10** does not detect any faults, the wireless power transfer device **10** may proceed to stage S**601** to determine the SoC of the internal battery.

[0131] FIG. **14** shows a schematic view of a wireless power transfer system according to some embodiments. FIG. **15** shows a schematic view of a wireless power transfer system according to some embodiments. FIG. **16** shows a cross-sectional partial view of the cable illustrated in FIG. **15**.

[0132] Referring to FIGS. **1** and **14**-**16**, the wireless power transfer device **10** may include a coil assembly **14** and an electronics assembly **16** spaced apart from the coil assembly **14**. The coil assembly **14** includes the first transmitting coil **100**, the second transmitting coil **200**, and the non-magnetic material in the intermediate space **300***a*, and the electronics assembly **16** may include one or more electronic components **17** of the wireless power transfer device **10**. By including the electronic components **17** in the electronics assembly **16** and spacing the electronics assembly **16** apart from the coil assembly **14**, negative interactions between the electronic components **17** and a magnetic field generated by the first and second transmitting coils **100** and **200** may be reduced or minimized, as explained in more detail below.

[0133] The coil assembly **14** may include one or more electronic components (see **55** in FIG. **22**A). The electronic components of the coil assembly **14** and the electronic components of the electronics assembly **16** may each include active electronic components and/or passive electronic components. Active electronic components may refer to electronic components that require a source of energy (e.g., a current) to perform their function, and passive electronic components may refer to electronic components that are able to influence the flow of electricity running through them. Active electronic components may include, for example, transistors and diodes, and passive electronic components may include, for example, resistors, capacitors, inductors, and transducers.

[0134] In some embodiments, the electronic components in the coil assembly **14** may include circuit elements of one or more LC resonant circuits and/or circuit elements of one or more current sensors. For example, the coil assembly **14** may include one or more transistors, one or more resistors, one or more capacitors, one or more inductors, one or more transformers, one or more diodes, one or more transducers, etc.

[0135] The electronics assembly **16** may include a battery **18**, which may be a permanent or rechargeable battery. In some embodiments, the electronics components **17** of the electronics assembly **16** include the first and second drivers **410** and **420**, the first and second power modulation electronics **510** and **520**, the controller **600**, the receiver **700**, and/or other circuit elements (e.g., circuit elements of one or more LC resonant circuits and/or circuit elements of one or more current sensing circuits).

[0136] The components of the coil assembly **14** may be housed in a coil assembly container **14**C that partially or entirely surrounds or encloses the components of the coil assembly **14** and that includes any suitable material such as plastic, glass, metal, etc.

[0137] The components of the electronics assembly **16** may be housed in an electronics assembly container **16**C that partially or entirely surrounds or encloses the components of the electronics assembly **16** and that includes any suitable material such as plastic, glass, metal, etc.

[0138] The electronics assembly **16** may be spaced apart from the coil assembly **14** by a set distance in order to decrease the negative interactions between the electronic components **17** in the electronics assembly **16** and the magnetic field generated by the first and second transmitting coils **100** and **200**. The electronic components **17** may convert energy from the magnetic field into eddy currents, which may reduce the efficiency of the wireless power transfer device **10** to wirelessly transfer energy to the electronic device **20**, thereby requiring a larger power supply and a larger battery (e.g., battery **18**). The eddy currents created in the electronic components **17** will also generate magnetic fields, which may distort the magnetic field generated by the first and second transmitting coils **100** and **200** at the electronic device **20**, and thus, may reduce the accuracy of the wireless power transfer device's alignment of the magnetic field generated by the first and second transmitting coils **100** and **200** with the electronic device **20** at the electronic device **20**. At least some of the energy of the eddy currents in the electronic components **17** will be dissipated as heat in regions around the electronic components **17**, thereby increasing the temperature of the electronic components **17** and reducing their efficiency, thus requiring a larger power supply and a larger battery (e.g., battery **18**).

[0139] The above-described negative interactions between electronic components **17** and the magnetic field generated by the first and second transmitting coils **100** and **200** may be reduced by including the electronic components **17** in the electronics assembly **16** and spacing the electronics assembly **16** apart from the coil assembly **14** by a set distance. Because the magnetic field generated by the first and second transmitting coils **100** and **200** will generally decrease in magnitude as distance from the first and second transmitting coils **100** and **200** increases, increasing the set distance between the electronics assembly **16** and the coil assembly **14** will reduce the above-described negative interactions.

[0140] Referring to FIG. **14**, the coil assembly **14** and the electronics assembly **16** may be in a housing container **12** and spaced apart from each other in the housing container **12** by a first distance D**1**. The first distance D**1** may be a smallest distance between the coil assembly **14** and the electronics assembly **16**. The housing container **12** may include any suitable material, such as plastic, glass, etc.

[0141] The housing container **12** may partially or entirely surround the coil assembly **14** and the electronics assembly **16**. The coil assembly **14** and the electronics assembly **16** may be set or fixed in respective regions within the housing container **12** by any suitable means. For example, the coil assembly **14** and the electronics assembly **16** may each be attached to a wall of the housing container **12** by an adhesive. In some embodiments, the coil assembly **14** and the electronics assembly **16** may each be integrated with the housing container **12**.

[0142] In some embodiments, the coil assembly container **14**C and/or the electronics assembly container **16**C is not provided, and the components of the coil assembly **14** are spaced apart from the components of the electronics assembly **16** in the housing container **12** with or without a shielding material (e.g., a shielding layer) provided between the components of the coil assembly **14** and the components of the electronics assembly **16**. The shielding material may include any suitable material such as a metal (e.g., steel, copper, brass, nickel, silver, and/or tin) and/or a nonmagnetic material. One or more wires may be provided to electrically couple the components of the electronics assembly **16** to the components of the coil assembly **14**.

[0143] The first distance D1 may be a distance that suitably or desirably reduces interactions between the electronic components **17** in the electronics assembly **16** and the magnetic field generated by the first and second transmitting coils **100** and **200**. Factors that may affect the distance D**1** may include the length of the first transmitting coil **100**, the length of the second transmitting coil **200**, and/or the number, arrangement, and materials of the electronic components **17** in the electronics assembly **16**. In some embodiments, the first distance D**1** may be greater than or equal to 0.25, 0.5, 0.75, 1.0, 1.5, or 2.0 times a length of the first transmitting coil **100** along the first axis **100**A and/or a length of the second transmitting coil **200** along the second axis **200**A.

[0144] Although interaction between the electronic components **17** in the electronics assembly **16** and the magnetic field generated by the first and second transmitting coils **100** and **200** may be reduced by spacing the electronics assembly **16** away from the coil assembly **14**, some such interaction may be unavoidable. However, a shape of a collective magnetic field (i.e., a magnetic field defined as a superposition of the magnetic fields) generated by the eddy currents in the electronic components **17** of the electronics assembly **16** in response to the magnetic field generated by the first and second transmitting coils **100** and **200** is determined at least in part by the configuration of the electronic components **17** (e.g., the position and/or orientation of the electronic components **17** relative to each other) in the electronics assembly **16**.

[0145] The configuration of the electronic components **17** of the electronics assembly **16** may be a balanced configuration such that the magnitude of the collective magnetic field at the electronic device **20** is substantially reduced or minimized compared to other configurations and/or such that alignment between the direction of the collective magnetic field and the magnetic field generated by the first and second transmitting coils **100** and **200** at the electronic device **20** is increased or maximized compared to other configurations (e.g., compared to 85%, 87%, 90%, 93%, 95%, 97%, or 99% of all potential configurations of the electronic components **17**). A balanced configuration of the electronic components **17** in the electronics assembly **16** may reduce or eliminate distortion in the direction of the magnetic field generated by the first and second transmitting coils **100** and **200** at the electronic device **20**.

[0146] Referring to FIG. **15**, the electronics assembly **16** may be electrically coupled to the coil assembly **14** by a cable (or board) **40**. The cable **40** may include one or more internal wires electrically coupled between electronic components **17** in the electronics assembly **16** and electronic components in the coil assembly **14** to allow signals to be transmitted between the electronic components **17** in the electronics assembly **16** and the electronic components in the coil assembly **14**.

[0147] A length of the cable **40** may be any length that suitably or desirably reduces interactions between the electronic components **17** in the electronics assembly **16** and the magnetic field generated by the first and second transmitting coils **100** and **200**. Factors that may affect the length of the cable **40** may include the length of the first transmitting coil **100**, the length of the second transmitting coil **200**, and/or the number, arrangement, and materials of the electronic components **17** in the electronics assembly **16**. In some embodiments, the first distance D**1** may be greater than or equal to 0.5, 0.75, 1.0, 1.5, 2.0, 5.0, or 10.0 times the length of the first transmitting coil **100** along the first axis **100**A and/or of the second transmitting coil **200** along the second axis **200**A.

[0148] The cable **40** may include a first connector **41** at a first end of the cable **40** configured to couple and decouple the first end of the cable **40** to the coil assembly **14**, or the first end of the cable **40** may be permanently coupled to the coil assembly **14**. The cable **40** may include a second connector **42** at a second end of the cable **40** configured to couple and decouple the second end of the cable **40** to the electronics assembly **16**, or the second end of the cable **40** may be permanently coupled to the electronics assembly **16**. The first connector **41** and/or the second connector **42** may be lockable connectors. A lockable connector may refer to a connector that includes a locking mechanism generally known or available in the art that, when the connector is coupled to an assembly (e.g., the coil assembly **14** or the electronics assembly **16**) and the locking mechanism is locked, prevents the connector from being decoupled from the assembly by a pulling force less than a threshold amount. The lockability of a connector provides a safety feature to reduce the risk of disconnection between the electronics assembly **16** and the coil assembly **14**, for example, when the wireless power transfer device **10** is in use.

[0149] Referring to FIG. **16**, the one or more internal wires in the cable **40** may include a first twisted pair of wires **44** including two wires, each electrically coupled to the first driver **410** at one end and electrically coupled to respective ends of the first wire **110** of the first transmitting coil **100** at another end. Accordingly, the first twisted pair of wires **44** may provide the first AC current to the first wire **110**. The internal wires in the cable **40** may also include a second twisted pair of wires including two wires, each electrically coupled to the second driver **420** at one end and electrically coupled to respective ends of the second wire **210** of the second transmitting coil **200** at another end. Accordingly, the second twisted pair of wires may provide the second AC current to the second wire **210**.

[0150] The internal wires may include a third twisted pair of wires **45** including two wires to respectively provide information about currents in the first and second wires **110** and **210** from the coil assembly **14** to the electronics assembly **16**. In some embodiments, one of the two wires of the third twisted pair of wires **45** may have one end electrically coupled to the first wire **110** or to a current sensing circuit configured to measure or sense current in the first wire **110**, and another end electrically coupled to the controller **600**. Another one of the two wires of the third twisted pair of wires **45** may have one end electrically coupled to the second wire **210** or to a current sensing circuit configured to measure or sense current in the second wire **210**, and another end electrically coupled to the controller **600**.

[0151] The information about the currents in the first and second transmitting coils **100** and **200** that is provided via the third twisted pair of wires **45** may be utilized in a feedback system as described herein, for example, the second feedback system that utilizes load modulation. For example, the information about the currents in the first and second transmitting coils **100** and **200** may include and/or correspond to information in the signal transmitted from the receiver coil **800** to the wireless power transfer device **10** as described herein.

[0152] In some embodiments, at least one (e.g., all) of the one or more internal wires in the cable **40** is a shielded wire coated in a shielding material (e.g., braided copper or metallic coating). In some embodiments, a set of wires of the one or more internal wires may also be collectively shielded. For example, each of the two wires of the first twisted pair of wires **44** may be partially or entirely surrounded (e.g., coated) by a shielding material, and an additional shielding layer may partially or entirely surround (e.g., coat) both of the two wires of the first twisted pair of wires **44**. Thus, the two wires of the first twisted pair of wires may be at least double shielded by the shielding material surrounding the two wires individually and by another shielding material surrounding the two wires collectively. In some embodiments, the internal wires may include Litz wire.

[0153] The cable **40** may include a sheath **43** as an outermost layer that partially or entirely encloses the one or more internal wires. The sheath **43** may include a shielding material.

[0154] FIG. **17** shows a possible placement of an electronic device in a user. FIG. **18** shows a possible placement of a wireless power transfer device on the user of FIG. **17**. FIG. **19** shows another possible placement of an electronics device in a user. FIGS. **20** and **21** show a possible placement of the wireless power transfer device on the user of FIG. **19**.

[0155] Referring to FIGS. **17-21**, electrically and manually coupling the electronics assembly **16** to the coil assembly **14** with the cable **40** increases the freedom that a user has to place the wireless power transfer device **10**.

[0156] As shown in FIG. **17**, the electronic device **20** may include a stimulator **33** (e.g., an electrode to provide stimulation to biological tissue). FIG. **17** shows a possible placement of the electronic device **20** in a user (e.g., in an upper torso region), and FIG. **18** illustrates how the cable **40** may allow the user to control placement of the coil assembly **14** in proximity with the electronic device **20** and space the electronics assembly **16** away from the coil assembly **14**. For example, the user may wrap the cable **40** around his or her neck to allow the coil assembly **14** to be in proximity with the electronic device **20** at the left side of his or her chest and to allow the electronics assembly **16** to be at the right side of his or her chest.

[0157] FIG. **19** shows another possible placement of the electronic device **20** in a user (e.g., a lower torso region), and FIGS. **20** and **21** illustrate how the cable **40** may allow the user to control placement of the coil assembly **14** in proximity with the electronic device **20** and space the electronics assembly **16** away from the coil assembly **14**. For example, the user may wrap the cable around the right or left side of his or her torso to allow the coil assembly **14** to be in proximity with the electronic device **20** at a front side of the user's lower torso and to allow the electronics assembly **16** to be at the back side of the user's lower torso. In some embodiments, the coil assembly **14** and the electronics assembly **16** may be attachable to a belt **34** configured to allow the coil assembly **14** and the electronics assembly to be attached or secured thereto. In some embodiments, the electronics assembly **16** may include a display to provide an interface with the wireless power transfer system.

[0158] FIG. **22**A shows a plan view of a coil assembly according to some embodiments. FIG. **22**B shows a perspective view of a magnetic field shallow zone of FIG. **22**A according to some embodiments. FIG. **23** shows a side view of the first and second transmitting coils according to some embodiments. FIG. **24** shows a plan view of the first and second transmitting coils and a graph of a magnitude of the magnetic field along line A-B generated by the first and second transmitting coils when the first and second transmitting coils are driven with AC currents that are in-phase and of a same amplitude, according to some embodiments. FIG. **25** shows a plan view of the first and second transmitting coils and a graph of a magnitude of the magnetic field along line C-D generated by the first and second transmitting coils when the first and second transmitting coils are driven with AC currents that are in-phase and of a same amplitude, according to some embodiments. FIG. **26** shows a plan view of the first and second transmitting coils and a graph of a magnitude of the magnetic field along line E-F generated by the first and second transmitting coils when the first transmitting coil is driven with AC current and the second transmitting coil is not driven, according to some embodiments. FIG. **27** shows a plan view of the first and second transmitting coils and a graph of a magnitude of the magnetic field along line G-H generated by the first and second transmitting coils when the first transmitting coil is driven with AC current and the second transmitting coil is not driven, according to some embodiments.

[0159] Referring to FIGS. **22**A-**27**, at least one electronic component **55** may be included in the coil assembly **14** and positioned in a magnetic field shallow zone. The electronic components **55** may include active electronic components and/or passive electronic components. The electronic components **55** may include electronic components to drive the first and second transmitting coils **100** and **200**, electronic components of one or more LC resonant circuits, electronic components of a feedback system, and/or electronic components utilized to align a magnetic field generated by the first and second transmitting coils **100** and **200** with the electronic device **20**.

[0160] As explained herein, negative interactions between the electronic components **55** and the magnetic field generated by the first and second transmitting coils **100** and **200** may occur, and the severity of these negative interactions is generally proportional to the magnetic flux of the magnetic field through surfaces of the electronic components **55**. The magnetic flux through a surface of the electronic components **55** generally increases as the magnitude of the magnetic field at the surface increases and as the angle between the surface and the magnetic field at the surface gets closer to 90 degrees. Accordingly, it is desirable to position and/or orient the electronic components **55** in the coil assembly **14** to reduce the magnitude of the magnetic field at surfaces of the electronic components **55** and/or to decrease the angle between the surfaces and the magnetic field at the surfaces.

[0161] One or more magnetic field shallow zones may exist near the first and second transmitting coils **100** and **200**, where a magnitude of a magnetic field generated by the first and second transmitting coils **100** and **200** is relatively low and/or substantially reduced, and where one or more of the electronic components **55** may be positioned in the magnetic field shallow zones to reduce or minimize the negative interactions between the electronic components and the magnetic field.

[0162] Referring to FIG. **22**A, the first and second transmitting coils **100** and **200** may cross each other in a plan view at the area of overlap **300**, and the magnetic field shallow zones may be positioned in a plan view angularly between the first transmitting coil **100** and the second transmitting coil **200**.

[0163] For example, the first transmitting coil **100** may include a first portion **130** extending in the plan view from the area of overlap **300** (e.g., from a first side of the area of overlap **300**) and a second portion **140** extending in the plan view from the area of overlap **300** (e.g., from a second side of the area of overlap **300** opposite to the first side), and the second transmitting coil **200** may include a first portion **230** extending in the plan view from the area of overlap **300** (e.g., from a third side of the area of overlap **300**) and a second portion **240** extending in the plan view from the area of overlap **300** (e.g., from a fourth side of the area of overlap **300** opposite to the third side). In some embodiments, the area of overlap **300** may form a square or rectangle shape in the plan view defined by the first side, the second side, the third side, and the fourth side of the area of overlap **300**.

[0164] A first magnetic field shallow zone **51** may be positioned in the plan view angularly between the first portion **130** and the first portion **230**, a second magnetic field shallow zone **52** may be positioned in the plan view angularly between the second portion **140** and the first portion **230**, a third magnetic field shallow zone **53** may be positioned in the plan view between the second portion **140** and the second portion **240**, and a fourth magnetic field shallow zone **54** may be positioned in the plan view angularly between the first portion **130** and the second portion **240**.

[0165] The magnetic field shallow zones may all be the same or similar in geometric shape, or one or more magnetic field shallow zones may be different in shape compared to one or more of the remaining magnetic field shallow zones.

[0166] In some embodiments, the first magnetic field shallow zone **51** may have a planar shape in the plan view of a rectangle (e.g., a square) or of a sector of a circle, ellipse, or egg shape. The planar shape may correspond to a top surface and/or bottom surface of the first magnetic field shallow zone **51**. When the planar shape is a sector, the sector may span an angle ranging from about 15 degrees to about 165 degrees, about 45 degrees to about 135 degrees, about 88 degrees to about 92 degrees, 89 degrees to 91 degrees, or about 90 degrees. Two straight sides of the sector may be generally parallel to, and/or adjacent to, sidewalls of the first and second portions **130** and **230** that face the first magnetic field shallow zone **51**. The corner of the sector where the two straight sides cross may be at or near, or may correspond to, a corner in the plan view where the sidewalls of the first and second portions **130** and **230** that face toward the first magnetic field shallow zone **51** cross. The two straight sides of the sector may have lengths respectively equal to or less than the sidewalls of the first and second portions **130** and **230** that face the first magnetic field shallow zone **51**. In some embodiments, the planar shape of the first magnetic field shallow zone **51** is a sector of a circle having a radius equal to or less than the length of the first portion **130** and/or of the first portion **230**. For example, the radius may be equal to or less than a distance between a first point along the first axis **100**A corresponding to an end of the first transmitting coil **100** and a second point along the first axis **100**A corresponding to the first side of the area of overlap **300**.

[0167] In some embodiments, the planar shape of the first magnetic field shallow zone **51** is a rectangle, and two crossing sides of the rectangle and the corner of the rectangle where the two crossing sides cross may have features the same as or similar to the features described herein of the two straight sides of the sector and of the corner of the sector where the two straight sides of the sector cross.

[0168] The first magnetic field shallow zone **51** may have a thickness in a thickness direction (e.g., the Z-direction, as shown in FIG. **22**A) perpendicular to the plan view (e.g., the X-Y plane, as shown in FIG. **22**A), and the thickness of the first magnetic field shallow zone **51** may be uniform or variable over the planar shape of the first magnetic field shallow zone **51**. In some embodiments, the thickness of the first magnetic field shallow zone **51** may be equal to or less than a largest or smallest distance in the thickness direction between a top side of a topmost one of the first and second transmitting coils **100** and **200** and a bottom side of another one of the first and second transmitting coils **100** and **200**, for example, equal to or less than 0.5, 0.25, 0.10, 0.05, or 0.01 times any such thickness. In some examples, the thickness of the first magnetic field shallow zone **51** may be equal to or less than a largest, smallest, or average thickness of the first transmitting coil **100** or of the second transmitting coil **200**, for example, equal to or less than 0.5, 0.25, 0.10, 0.05, or 0.01 times any such thickness.

[0169] The first magnetic field shallow zone **51** may be positioned along the thickness direction between the first and second transmitting coils **100** and **200** (e.g., between a top surface of a topmost one of the first and second transmitting coils **100** and **200** and a bottom surface of another one of the first and second transmitting coils **100** and **200**).

[0170] Referring to FIG. **23**, a plane **58** parallel to the plan view (e.g., parallel to the X-Y plane) may extend between the first and second transmitting coils **100** and **200**, for example, between a bottom surface of a topmost one of the first and second transmitting coils **100** and **200** and a top surface of another one of the first and second transmitting coils **100** and **200**. In some embodiments, the plane **58** may extend through the intermediate space **300***a*. In some embodiments, the plane **58** may extend through (e.g., intersect) a point equidistant in the thickness direction between the first and second transmitting coils **100** and **200** (e.g., equidistant between geometric centers of the first and second transmitting coils **100** and **200**) or a point corresponding to a center (e.g., a geometric center) of the intermediate space **300***a*, and the first magnetic field shallow zone **51** may be centered in the thickness direction on the plane **58**.

[0171] In some embodiments, the first magnetic field shallow zone **51** may include (e.g., be) a region where a magnitude of a magnetic field generated by the first and second transmitting coils **100** and **200** is lower than a set or threshold value.

[0172] In more detail, the first and second portions **130** and **140** of the first transmitting coil **100** may respectively include a first and second end of the first transmitting coil **100**, and the first and second portions **230** and **240** of the second transmitting coil **200** may respectively include a first and second end of the second transmitting coil **200**. For example, the first and second ends of the first transmitting coil **100** may correspond to the two first thick portions **120***b* (see FIG. **2**) of the first transmitting coil **100**, and the first and second ends of the second transmitting coil **200** may correspond to the two second thick portions **220***b* (see FIG. **2**) of the second transmitting coil **200**.

[0173] In some embodiments, the first magnetic field shallow zone **51** may include (e.g., be) a region where, when the first and second transmitting coils are driven with in-phase AC currents of a same magnitude, a first ratio of a first magnitude of a magnetic field at any point in the region to a second magnitude of a magnetic field at the first end of the first transmitting coil **100** (e.g., just inside the first rod **120** at a first end of the first rod **120**) is less than a set value such as 0.30, 0.25, 0.20, 0.15, 0.10, 0.08, 0.05, 0.03, or 0.01. The first and second magnitudes may each be instantaneous magnitudes at a same point in time or may be magnitudes that are time-averaged over a set time span. The time span may be one or more periods (e.g., 1, 2, 5, 10, 20, 50, 100, or 1,000 periods) of the first AC current and/or the second AC current. In some embodiments, the time span is within a range of 0.01 second to 10 minutes.

[0174] The graph of FIG. **24** shows that, when the first and second transmitting coils **100** and **200** are driven with AC currents of a same magnitude and the first and second transmitting coils **100** and **200** are surrounded by air, the magnitude of the magnetic field generated by the first and second transmitting coils **100** and **200** is substantially reduced at portions of the line A-B outside of the first and second rods **120** and **220** and angularly between the first and second transmitting coils **100** and **200** compared to at and in end portions of the first and second rods **120** and **220**. Referring to FIGS. **24** and **25**, the graph of FIG. **25** shows that, when the first and second transmitting coils **100** and **200** are driven with AC currents of a same magnitude and the first and second transmitting coils **100** and **200** are surrounded by air, the magnitude of the magnetic field generated by the first and second transmitting coils **100** and **200** is substantially less along the line C-D angularly between the first and second transmitting coils **100** and **200** compared to at and in the end portions of the first and second rods **120** and **220**.

[0175] In theory, when the first and second transmitting coils **100** and **200** are driven with in-phase AC currents of the same amplitude, there may be one or more isolated points in time over a period of the first AC current and/or the second AC current when the first and second transmitting coils **100** and **200** cease to generate magnetic fields, and the first ratio is undefined because the denominator is zero. However, it is to be understood that, when the first and second magnitudes of the first ratio are instantaneous magnitudes, the first and second magnitudes are magnitudes at a point of time different than points in time in which the first ratio may be undefined. It is to also be understood that when the first and second magnitudes of the first ratio are time-averaged magnitudes, the time-average does not include the first and second magnitudes at the isolated points in time where the first ratio may be undefined.

[0176] Because the magnetic field generated by the first and second transmitting coils **100** and **200** generally decreases as the distance from the first and second transmitting coils **100** and **200** increases, it will be understood that the region where the first ratio is below the set value may be further confined (e.g., truncated) by a shallow zone confinement region including all points that are (i) angularly between the first portions **130** and **230** in the plan view, and

(ii) positioned in the thickness direction between a top surface of a topmost one of the first and second transmitting coils **100** and **200** and a bottom surface of another one of the first and second transmitting coils **100** and **200**.

[0177] In some embodiments, the first magnetic field shallow zone **51** may include (e.g., be) a region where, when one of the first and second transmitting coils **100** and **200** is driven with AC current and another one of the first and second transmitting coils **100** and **200** is not driven, a second ratio of a first magnitude of a magnetic field at any point in the region to a second magnitude of a magnetic field at an end of the one of the first and second transmitting coils **100** and **200** (e.g., just inside the rod at an end of the rod of the one of the first and second transmitting coils **100** and **200**) is less than a set value such as 0.30, 0.25, 0.20, 0.15, 0.10, 0.08, 0.05, 0.03, or 0.01. The first and second magnitudes may each be instantaneous magnitudes at a same point in time or may be magnitudes that are time-averaged over a set time span, as described herein. The graph of FIG. **26** shows that, when the second transmitting coil **200** is driven with AC current and the first transmitting coil **100** is not driven, and the first and second transmitting coils **100** and **200** are surrounded by air, the magnitude of the magnetic field generated by the first and second transmitting coils **100** and **200** is substantially reduced at portions of the line E-F outside of the first and second rods **120** and **220** and angularly between the first and second transmitting coils **100** and **200** compared to at and in an end portion of the second rod **220**. Referring to FIGS. **26-27**, the graph of FIG. **27** shows that, when the second transmitting coil **200** is driven with AC current and the first transmitting coil **100** is not driven, and the first and second transmitting coils **100** and **200** are surrounded by air, the magnitude of the magnetic field generated by the first and second transmitting coils **100** and **200** is substantially less along the line G-H angularly between the first and second transmitting coils **100** and **200** compared to at and in the end portion of the second rod **220**.

[0178] In some embodiments, the first magnetic field shallow zone **51** may include a portion of a low-angle magnetic field plane that is parallel to the plan view (e.g., parallel to the X-Y plane) and between the first and second transmitting coils **100** and **200**, where an angle between a magnetic field generated by the first and second transmitting coils **100** and **200** at the low-angle magnetic field plane to the low-angle magnetic field plane is less than a set angle such as 20 degrees, 15 degrees, 10 degrees, or 5 degrees. In some embodiments, the low-angle magnetic field plane is the plane **58**. One or more of the electronic components **55** may be at the low-angle magnetic field plane, for example, may intersect the low-angle magnetic field plane or be spaced apart from the low-angle magnetic field plane in the thickness direction by less than a set distance. In some embodiments, the set distance may be a largest, smallest, or average thickness of the first transmitting coil **100** or 0.5, 0.25, 0.20, 0.15, 0.10, or 0.05 times any such thickness. The electronic components **55** at the low-angle magnetic field plane may be oriented to have their largest-area surface(s) generally parallel to the low-angle magnetic field plane. For example, the electronic components **55** at the low-angle magnetic field plane may be oriented to maximize their area in the plan view or to have an area in the plan view greater than a percentage of all possible orientations, such as 90%, 93%, 95%, 97%, or 99%.

[0179] Because the first and second axes **100**A and **200**A of the first and second transmitting coils **100** and **200** may be parallel in the plan view to the low-angle magnetic field plane and spaced apart in the thickness direction from the low-angle magnetic field plane by a relatively small distance compared to the lengths of the first and second transmitting coils **100** and **200**, when one or both of the first and second transmitting coils **100** and **200** are driven with AC current, a direction of a magnetic field generated by the first and second transmitting coils **100** and **200** at the low-angle magnetic field plane may form a small angle to the low-angle magnetic field plane. Accordingly, the magnetic flux of the magnetic field generated by the first and second transmitting coils **100** and **200** through surfaces of electronic components **55** at the low-angle magnetic field plane and oriented to have their largest-area surface generally parallel with the low-angle magnetic field plane may be reduced.

[0180] The second, third, and fourth magnetic field shallow zones **52**, **53**, and **54** may each have any shape that the first magnetic field shallow zone **51** may have, and the second, third, and fourth magnetic field shallow zones **52**, **53**, and **54** may each have a shape that is the same as or different from the shape of the first magnetic field shallow zone **51**. The second, third, and fourth magnetic field shallow zones **52**, **53**, and **54** may each be positioned and oriented in any manner similar to or the same as the first magnetic field shallow zone **51**, and the second, third, and fourth magnetic field shallow zones **52**, **53**, and **54** may each be positioned and/or oriented in a manner that is the same as or different from the manner in which the first magnetic field shallow zone **51** is positioned and/or oriented. In some embodiments, the first and second axes **100**A and **200**A of the first and second transmitting coils **100** and **200** are perpendicular to each other in the plan view, and the first to fourth magnetic field shallow zones **51-54** are positioned in the plan view in four quadrants defined by the first and second transmitting coils **100** and **200**.

[0181] FIG. **28** shows a schematic view of a circuit diagram of the wireless power transfer system according to some embodiments.

[0182] Referring to FIG. **28**, the wireless power transfer device **10** may include the coil assembly **14**, the electronics assembly **16**, and a cable **40** coupled between the coil assembly **14** and the electronics assembly **16**.

[0183] The coil assembly **14** may include the first and second transmitting coils **100** and **200**, a first capacitor C**1** coupled in parallel with the first wire **110** of the first transmitting coil **100**, a second capacitor C**2** coupled in series with the first capacitor C**1** and first wire **110**, a third capacitor C**3** coupled in parallel with the second wire **210** of the second transmitting coil **200**, a fourth capacitor C**4** coupled in series with the third capacitor C**3** and second wire **210**, a first current sensor **24** coupled to the first wire **110**, and a second current sensor **25** coupled to the second wire **210**.

[0184] The wireless power transfer device **10** may include a first LC resonant circuit corresponding to the first transmitting coil **100** and a second LC resonant circuit corresponding to the second transmitting coil **200**. The first LC resonant circuit includes the first wire **110**, the first capacitor C**1**, and the second capacitor C**2**, and the second LC resonant circuit includes the second wire **210**, the third capacitor C**3**, and the fourth capacitor C**4**. However, the present disclosure is not limited thereto. For example, in some embodiments, the first LC resonant circuit includes the first wire **110** and the first capacitor C**1**, and the second capacitor C**2** is not included, and/or the second LC resonant circuit includes the second wire **210** and the third capacitor C**3**, and the fourth capacitor C**4** is not included.

[0185] The first and second capacitors C**1** and C**2** may form an impedance matching network that matches the impedance of the first driver **410**. The resonant frequency of the first LC resonant circuit may be defined by equation 1 below,

$$f_{res1} = \frac{1}{2\pi\sqrt{L_{110}(C1_{cap} + C2_{cap})}}, \quad \text{[Equation 1]}$$

wherein f_{res1} is the resonant frequency of the first LC resonant circuit, L_{110} is the inductance of the first wire **110**, and $C\mathbf{1}_{cap}$ and $C\mathbf{2}_{cap}$ are the first and second capacitances of the first and second capacitors C**1** and C**2**, respectively. The resonant frequency of the second LC resonant circuit may be defined in a manner similar to how the resonant frequency of the first LC resonant circuit is defined. In some embodiments, the resonant frequencies of the first and second LC resonant circuits are the same or similar, and an angle between the first and second axes **100**A and **200**A of the first and second transmitting coils may be within a range of 89 degrees to 91 degrees to avoid substantial coupling between the first and second transmitting coils **100** and **200** when the first transmitting coil **100** and/or the second transmitting coil **200** are driven.

[0186] A ratio of the second capacitance $C\mathbf{2}_{cap}$ to the first capacitance $C\mathbf{1}_{cap}$ may be set such that, when the first driver **410** produces its highest pulse voltage, the electronic device **20** will receive its required power dependent on a coupling coefficient between the electronic device **20** and the wireless power transfer device **10**.

[0187] The first and second current sensors **25** and **26** are respectively configured to measure or sense a current flowing through the first and second wires **110** and **210** and to provide information about the current to the controller **600**.

[0188] The electronics assembly **16** may include the first and second drivers **410** and **420**, the first and second power modulation electronics **510** and **520**, the controller **600**, the receiver **700**, and a permanent or rechargeable battery **22**. The controller **600** may include a microcontroller or system on a chip that contains firmware and hardware. The controller **600** may be configured to output analog or digital signals to the first and second power modulation electronics **510** and **520** and to output digital square wave signals to the first and second drivers **410** and **420**. The controller **600** may be configured to receive signals (e.g., voltage feedback) from the outputs of the first and second power modulation electronics **510** and **520**, the first and second current sensors **24** and **25**, and the receiver **700**.

[0189] The first and second drivers **410** and **420** may output square wave voltages to the first and second LC resonant circuits. Sinusoidal voltage and current may be provided to the first and second wires **110** and **210** respectively in the first and second LC resonant circuits. Local feedback information may be provided to the controller **600** from the first and second current sensors **24** and **25**, and global feedback information may be provided to the controller **600** from the receiver **700** that receives the global feedback information from the electronic device **20** (e.g., from the transmitter **1000**). The local and/or global feedback information may be utilized in a feedback system, such as any feedback system described herein.

[0190] The electronic device **20** may include the receiver coil **800** comprising a receiver rod **820** and a receiver wire **810** wound around the receiver rod **820**. The receiver rod **820** may include any material that the first rod **120** may include, and the receiver rod **820** may include a same or different material as the first rod **120** includes. The receiver wire **810** may be wound around the receiver rod **820**, for example, to form a solenoid.

[0191] The electronic device **20** may include a fifth capacitor C**5** coupled in parallel with the receiver wire **810** to form at least part of a third LC resonant circuit, a rechargeable battery **28**, a power management system **26**, and the transmitter **1000**. In some embodiments, the third LC resonant circuit may include a sixth capacitor coupled in series with the fifth capacitor C**5** and receiver wire **810**. The fifth capacitor C**5** and the sixth capacitor may form at least part of a capacitive matching network.

[0192] The power management system **26** may be configured to regulate system voltage and charging of the rechargeable battery **28**, and may be configured to convert an AC voltage in the third LC resonant circuit to a DC voltage.

[0193] The transmitter **1000** may transmit information about a state of charge of the rechargeable battery **28**, a voltage of the rechargeable battery **28**, and/or a rectified voltage of the receiver coil **800** and/or of the third LC resonant circuit.

[0194] In some embodiments, the wireless power transfer device **10** is configured to pre-align, with the receiver coil **800** of the electronic device **20**, a magnetic field to be generated by the wireless power transfer device **10** such that, in response to the wireless power transfer device **10** generating the magnetic field, the magnetic field is aligned, at the receiver coil **800**, with the receiver coil **800**.

[0195] The wireless power transfer device **10** (e.g., the controller **600** of the wireless power transfer device **10**) may be configured to determine (e.g., calculate, for example, via an algorithm) a magnetic field (e.g., configured to determine the magnetic field before generating the magnetic field), from among a plurality of directionally different potential magnetic fields that the wireless power transfer device **10** is configured to generate, that has, at the receiver coil **800**, a direction aligned with the receiver coil **800**. As utilized herein, reference to a direction of a magnetic field at the receiver coil **800** being aligned with the receiver coil **800** may include a direction of exact alignment (i.e., a direction parallel to an axis of the receiver coil **800**) and a direction substantially optimally or suitably aligned (e.g., a direction within 15 degrees, 10 degrees, 5 degrees, 3 degrees, 1 degree, or 0.5 degrees from a direction closest to exact alignment) with the receiver coil **800** from among directions of the potential magnetic fields that the wireless power transfer device **10** is configured to generate. In some embodiments, based, for example, on the geometry of the wireless power transfer device **10** relative to the electronic device **20**, the wireless power transfer device **10** is not able to generate a magnetic field having a direction at the receiver coil **800** that is exactly aligned with the receiver coil **800**. However, the wireless power transfer device **10** may be configured to generate a plurality of directionally different magnetic fields having, at the receiver coil **800**, different degrees of alignment with the receiver coil **800**, including an optimal degree alignment (e.g., a degree of alignment closest to the exact alignment from among the different degrees of alignment), and the wireless power transfer device **10** may be configured to determine a magnetic field, from among the directionally different magnetic fields, having a degree of alignment with the receiver coil **800** that is the optimal degree of alignment or that deviates from the optimal degree of alignment by less than 15 degrees, 10 degrees, 5 degrees, 3, degrees, 1 degree, or 0.5 degrees.

[0196] In some embodiments, as explained herein, the wireless power transfer device **10** is configured to differentially drive the first and second transmitting coils **100** and **200** respectively with first and second currents (e.g., first and second AC currents) having controllably different amplitudes, and to thereby directionally control the magnetic field generated by the first and second transmitting coils **100** and **200**. For example, a direction at a set position (e.g., at the receiver coil **800**) of a potential magnetic field that the wireless power transfer device **10** is configured to generate may depend on a potential amplitude ratio of (i) an amplitude of a first current that the wireless power transfer device **10** is configured to drive the first transmitting coil **100** with to generate the potential magnetic field, to (ii) an amplitude of a second current that the wireless power transfer device **10** is configured to drive the second transmitting coil **200** with to generate the potential magnetic field. The wireless power transfer device **10** may be configured to determine (e.g., calculate, for example, by an algorithm) an amplitude ratio such that, in response to the first transmitting coil **100** being driven with a first current, the second transmitting coil **200** being driven with a second current, and a ratio of an amplitude of the first current to an amplitude of the second current being the amplitude ratio, the wireless power transfer device **10** will generate a magnetic field having, at the receiver coil **800**, a direction aligned with the receiver coil **800**. As utilized herein, reference to determining the amplitude ratio may include determining a ratio of amplitudes (e.g., from which any number of pairs of amplitudes of the first and second currents can be determined) and/or determining a pair of amplitudes of the first and second currents that satisfy the amplitude ratio. In some embodiments, the wireless power transfer device **10** may be configured to further determine a relative phase difference (e.g., in-phase corresponding to a relative phase difference of zero degrees, or a 180 degree relative phase difference) between the first and second currents such that, when the first and second transmitting coils are respectively driven with the first and second currents satisfying the amplitude ratio and the relative phase difference, the wireless power transfer device **10** generates the magnetic field having, at the receiver coil **800**, the direction aligned with the receiver coil **800**.

[0197] For example, FIG. **29** shows a graph displaying the direction of a potential magnetic field (horizontal axis) that can be generated by the first and second transmitting coils **100** and **200** at a position above an area of overlap between the first and second transmitting coils **100** and **200** versus a pair of potential amplitudes (vertical axis) of first and second currents that can be utilized to respectively drive in-phase the first and second transmitting coils **100** and **200** to generate the potential magnetic field. The amplitude axis (vertical axis) in FIG. **29** is unitless for convenience of illustration. FIG. **30** shows a graph displaying the directions of some of the potential magnetic fields, at a position above an area of overlap between the first and second transmitting coils **100** and **200**, that may be generated by the first and second transmitting coils **100** and **200** in response to being respectively driven with some of the pairs of the first and second currents shown in FIG. **29**. In FIG. **30**, the first and second transmitting coils **100** and **200** are respectively aligned parallel to the 0 degree line and to the 90 degree line. In the embodiment of FIG. **29**, the amplitudes of the first and second currents are shown as having sinusoidal shapes such that the magnitude of the potential magnetic field at the position above the area of overlap in FIG. **30** is substantially constant.

[0198] As explained herein, because the wireless power transfer device **10** may be configured to controllably drive the first and second currents either in-phase or 180 degree out-of-phase, the wireless power transfer device **10** can control the direction of the magnetic field to have any direction within the 0 to 90 degree range (corresponding to when the first and second currents are in-phase) and to have any direction within the 90 to 180 degree range (corresponding to when the first and second currents are 180 degrees out-of-phase). Furthermore, because the first and second currents may be AC currents, the 0 to 90 degree range also covers the 180 to 270 degree range, and the 90 to 180 degree range also covers the 270 to 360 degree range. For example, when the first current has an amplitude of $(3^{1/2})/2$ and the second current has an amplitude of ½ and is in-phase with the first current, the potential magnetic field may have a direction along the 22.5 degree line shown in FIG. **30**. When the first current has an amplitude of ½ and the second current has an amplitude of $(3^{1/2})/2$ and is 180 degrees out-of-phase from the first current, the potential magnetic field may have a direction along the 112.5 degree line shown in FIG. **30**. When the first current has an amplitude of $1/(2^{1/2})$ and the second current has an amplitude of $1/(2^{1/2})$ and is 180 degrees out-of-phase from the first current, the potential magnetic field may have a direction along the 135 degree line shown in FIG. **30**.

[0199] Accordingly, in non-limiting and non-exhaustive embodiments where the receiver coil **800** is positioned above the area of overlap between the first and second transmitting coils **100** and **200**, and is oriented in a plane parallel to both the first and second transmitting coils **100** and **200**, then there is an amplitude ratio and a relative phase difference (e.g., in-phase or 180 degrees out-of-phase) such that, if the first transmitting coil **100** is driven with a first current, the second transmitting coil **200** is driven with a second current, the ratio of an amplitude of the first current to an amplitude of the second current is the amplitude ratio, and the first and second currents are driven with the relative phase difference, a magnetic field will be generated by the first and second transmitting coils **100** and **200** that is aligned with the receiver coil **800**. The wireless power transfer device **10** may be configured to determine the amplitude ratio and the relative phase difference as described herein.

[0200] Because the wireless power transfer device **10** is able to determine, and selectively generate, the magnetic field that will be directionally aligned with the receiver coil **800** at the receiver coil **800** (e.g., by being able to determine the amplitude ratio and the relative phase difference), the wireless power transfer device **10** can test the sufficiency of its position and/or orientation relative to the electronic device **20** faster. For example, as described herein (e.g., in the discussion of FIG. **11**), a person in whom the electronic device **20** may be implanted may first find a suitable position and/or orientation of the wireless power transfer device **10** relative to the electronic device **20** before utilizing the wireless power transfer device **10** to charge the electronic device **20**. The person may place the wireless power transfer device **10** at various positions and/or orientations relative to the electronic device **20** (e.g., the person may press the wireless power transfer device **10** against his or her body, such as against his or her outer skin or outer clothing, at various positions across his or her body near to where the person knows the electronic device **20** is approximately implanted at) and receive feedback information from the electronic device **20** regarding the rate of power transfer from the wireless power transfer device **10** to the electronic device **20** when the wireless power transfer device **10** generates a magnetic field aligned with the receiver coil **800**.

[0201] In some embodiments, the wireless power transfer device **10** finds the magnetic field that is aligned with the receiver coil **800** by generating a plurality of preliminary magnetic fields (e.g., rotating through a range of preliminary magnetic fields) and receiving feedback data from the electronic device **20** regarding the rate of power transfer. The preliminary magnetic field associated with the highest rate of power transfer may be determined to be the magnetic field that is aligned with the receiver coil **800** for that position and/or orientation of the wireless power transfer device **10** relative to the electronic device **20**. However, the process of testing the plurality of preliminary magnetic fields to determine which one is aligned with the receiver coil **800** before moving the wireless power transfer device **10** to another position and/or orientation can require an undesirably long period of time that can frustrate the person and increase the likelihood of error caused by the person accidentally or unintentionally moving the wireless power transfer device **10** while the wireless power transfer device **10** is testing the plurality of preliminary magnetic fields. Accordingly, in embodiments where the wireless power transfer device **10** is configured to determine the magnetic field that is aligned with the receiver coil **800** without testing the plurality of preliminary magnetic fields, the process of positioning and/or orienting the wireless power transfer device **10** prior to charging the electronic device **20** can be made faster, easier, and less prone to errors.

[0202] The wireless power transfer device **10** (e.g., the controller **600**) may be configured to determine, from among the plurality of potential magnetic fields that the wireless power transfer device **10** is configured to generate, the magnetic field that has, at the receiver coil **800**, a direction aligned with the receiver coil **800** based on at least one of (i) a gravity orientation of the wireless power transfer device **10** (e.g., a gravity orientation of the coil assembly **14** or of the first and second transmitting coils **100** and **200**) relative to a gravity vector (e.g., a vector pointing along a direction parallel to a direction of gravity); (ii) a gravity orientation of the electronic device **20** (e.g., a gravity orientation of the receiver coil **800**) relative to a gravity vector; (iii) a bodily orientation of the wireless power transfer device **10** (e.g., a bodily orientation of the coil assembly **14** or of the first and second transmitting coils **100** and **200**) relative to a body that the electronic device **20** may be implanted in; (iv) a bodily orientation of the electronic device **20** (e.g., a bodily orientation of the receiver coil **800**) relative to a body that the electronic device **20** may be implanted in; (v) information about a prior operation of the wireless power transfer device **10** that generated a prior magnetic field having, at the receiver coil **800**, a direction aligned with the receiver coil **800**; or (vi) first and second reflected loads (or first and second reflected impedances) in the first and second LC resonant circuits of the wireless power transfer device **10** that respectively include the first and second transmitting coils **100** and **200** (e.g., respectively including the first and second wires **110** and **210** of the first and second transmitting coils **100** and **200**).

[0203] In some embodiments, the wireless power transfer device **10** is configured to determine the magnetic field (e.g., the amplitude ratio and the relative phase difference) based on the gravity orientation of the wireless power transfer device **10** (e.g., of the coil assembly **14** or of the first and second transmitting coils **100** and **200**) and the gravity orientation of the electronic device **20** (e.g., of the receiver coil **800**).

[0204] The wireless power transfer device **10** (e.g., the coil assembly **14**) may include a first inertial measurement unit (IMU) **17** configured to measure the gravity orientation of the wireless power transfer device **10** (e.g., of the coil assembly **14** or of the first and second transmitting coils **100** and **200**), and the wireless power transfer device **10** (e.g., the electronics assembly **16**) may include a first memory **27** configured to store information (e.g., information received from the first IMU **17**). The first IMU **17** may be communicatively coupled (e.g., through the cable **40**) to the controller **600** and/or to a first memory **27**, and the first memory **27** may be communicatively coupled to the controller **600**. In some embodiments, the first IMU **17** is communicatively coupled to the first memory **27** through the controller **600**. Thus, information about the gravity orientation of the wireless power transfer device **10** can be stored in the first memory **27** and utilized by the controller **600**.

[0205] The electronic device **20** may include a second IMU **18** configured to measure the gravity orientation of the electronic device **20** (e.g., of the receiver coil **800**), and the electronic device **20** may include a second memory **29** configured to store information (e.g., information received from the second IMU **18**). The second IMU **18** may be communicatively coupled to the transmitter **1000** and/or to the second memory **29**, and the second memory **29** may be communicatively coupled to the transmitter **1000**. Thus, the information about the gravity orientation of the receiver coil **800** may be stored in the second memory **29** and/or transmitted via the transmitter **1000** to the wireless power transfer device **10** (e.g., to the controller **600**). For example, the information about the gravity orientation of the receiver coil **800** may be transmitted to the wireless power transfer device **10** to be stored in the first memory **27** before being transmitted to the controller **600**, or the information about the gravity orientation of the receiver coil **800** may be transmitted to the controller **600** from the second memory **29** without first being stored in the first memory **27**.

[0206] The wireless power transfer device **10** may be configured to determine the magnetic field, for example, by determining a relative orientation of the receiver coil **800** relative to the first and second transmitting coils **100** and **200** based on the gravity orientation of the electronic device **20** (e.g., of the receiver coil **800**) and the gravity orientation of the wireless power transfer device **10** (e.g., of the coil assembly **14** or of the first and second transmitting coils **100** and **200**). Based on the relative orientation of the receiver coil **800**, the wireless power transfer device **10** may be configured to determine the magnetic field (e.g., the amplitude ratio and the relative phase difference that will generate the magnetic field) having, at the receiver coil **800**, a direction aligned with the receiver coil **800**.

[0207] For example, if the wireless power transfer device **10** determines that the receiver coil **800** is parallel to the first transmitting coil **100**, the wireless power transfer device **10** may determine that driving the first transmitting coil **100** with a first current and not driving the second transmitting coil **200** will generate a magnetic field that has, at the receiver coil **800**, a direction aligned with the receiver coil **800**. If the wireless power transfer device **10** determines that the receiver coil **800** is oriented in a plane parallel to the first and second transmitting coils **100** and **200** and at a 135 degree angle from the first transmitting coil **100** (see FIG. **30**), then the wireless power transfer device **10** may determine that driving the first and second transmitting coils **100** and **200** with first and second currents having equal amplitudes (e.g., corresponding to an amplitude ratio of 1) and with a 180 degree relative phase difference will generate a magnetic field having, at the receiver coil **800**, a direction aligned with the receiver coil **800**.

[0208] In some embodiments, in response to determining that the receiver coil **800** (e.g., an axis of the receiver coil **800**) is oriented in a plane nonparallel to the first and second transmitting coils **100** and **200**, the wireless power transfer device **10** may estimate the relative orientation of the receiver coil **800** relative to the first and second transmitting coils **100** and **200** to be the relative orientation of a projection of the receiver coil **800** onto a plane parallel to the first and second transmitting coils **100** and **200**.

[0209] In some embodiments, the wireless power transfer device **10** may be configured to determine the magnetic field (e.g., the amplitude ratio and the relative phase difference) based on the bodily orientation of the wireless power transfer device **10** (e.g., of the coil assembly **14** or of the first and second transmitting coils **100** and **200**) and the bodily orientation of the electronic device **20** (e.g., or the receiver coil **800**). For example, as explained herein, in some embodiments the electronic device **20** is an implantable medical device configured, for example, to provide stimulation (e.g., electrical stimulation) and/or to sense bodily information (e.g., biophysical characteristics, bioindicators, etc.).

[0210] In some embodiments, the bodily orientation of the receiver coil **800** and/or of the first and second transmitting coils **100** and **200** may include (e.g., be) an orientation relative to a reference axis of a portion of the body (e.g., a portion of the body where the electronic device **20** is implanted in). For example, the bodily orientation may include an orientation relative to a reference axis of a torso of the body, an axis of a neck of the body, or an axis of a limb (e.g., a leg or an arm) of the body. The torso axis of the body of a person may be a useful reference axis because this axis may reliably be substantially parallel to the gravity vector when the person is standing or sitting upright. The torso axis may extend in a direction parallel to a line intersecting a sagittal (or longitudinal) plane of the body and a coronal (or frontal) plane of the body, for example, in a direction perpendicular to a horizontal (or transverse) plane of the body. For example, the torso axis may be oriented along the line intersecting the sagittal plane and the coronal plane. In some embodiments, the reference axis is along a direction perpendicular to the sagittal plane, which can be a useful reference axis because it may reliably be substantially parallel to the ground (e.g., substantially perpendicular to a gravity direction) when the person is standing or sitting upright.

[0211] The electronic device **20** may be configured receive information about the bodily orientation of the receiver coil **800** and to store the information in the second memory **29**. For example, the electronic device **20** may have a receiver or a transceiver configured to receive (e.g., wirelessly receive) the information about the bodily orientation of the receiver coil **800**, and the receiver or the transceiver may be communicatively coupled to the second memory **29** so that the information about the bodily orientation of the receiver coil **800** can be stored in the second memory **29**. In some embodiments, the transceiver of the electronic device **20** includes the transmitter **1000**. Accordingly, the electronic device **20** may be configured to transmit the information about the bodily orientation of the receiver coil **800** to the wireless power transfer device **10** (e.g., to the controller **600**) so that the wireless power transfer device **10** may determine, based on the bodily orientation of the receiver coil **800**, the magnetic field having, at the receiver coil **800**, a direction aligned with the receiver coil **800** . . . . The bodily orientation of the receiver coil **800** may be assumed to be substantially static (e.g., substantially static for at least a set period of time), and thus, the information about the bodily orientation of the receiver coil **800** may be relied upon by the wireless power transfer device **10** to determine the magnetic field even after the bodily orientation of the receiver coil **800** is received by the electronic device **20** and stored in the second memory **29**. Because the electronic device **20** may be provided separately from the wireless power transfer device **10**, the bodily orientation of the receiver coil **800** may be stored in the second memory **29** instead of in the first memory **27** of the wireless power transfer device **10**.

[0212] In some embodiments, such as embodiments where the wireless power transfer device **10** and the electronic device **20** are provided together (e.g., sold together or collectively provided to a patient in whom the electronic device **20** is implanted from a physician or medical provided), the wireless power transfer device **10** is configured to receive (e.g., via the receiver **700**) the information about the bodily orientation of the receiver coil **800** and to store the information about the bodily orientation of the receiver coil **800** in the first memory **27**. For example, the receiver **700** may be communicatively coupled to the first memory **27**. Storing the information about the bodily orientation of the receiver coil **800** in the first memory (instead of in the second memory **29**) may be beneficial in the aspect that the electronic device **20** would not need to transmit the information to the wireless power transfer device **10** every time the wireless power transfer device **10** determines the magnetic field. Additionally, it may allow the electronic device **20** to be manufactured without the second memory **29** in some embodiments, thereby simplifying the manufacturing process and making it less expensive. The controller **600** may receive the information about the bodily orientation of the receiver coil **800** from the first memory **27** or from the second memory **29** in order to generate its determination of the magnetic field (e.g., of the amplitude ratio and the relative phase difference).

[0213] The information about the bodily orientation of the receiver coil **800** may be input into the first memory **27**

and/or into the second memory **29** by, for example, a physician at the time of the electronic device **20** being implanted or at some time thereafter (e.g., during a follow up visit by the patient to determine if the electronic device **20** has moved since it was implanted) and via, for example, a physician programmer or controller communicatively coupled to the wireless power transfer device **10** and/or to the electronic device **20**. The information about the bodily orientation of the receiver coil **800** may need to be updated periodically to account for unintended changes to the bodily orientation of the receiver coil **800** over time (e.g., after a sufficiently long time after the information about the bodily orientation was last input into the first memory **27** and/or into the second memory **29**) or to account for changes to the bodily orientation of the receiver coil **800** caused by the person in whom the electronic device **20** is implanted (e.g., to account for changes resulting from twiddlers syndrome).

[0214] In some embodiments, the electronic device **20** may include the second IMU **18**. The electronic device **20** may be configured, at a set time, to measure (by the second IMU **18**) a gravity orientation of the receiver coil **800** relative to the gravity vector and to receive (e.g., from the physician programmer or the controller) information about the orientation of the body (e.g., the orientation of a reference axis of the body, such as a torso axis) relative to the gravity vector. The electronic device **20** (e.g., a controller of the electronic device **20**) may be configured to define or estimate the bodily orientation of the receiver coil **800** (e.g., of the receiver coil **800** relative to the reference axis) based on the gravity orientation of the receiver coil **800** and the orientation of the body relative to the gravity vector at the set time. For example, the gravity orientation of the receiver coil **800** at the set time may be measured to be parallel to the gravity vector, the electronic device **20** may receive information that the reference axis (e.g., the torso axis) was parallel to the gravity vector at the set time (e.g., information that a person in whom the electronic device **20** is implanted was sitting or standing upright at the set time), and the electronic device **20** may therefore determine that the bodily orientation of the receiver coil **800** is parallel to the reference axis. In some other embodiments, the electronic device **20** (or the wireless power transfer device **10**) may base its determination of the bodily orientation of the receiver coil **800** on an assumption that the receiver coil **800** is oriented in a plane parallel to (or in) the body's coronal plane. Therefore, the electronic device **20** may define or estimate the bodily orientation of the receiver coil **800** even if the gravity orientation of the receiver coil **800** is not parallel to the gravity vector. The electronic device **20** may be configured to store the bodily orientation of the receiver coil **800** in the second memory **29**. In some embodiments, the gravity orientation of the receiver coil **800** and the information about the orientation of the body relative to the gravity vector may be transmitted to the wireless power transfer device **10**, and the wireless power transfer device **10** (e.g., the controller **600**) may be configured to determine the bodily orientation of the receiver coil **800** based on the gravity orientation of the receiver coil **800** and the information about the orientation of the body relative to the gravity vector.

[0215] In some embodiments, the bodily orientation of the wireless power transfer device **10** (e.g., of the coil assembly **14** or of the first and second transmitting coils **100** and **200**) may be based on (e.g., assumed from) the configuration (e.g., shape, size, configurability to couple to a body, etc.) of the wireless power transfer device **10**. The wireless power transfer device **10** may be configured to couple (e.g., attach) to the body such that, in response to the wireless power transfer device **10** being so coupled to the body, the first and second transmitting coils **100** and **200** have a substantially fixed bodily orientation relative to the body. For example, the wireless power transfer device **10** may be configured to fixedly couple to (e.g., lock onto) the body or may be configured to couple to the body in a manner such that it is configured to remain in place, for example, under the influence of gravity.

[0216] In some embodiments, the wireless power transfer device **10** includes the coil assembly **14**, the electronics assembly **16**, and the cable **40** coupled between the coil assembly **14** and the electronics assembly **16**. The wireless power transfer device **10** may be configured to be fitted over a neck of the body so that the coil assembly **14** (e.g., the first and second transmitting coils **100** and **200**) is positioned over a front or a back of the body with a substantially fixed orientation and/or position relative to the body. FIG. **31** shows an electronic device **20** implanted in a person's body according to an embodiment, and FIG. **32** shows an electronic device **20** implanted in a person's body according to another embodiment. The receiver coil **800** of the electronic device **20** is oriented perpendicular to the person's torso axis (perpendicular to the body's sagittal plane) in FIG. **31**, and the receiver coil **800** is oriented parallel to the person's torso axis (perpendicular to the body's horizontal plane) in FIG. **32**. Other orientations of the receiver coil **800** are also possible. For example, the receiver coil **800** can be oriented anywhere in a plane substantially parallel to the body's coronal plane. FIG. **33** shows a wireless power transfer device **10** coupled to a person's body according to an embodiment, and FIG. **34** shows another wireless power transfer device **10** coupled to a person's body according to another embodiment. The wireless power transfer device **10** can be fitted over the person's neck with the coil assembly **14** of the wireless power transfer device **10** positioned and oriented to cover the electronic device **20**. FIG. **33** shows a magnetic field direction MFD of a magnetic field generated by the wireless power transfer **10** so that the magnetic field is aligned with the receiver coil **800** oriented in the person's body as shown in FIG. **31**. FIG. **34** shows an embodiment where the coil assembly **14** includes the first IMU **17**.

[0217] The wireless power transfer device **10** may be configured to determine the magnetic field (e.g., the amplitude ratio and the relative phase difference), for example, by determining a relative orientation of the receiver coil **800** relative to the first and second transmitting coils **100** and **200** based on the bodily orientation of the receiver coil **800** and the bodily orientation of the first and second transmitting coils **100** and **200**. Based on the relative orientation of the receiver coil **800**, the wireless power transfer device **10** may be configured to determine the magnetic field (e.g., the amplitude ratio and the relative phase difference that will generate the magnetic field) having, at the receiver coil **800**, a direction aligned with the receiver coil **800**.

[0218] For example, the bodily orientation of the receiver coil **800** may be parallel to torso axis of the body, the first and second transmitting coils **100** and **200** may have a bodily orientation where each of the first and second transmitting coils **100** and **200** are oriented 45 degrees relative to the torso axis, and the wireless power transfer device **10** may determine that the receiver coil **800** has a relative orientation relative to the first and second transmitting coils **100** and **200** of 45 degrees from each of the first and second transmitting coils **100** and **200**. The wireless power transfer device **10** may thus determine the amplitude ratio to be a value of 1 and the relative phase difference to be 0 degrees (i.e., the first and second currents are to be driven in-phase). In some other examples, the bodily orientation of the receiver coil **800** may be oriented perpendicular to the body's sagittal plane, the first and second transmitting coils **100** and **200** may have a bodily orientation in a plane parallel to the body's coronal plane with the first transmitting coil **100** oriented in a direction perpendicular to the body's sagittal plane and with the second transmitting coil **200** oriented perpendicular to the first transmitting coil **100**. The wireless power transfer device **10** may determine that the receiver coil **800** has a relative orientation relative to the first and second transmitting coils **100** and **200** of 0 degrees relative to the first transmitting coil **100** and 90 degrees relative to the second transmitting coil **200**. The wireless power transfer device **10** may thus determine that driving the first transmitting coil **100** and not driving the second transmitting coil **200** will generate a magnetic field having a direction, at the receiver coil **800**, aligned with the receiver coil **800**.

[0219] In some embodiments, the wireless power transfer device **10** may assume in its determination of the magnetic field that the receiver coil **800** is oriented in a plane parallel to the first and second transmitting coils **100** and **200**. For example, the wireless power transfer device **10** may assume that the receiver coil **800**, as well as the first and second transmitting coils **100** and **200** (collectively), are oriented in planes parallel to the body's coronal plane or to the body's sagittal plane. In some embodiments, the wireless power transfer device **10** may be configured to determine that the receiver coil **800** is oriented in a plane parallel or nonparallel to the first and second transmitting coils **100** and **200**. In response to determining that the receiver coil **800** is oriented in a plane nonparallel to the first and second transmitting coils **100** and **200**, the wireless power transfer device **10** may be configured to estimate the relative orientation of the receiver coil **800** relative to the first and second transmitting coils **100** and **200** as the relative orientation of a projection of the receiver coil **800** (e.g., a projection of the axis of the receiver coil **800**) onto a plane parallel to the first and second transmitting coils **100** and **200**.

[0220] The wireless power transfer device **10** may be configured to determine the magnetic field (e.g., the amplitude ratio and the relative phase difference) based on the gravity orientation of the wireless power transfer device **10** and the bodily orientation of the electronic device **20** (e.g., of the receiver coil **800**) relative to a body. For example, the wireless power transfer device **10** may be configured to determine a relative orientation of the receiver coil **800** relative to the first and second transmitting coils **100** and **200** based on the gravity orientation of the wireless power transfer device **10** and the bodily orientation of the receiver coil **800**, and to determine the magnetic field based on the relative orientation of the receiver coil **800** in a similar or same manner as has been described hereinabove.

[0221] In some embodiments, the wireless power transfer device **10** is configured to determine (e.g., estimate) a gravity orientation of the receiver coil **800** based on the bodily orientation of the receiver coil **800** relative to a reference axis (e.g., a torso axis or an axis perpendicular to the body's sagittal plane), and to determine the relative orientation of the receiver coil **800** relative to the first and second transmitting coils **100** and **200** based on the gravity orientation of the receiver coil **800**.

[0222] For example, the wireless power transfer device **10** may be configured to determine the gravity orientation of the receiver coil **800** based on the bodily orientation of the receiver coil **800** relative to the reference axis and the orientation of the body (e.g., based on the orientation of the reference axis) relative to a gravity vector.

[0223] In some embodiments, the wireless power transfer device **10** may determine the orientation of the reference axis relative to the gravity vector based on the gravity orientation of the first and second transmitting coils **100** and **200** (e.g., as measured by the first IMU). For example, if the reference axis is a torso axis, the wireless power transfer device **10** may be configured, in response to determining (e.g., via measuring the gravity orientation of the first and second transmitting coils **100** and **200** by the first IMU **17**) that the first and second transmitting coils **100** and **200** are both parallel to a plane parallel to the gravity direction (e.g., a plane that a gravity vector lies within), to determine that the torso axis is parallel to the gravity vector. This determination may be based in some embodiments on the assumption that the wireless power transfer device **10** would be held against the body in a manner such that the first and second transmitting coils **100** and **200** are both parallel to a plane tangential to the outer surface of the torso, which, if the plane tangential to the outer surface of the body is parallel to the gravity direction, would indicate that the torso axis is parallel to the gravity vector.

[0224] In some other embodiments, if the reference axis is the torso axis, the wireless power transfer device **10** may be configured to determine the orientation of the reference axis relative to the gravity vector to be parallel to the gravity vector. This determination may be based in some embodiments on the assumption that the person is standing or sitting uprightly, for example, in embodiments where standard operating instructions of the wireless power transfer device **10** require that the person in whom the electronic device **20** is implanted be standing or sitting uprightly when charging the electronic device **20**.

[0225] In some other embodiments, the wireless power transfer device **10** may be configured to determine the orientation of the reference axis (e.g., the torso axis) relative to the gravity vector based on an algorithm, for example, predicting when (e.g., what times during the day) the reference axis is oriented parallel to the gravity vector and when the reference axis is not oriented parallel to the gravity vector. The wireless power transfer device **10** may then determine (e.g., estimate) the gravity orientation of the receiver coil **800** based on a determination (e.g., via the algorithm and the current time of day) of the orientation of the reference axis relative to the gravity vector.

[0226] For example, the electronic device **20** may include the second IMU **18** and may be configured (e.g., via the second IMU **18** and a controller in the electronic device **20**) to monitor and store, for example, in the second memory **29** and/or in the first memory **27**, information about the gravity orientation of the body (e.g., about the orientation of the reference axis relative to the gravity vector) over time (e.g., over one or more days). As explained herein, in some embodiments, the bodily orientation of the receiver coil **800** is determined based on the gravity orientation of the receiver coil **800** and the gravity orientation of the body at the same set time. In some such embodiments, the electronic device **20** may be configured to determine the gravity orientation of the body at any particular time based on the gravity orientation of the body at the set time and a comparison between the gravity orientation of the receiver coil **800** at the set time and the gravity orientation of the receiver coil **800** at the particular time. The electronic device **20** may therefore be configured to determine, monitor, and store information about the orientation of the reference axis relative to the gravity vector over time. An algorithm may then be generated (e.g., by the controller **600** or by a controller of the electronic device **20**), based on the monitored information about the orientation of the reference axis relative to the gravity vector, to predict the orientation of the reference axis relative to the gravity vector based on the time (e.g., current time). The gravity orientation of the receiver coil **800** may then be determined utilizing the algorithm and the time.

[0227] In some embodiments, the wireless power transfer device **10** is configured to determine the magnetic field (e.g., the amplitude ratio and the relative phase difference) based on the gravity orientation of the receiver coil **800** and the bodily orientation of the first and second transmitting coils **100** and **200**.

[0228] In some embodiments, the wireless power transfer device **10** is configured to determine the magnetic field (e.g., the amplitude ratio and the relative phase difference) based on information about a prior operation of the wireless power transfer device **10**, for example, a prior operation where the wireless power transfer device **10** generated a magnetic field at the receiver coil **800** that was aligned with the receiver coil. The information about the prior operation may include information about a prior magnetic field generated by the wireless power transfer device **10** during the prior operation that had, at the receiver coil **800**, a direction aligned with the receiver coil **800**. For example, the information about the prior magnetic field may include information about a prior amplitude ratio of an amplitude of a prior first current to an amplitude of a prior second current and of a relative phase difference between the prior first current and the prior second current. The prior first current and the prior second current may have been utilized during the prior operation to respectively drive the first and second transmitting coils **100** and **200** with the prior relative phase difference to generate the prior magnetic field.

[0229] The prior magnetic field that had, at the receiver coil **800**, the direction aligned with the receiver coil **800**, may have been determined by the wireless power transfer device to be aligned with the receiver coil **800** via any suitable manner, including any manner disclosed herein or within the scope of the present disclosure. For example, the wireless power transfer device **10** may have determined that the prior magnetic field was aligned with the receiver coil **800** by utilizing a feedback process as described herein. The feedback process may include generating, by the wireless power transfer device **10**, a plurality of magnetic fields and receiving, from the electronic device **20** and for each of the plurality of magnetic fields, feedback information about how aligned the magnetic field was with the receiver coil **800** (e.g., information about a degree of alignment between the magnetic field and the receiver coil **800**). The prior magnetic field may be determined by the wireless power transfer device **10** to be a magnetic field from among the plurality of magnetic fields that was determined (e.g., by the wireless power transfer device **10**) to be most closely aligned with the receiver coil **800**. During subsequent operations after the prior operation, the wireless power transfer device **10** can determine the magnetic field that will have, at the receiver coil **800**, a direction aligned with the receiver coil **800** based on the information about the prior operation without needing to utilize the feedback process again. In some other embodiments, the wireless power transfer device **10** may have determined the prior magnetic field based on first and second reflected loads (or first and second reflected impedances) in the first and second LC resonant circuits of the wireless power transfer device **10**, as described herein.

[0230] The information about the prior operation may include, in addition to the information about the prior magnetic field, information about a prior gravity orientation of the first and second transmitting coils **100** and **200**. For example, the wireless power transfer device **10** may include the first IMU **17**, and the prior gravity orientation of the first and second transmitting coils **100** and **200** may have been measured by the first IMU **17** and stored in the first memory **27**. The wireless power transfer device **10** may be configured to determine the magnetic field having the direction at the receiver coil **800** aligned with the receiver coil **800** based on a gravity orientation (e.g., a current gravity orientation) of the first and second transmitting coils **100** and **200** and the information about the prior operation. For example, the wireless power transfer device **10** may be configured to measure, by the first IMU **17**, the gravity orientation of the first and second transmitting coils **100** and **200**, and to determine a coil angular difference between the gravity orientation of the first and second transmitting coils **100** and **200** and the prior gravity orientation of the first and second transmitting coils **100** and **200**. The wireless power transfer device **10** may be configured to then determine that the magnetic field is a magnetic field having a direction at a set position (e.g., at a position above the area of overlap between the first and second transmitting coils **100** and **200**) that has an magnetic field angular difference relative to a prior direction of the prior magnetic field at the set position that is equal to the coil angular difference. Accordingly, the wireless power transfer device **10** may be configured to account for angular changes of the wireless power transfer device **10** between the prior and current operations. In some embodiments, determining the coil angular difference may include assuming that the first and second transmitting coils **100** and **200** during the current operation are both parallel to a same reference plane that the first and second transmitting coils **100** and **200** were parallel to during the prior operation.

[0231] In some embodiments, the wireless power transfer device **10** may be configured to determine the magnetic field (e.g., the amplitude ratio and the relative phase difference) based on a bodily orientation (e.g., a current bodily orientation) of the first and second transmitting coils **100** and **200** and the information about the prior operation. For example, as explained herein, the wireless power transfer device **10** may be configured to couple to the body in which the electronic device **20** is implanted such that, when the wireless power transfer device **10** is so coupled to the body, the first and second transmitting coils **100** and **200** have a substantially fixed bodily orientation relative to the body. In some other embodiments, the wireless power transfer device **10** may be configured to assume that bodily orientation of the first and second transmitting coils **100** and **200** is a set bodily orientation relative to the body based, for example, on how the wireless power transfer device **10** is configured to be held or positioned and/or oriented relative to the body during operation, or on standard instructions for how the wireless power transfer device **10** should be held or positioned and/or oriented during operation. For example, the wireless power transfer device **10** may have an orientation indicator configured to visually indicate how the wireless power transfer device **10** (and thus, the first and second transmitting coils **100** and **200**) should be oriented relative to the body during operation. In some embodiments, the wireless power transfer device **10** may have a disc shape with an orientation indicator at a position around the perimeter of the disc shape to indicate that the wireless power transfer device **10** should be oriented relative to the body such that the orientation indicator is positioned closest to a head of the body.

[0232] The wireless power transfer device **10** may thus be configured to determine that the magnetic field that will be aligned with the receiver coil **800** is the same as the prior magnetic field. This can be based on an assumption that the first and second transmitting coils **100** and **200** have a same orientation relative to the receiver coil **800** as they had during the prior operation, which can derive from the assumption that the bodily orientation of each of the receiver coil **800** and of the first and second transmitting coils **100** and **200** is the same as during the prior operation.

[0233] In some embodiments, the wireless power transfer device **10** may be configured to determine the magnetic field that will be aligned with the receiver coil **800** based on first and second reflected loads (or first and second reflected impedances) in the first and second LC resonant circuits of the wireless power transfer device **10**. As described above, the first LC resonant circuit may include the first transmitting coil **100** (e.g., the first wire **110** of the first transmitting coil **100**) and the first capacitor C**1**, and the second LC resonant circuit may include the second transmitting coil **200** (e.g., the second wire **210** of the second transmitting coil **200**). The electronic device **20** may include the third LC resonant circuit including the receiver coil **800** (e.g., the receiver wire **810** of the receiver coil **800**) and the fifth capacitor C**5**.

[0234] During driving of the first and second transmitting coils **100** and **200**, the amplitude of the first current through the first transmitting coil **100** may be proportional to a first bus voltage provided by the first power modulation electronics **510** to the first driver **410**, and the amplitude of the second current through the second transmitting coil **200** may be proportional to a second bus voltage provided by the second power modulation electronics **520** to the second driver **420**. The first and second drivers **410** and **420** may respectively provide the first and second currents to the first and second transmitting coils **100** and **200** based, respectively, on the first and second bus voltages.

[0235] The amplitudes of the first and second currents respectively in the first and second transmitting coils **100** and **200** may also be affected by a reflected load (or reflected impedance) in each of the first and second LC resonant circuits that respectively results from the receiver coil **800** being coupled with the first and second transmitting coils **100** and **200**. When the magnetic field generated by the first and second transmitting coils **100** and **200** has, at the receiver coil **800**, a direction aligned with the receiver coil **800**, the effect on the first and second currents resulting from the receiver coil **800** can be substantially the same. Accordingly, when the magnetic field generated by the first and second transmitting coils **100** and **200** has, at the receiver coil **800**, the direction aligned with the receiver coil **800**, a voltage ratio of the first bus voltage to the second bus voltage can be substantially the same as an amplitude ratio of the amplitude of the first current in the first transmitting coil **100** (e.g., as measured by the first current sensor **24**) to the amplitude of the second current in the second transmitting coil **200** (e.g., as measured by the second current sensor **25**). However, when the magnetic field generated by the first and second transmitting coils **100** and **200** has a direction at the receiver coil **800** that is not aligned with the receiver coil **800**, the effect on the first and second currents resulting from the receiver coil **800** may differ, and the voltage ratio may differ from the amplitude ratio.

[0236] Accordingly, in some embodiments, the wireless power transfer device **10** may be configured to differentially drive the first and second transmitting coils **100** and **200** to generate a plurality of directionally different preliminary magnetic fields. In some embodiments, the wireless power transfer device **10** is configured to generate the plurality of preliminary magnetic fields to have different directions within a range of directions and at a set position (e.g., at the receiver coil **800** or at a position above an area of overlap between the first and second transmitting coils **100** and **200**). For example, the wireless power transfer device **10** may be configured to generate the plurality of preliminary magnetic fields having directions at the set position that form an angle relative to one of the first and second transmitting coils **100** and **200** (e.g., relative to the first transmitting coil **100**) that sequentially get larger as the preliminary magnetic fields are sequentially generated. Accordingly, the wireless power transfer device **10** can scan through a range of angles (e.g., 90 degrees or 180 degrees) via step changes in angle.

[0237] For each of the preliminary magnetic fields, the wireless power transfer device **10** may be configured to generate a corresponding comparison between a corresponding first reflected load (or first reflected impedance) in the first LC resonant circuit resulting from the receiver coil **800** and a corresponding second reflected load (or second reflected impedance) in the second LC resonant circuit resulting from the receiver coil **800**. The wireless power transfer device **10** may be configured to determine the magnetic field (e.g., the amplitude ratio and the relative phase difference) based on the plurality of comparisons.

[0238] In some embodiments, for each of the preliminary magnetic fields, the wireless power transfer device may be configured to generate a corresponding comparison between (i) a corresponding preliminary voltage ratio of a corresponding first preliminary bus voltage provided by the first power modulation electronics **510** to a corresponding second preliminary bus voltage provided by the second variable power supply **520**, and (ii) a corresponding preliminary amplitude ratio of an amplitude of a corresponding first preliminary current in the first transmitting coil **100** to an amplitude of a corresponding second preliminary current provided in the second transmitting coil **200**. The wireless power transfer device **10** (e.g., the controller **600**) may be configured to determine the magnetic field (e.g., the amplitude ratio and the relative phase difference) based on the plurality of comparisons.

[0239] The controller **600** may be configured to determine the first and second preliminary bus voltages based on the signals transmitted by the controller **600** to the first and second power modulation electronics **510** and **520**. In some other embodiments, the controller **600** may be configured to receive feedback voltages (e.g., the first and second preliminary bus voltages) from the first and second power modulation electronics **510** and **520** and to determine the first and second preliminary bus voltages based on the feedback voltages received from the first and second power modulation electronics **510** and **520**. In some embodiments, the first and second current sensors **24** and **25** may respectively be configured to measure the first and second preliminary currents in the first and second transmitting coils **100** and **200**, and the controller **600** may be configured to receive the first and second preliminary currents from the first and second current sensors **24** and **25**.

[0240] In some embodiments, the generating the corresponding comparison between the corresponding preliminary voltage ratio and the corresponding preliminary amplitude ratio includes generating a difference between the corresponding preliminary voltage ratio and the corresponding preliminary amplitude ratio. For example, the controller **600** may be configured to subtract a smaller one of the corresponding preliminary voltage ratio and the corresponding preliminary amplitude ratio from a larger one of the corresponding preliminary voltage ratio and the corresponding preliminary amplitude. In some other embodiments, the controller **600** may be configured to generate an absolute value of the difference between the corresponding preliminary voltage ratio and the corresponding preliminary amplitude. The controller **600** may determine that the magnetic field corresponds to (e.g., is the same as) the preliminary magnetic field whose corresponding comparison is smallest (or closest to zero) from among the plurality of comparisons.

[0241] In some embodiments, the generating the corresponding comparison between the corresponding preliminary voltage ratio and the corresponding preliminary amplitude ratio includes generating a ratio between the corresponding preliminary voltage ratio and the corresponding preliminary amplitude ratio. For example, the controller **600** may be configured to divide a larger one of the corresponding preliminary voltage ratio and the corresponding preliminary amplitude ratio from a smaller one of the corresponding preliminary voltage ratio and the corresponding preliminary amplitude (or vice versa). In some other embodiments, the controller **600** may be configured to always divide the corresponding preliminary voltage ratio from the corresponding preliminary amplitude ratio (or vice versa). The controller **600** may determine that the magnetic field corresponds to (e.g., is the same as) the preliminary magnetic field whose corresponding comparison is smallest (or closest to one) from among the plurality of comparisons.

[0242] The wireless power transfer device **10** may therefore be able to determine the magnetic field (e.g., the amplitude ratio and the relative phase difference) based on the reflected loads (or the reflected impedances) in the first and second LC resonant circuits, for example, without knowing the gravity orientation or the bodily orientation of either the wireless power transfer device **10** (e.g., of the first and second transmitting coils **100** and **200**) or the electronic device **20** (e.g., of the receiver coil **800**).

[0243] For each function, process, or operation that the wireless power transfer device **10** is disclosed herein as being configured to perform, the wireless power transfer device **10** may be configured in some embodiments to perform the function, process, or operation in response to executing (e.g., via the controller **600**) computer-readable instructions for performing the function, process, or operation and that are stored in a memory (e.g., the first memory **27**). For example, generating determinations, executing algorithms, etc. that the wireless power transfer device **10** is disclosed herein as being configured to do may be done by the wireless power transfer device **10** in response to executing computer-readable instructions that are stored in the memory and are for generating such determinations, executing such algorithms, etc. For each function, process, or operation that the electronic device **20** is disclosed herein as being configured to perform, the electronic device **20** may be configured in some embodiments to perform the function, process, or operation in response to executing (e.g., via a controller of the electronic device **20**) computer-readable instructions for performing the function, process, or operation and that are stored in a memory (e.g., the second memory **29**).

[0244] The system and/or any other relevant devices or components according to embodiments of the present invention described herein may be implemented utilizing any suitable hardware, firmware (e.g. an application-specific integrated circuit), software, or a combination of software, firmware, and hardware. For example, the various components of the system may be formed on one integrated circuit (IC) chip or on separate IC chips. Further, the various components of the system may be implemented on a flexible printed circuit film, a tape carrier package (TCP), a printed circuit board (PCB), or formed on one substrate. Further, the various components of the system may be a process or thread, running on one or more processors, in one or more computing devices, executing computer program instructions and interacting with other system components for performing the various functionalities described herein. The computer program instructions are stored in a memory which may be implemented in a computing device utilizing a standard memory device, such as, for example, a random access memory (RAM). The computer program instructions may also be stored in other non-transitory computer readable media such as, for example, a CD-ROM, flash drive, or the like. Also, a person of skill in the art should recognize that the functionality of various computing devices may be combined or integrated into a single computing device, or the functionality of a particular computing device may be distributed across one or more other computing devices without departing from the scope of the exemplary embodiments of the present invention.

[0245] Although some embodiments of the present disclosure have disclosed herein, the present disclosure is not limited thereto, and the scope of the present disclosure is defined by the appended claims and equivalents thereof.

What is claimed is:

1. A wireless power transfer device, the wireless power transfer device being configured:

to generate a plurality of directionally different potential magnetic fields; and

to select, from among the plurality of directionally different potential magnetic fields, a set magnetic field based on preliminary information about at least one of:

a gravity orientation of the wireless power transfer device relative to a gravity vector,

a bodily orientation of the wireless power transfer device relative to a patient's body, or a plurality of load comparisons, each between first and second loads in first and second LC resonant circuits of the wireless power transfer device and in response to the wireless power transfer device generating a corresponding one of the plurality of directionally different potential magnetic fields, the first and second LC resonant circuits respectively including first and second transmitting coils.

2. The wireless power transfer device of claim **1**, comprising:

at least one transmitting coil;

a driver configured to drive the at least one transmitting coil;

a memory storing instructions; and

a controller, the controller configured:

to select the set magnetic field based on the preliminary information and in response to executing the instructions, and

after selecting the set magnetic field, to generate the set magnetic field by driving the at least one transmitting coil via the driver.

3. The wireless power transfer device of claim **1**, wherein the selecting the set magnetic field comprises determining a first amplitude of a first current, a second amplitude of a second current, and a phase difference between the first and second currents, the wireless power transfer device being configured to generate the set magnetic field in response to driving the first and second transmitting coils with the first and second currents.

4. The wireless power transfer device of claim **1**, wherein the preliminary information is at least about the gravity orientation of the wireless power transfer device, and

wherein the wireless power transfer device comprises an inertial measurement unit (IMU) configured to measure the gravity orientation of the wireless power transfer device.

5. The wireless power transfer device of claim **4**, wherein the preliminary information is further about at least one of:

a gravity orientation of an implantable medical device (IMD) relative to a gravity vector;

a bodily orientation of the IMD relative to a patient's body; or

a prior magnetic field previously generated by the wireless power transfer device and a prior gravity orientation of the wireless power transfer device relative to a gravity vector while the wireless power transfer device generated the prior magnetic field.

6. The wireless power transfer device of claim **1**, wherein the preliminary information is at least about the bodily orientation of the wireless power transfer device relative to a patient's body.

7. The wireless power transfer device of claim **1**, wherein the preliminary information is at least about the plurality of load comparisons.

8. The wireless power transfer device of claim **7**, wherein a load comparison of the plurality of load comparisons comprises a comparison between a corresponding voltage ratio to a corresponding amplitude ratio,

wherein the corresponding amplitude ratio is based on a ratio of first amplitude of a first current provided to the first transmitting coil by a driver and based on a first bus voltage and a second amplitude of a second current provided to the second transmitting coil by the driver and based on a second bus voltage, and

wherein the corresponding voltage ratio is based on a ratio of the first bus voltage and the second bus voltage.

9. A wireless power transfer system, comprising:

the wireless power transfer device of claim **1**; and

an implantable medical device comprising a receiver coil,

wherein the selecting the set magnetic field comprises determining a degree of alignment between the set magnetic field and the receiver coil, and the set magnetic field is selected based on the determined degree of alignment.

10. A wireless power transfer device, comprising:

a first transmitting coil oriented along a first axis;

a second transmitting coil oriented along a second axis different from the first axis;

a driver configured to drive the first and second transmitting coils; and

a controller configured:

to simultaneously and differentially drive the first and second transmitting coils, via the driver, and

to determine a first amplitude of a first current, a second amplitude of a second current, and a phase difference between the first and second currents, the first and second transmitting coils being configured to generate a magnetic field aligned with a receiver coil of an electronic device in response to the first and second transmitting coils being driven with the first and second currents.

11. The wireless power transfer device of claim **10**, comprising an inertial measurement unit (IMU) configured to determine a gravity orientation of the first and second transmitting coils relative to a gravity vector,

wherein the controller is configured to determine the first amplitude, the second amplitude, and the phase difference based on the gravity orientation of the first and second transmitting coils.

12. The wireless power transfer device of claim **10**, where the wireless power transfer device is configured to couple to a patient's body such that the first and second transmitting coils have a set bodily orientation relative to the patient's body,

wherein the controller is configured to determine the first amplitude, the second amplitude, and the phase difference based on the bodily orientation of the first and second transmitting coils.

13. The wireless power transfer device of claim **10**, comprising:

a first LC resonant circuit comprising the first transmitting coil; and

a second LC resonant circuit comprising a second transmitting coil,

wherein the controller is configured to differentially drive the first and second transmitting coils to generate a plurality of directionally different preliminary magnetic fields, and

wherein, the controller is configured to determine the first amplitude, the second amplitude, and the phase difference based on a plurality of pairs of first and second reflected loads in the first and second LC resonant circuits, each of the pairs being in response to a corresponding one of the plurality of directionally different preliminary magnetic fields being generated.

14. A wireless power transfer system, comprising:

the wireless power transfer device of claim **10**; and the electronic device, the electronic device being an implantable medical device.

15. A method for transferring power from a wireless power transfer device to an electronic device, the method comprising:

selecting, from among a plurality of directionally different potential magnetic fields, a set magnetic field based on preliminary information about at least one of:

a gravity orientation of the wireless power transfer device relative to a gravity vector,

a bodily orientation of the wireless power transfer device relative to a patient's body, or

a plurality of load comparisons, each between first and second loads in first and second LC resonant circuits of the wireless power transfer device and in response to the wireless power transfer device generating a corresponding one of the plurality of directionally different potential magnetic fields, the first and second LC resonant circuits including first and second transmitting coils; and

generating, by the wireless power transfer device, the set magnetic field after selecting the set magnetic field.

16. The method of claim **15**, wherein the electronic device is an implantable medical device.

17. The method of claim **15**, wherein the preliminary information is at least about the gravity orientation of the wireless power transfer device, and

wherein the method further comprises measuring the gravity orientation via an inertial measurement unit (IMU) of the wireless power transfer device.

18. The method of claim **17**, wherein the preliminary information is further about at least one of:

a gravity orientation of the electronic device relative to a gravity vector;

a bodily orientation of the electronic device relative to the patient's body; or

a prior magnetic field previously generated by the wireless power transfer device and a prior gravity orientation of the wireless power transfer device relative to a gravity vector while the wireless power transfer device generated the prior magnetic field.

19. The method of claim **15**, wherein the preliminary information is at least about the bodily orientation of the wireless power transfer device relative to a patient's body.

20. The method of claim **15**, wherein the preliminary information is at least about the plurality of load comparisons.

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