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(54) **SYSTEMS AND METHODS FOR NULLIFYING ENERGY LEVELS FOR WIRELESS POWER TRANSMISSION WAVES**

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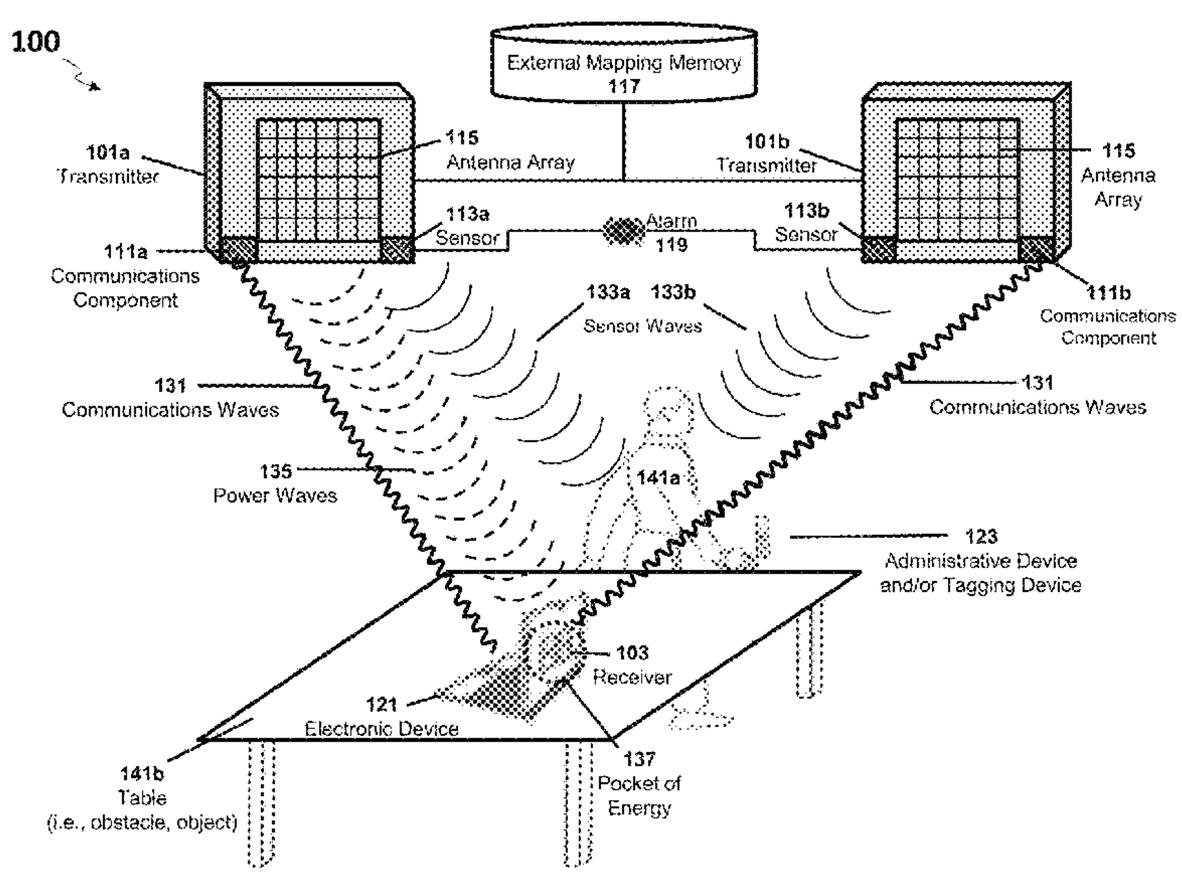
(57) **ABSTRACT**

Systems and methods to generate and transmit power waves are disclosed herein. An example method includes: receiving, by a transmitter, from one or more sensors, location data about a location associated with one or more objects within a transmission field of the transmitter. The one or more sensors may include a proximity sensor configured to send the location data of the one or more objects, and the one or more objects are associated with a maximum permissible exposure (MPE) level. The method also includes: transmitting, by the transmitter, one or more power waves to converge to form a pocket of energy at a location of an electronic device; and transmitting, by the transmitter, one or more power waves to converge destructively to form a null space at the location of the one or more objects, the null space having a power density level that is below the MPE level.

21 Claims, 32 Drawing Sheets



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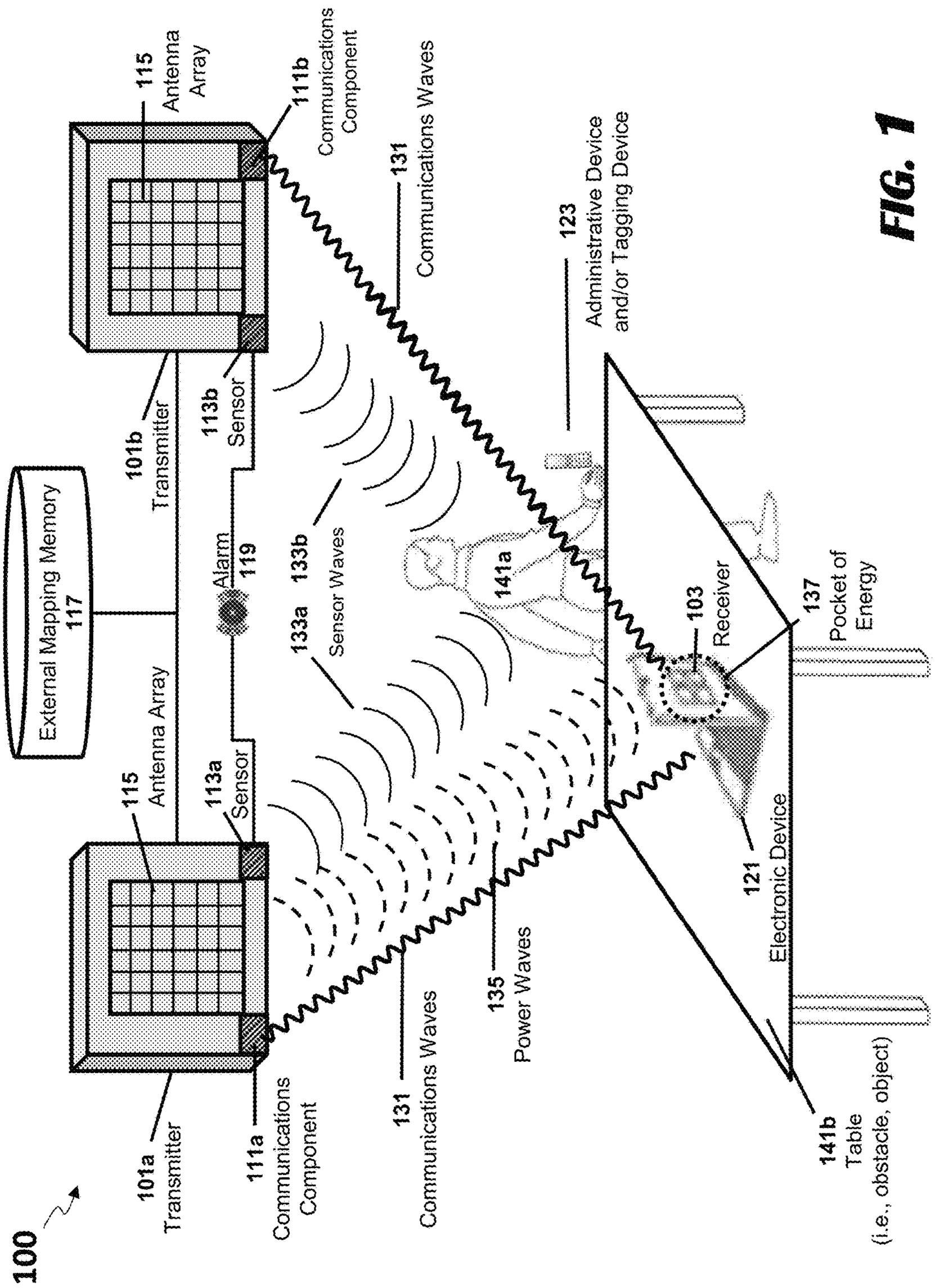
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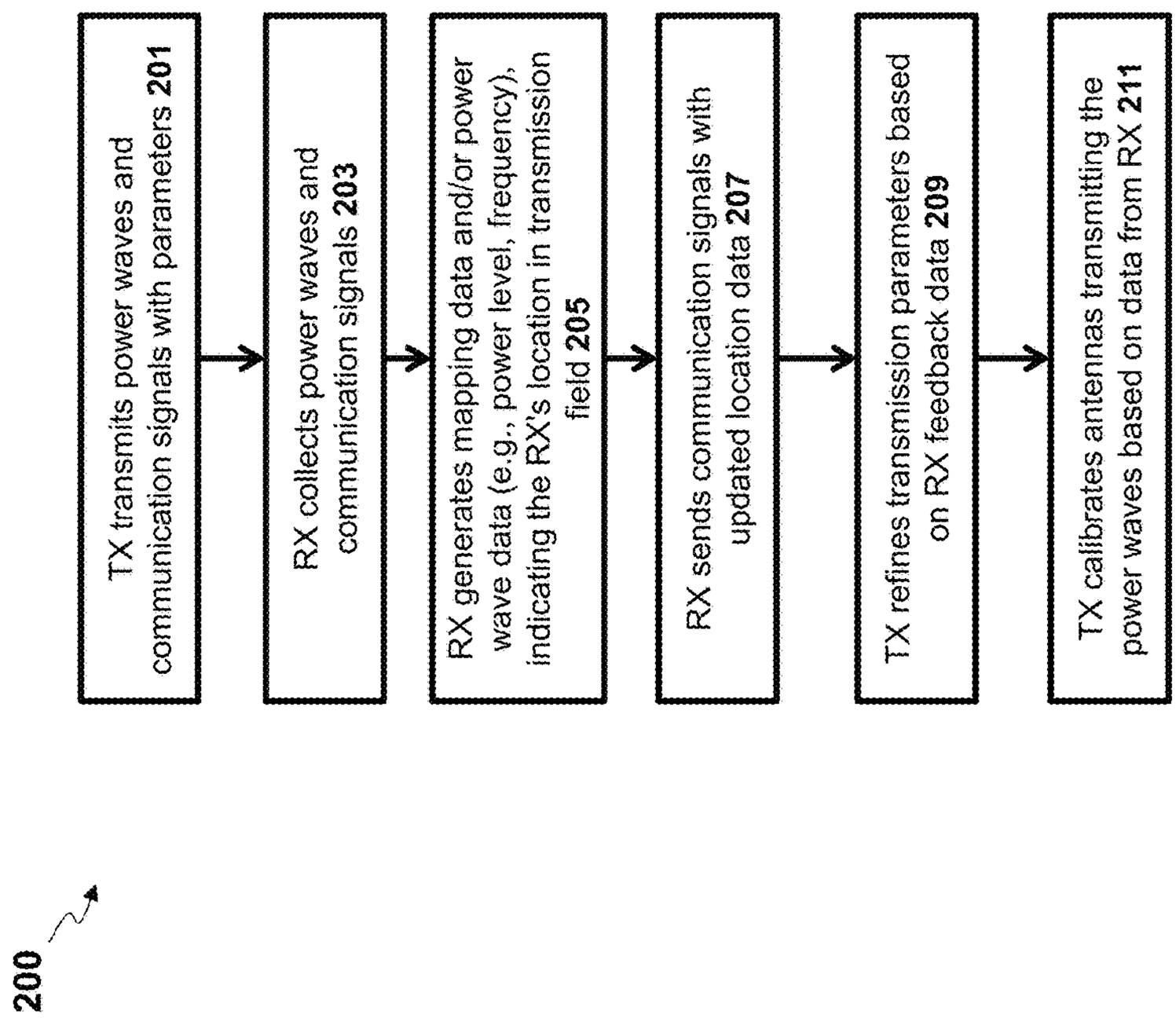
131 Communications Waves
115 Antenna Array
113a Sensor
External Mapping Memory 117
101b Transmitter
113b Sensor
Alarm 119
133a 133b Sensor Waves
115 Antenna Array
111b Communications Component
131 Communications Waves
135 Power Waves
123 Administrative Device and/or Tagging Device
141a
103 Receiver
137 Pocket of Energy
121 Electronic Device
141b Table (i.e., obstacle, object)

FIG. 1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TX transmits power waves and communication signals with parameters 201
RX collects power waves and communication signals 203
RX generates mapping data and/or power wave data (e.g., power level, frequency), indicating the RX's location in transmission field 205
RX sends communication signals with updated location data 207
TX refines transmission parameters based on RX feedback data 209
TX calibrates antennas transmitting the power waves based on data from RX 211

FIG. 2

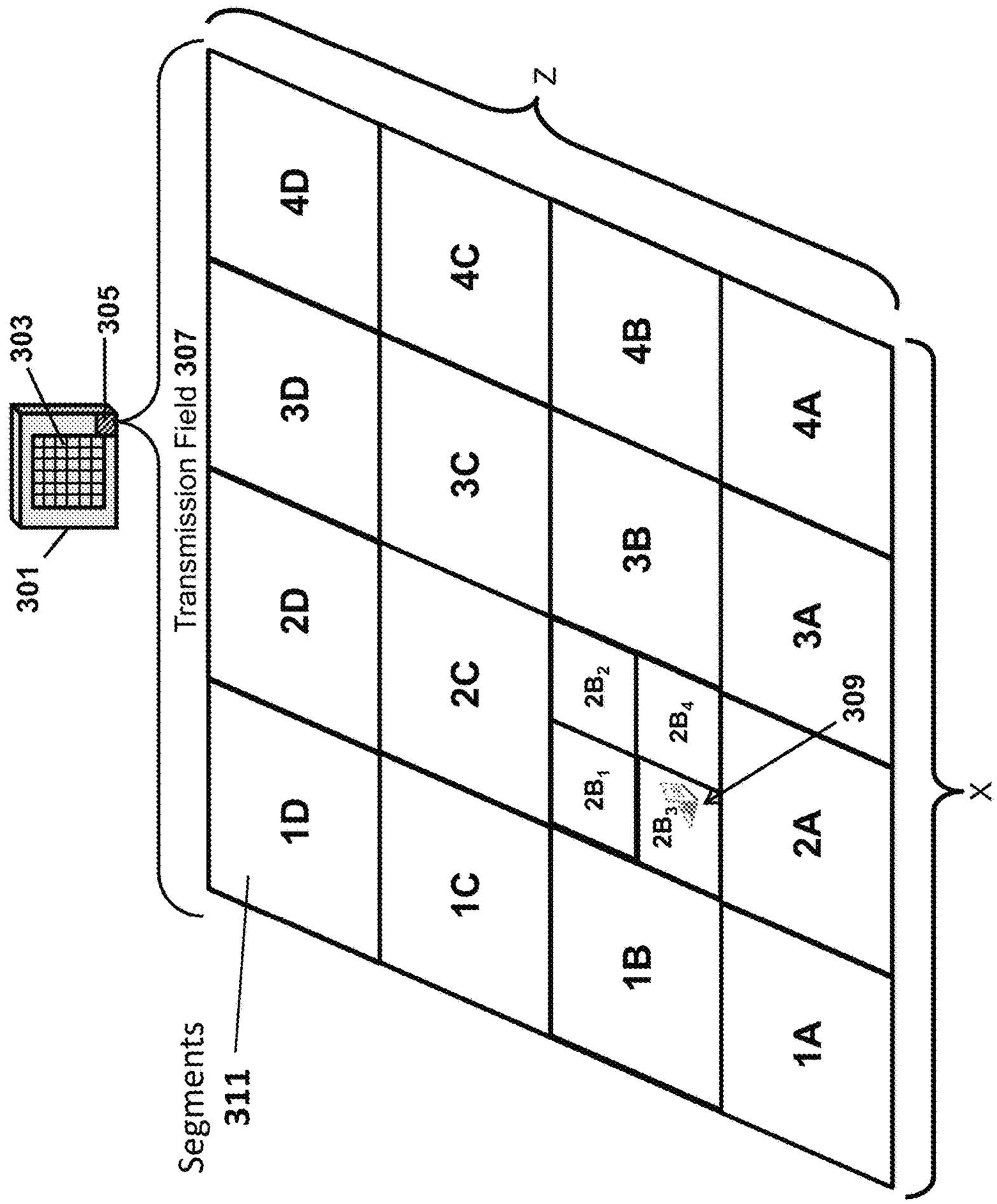
303
305
301
Transmission Field 307
Segments
311
N
X
4D
4C
4B
4A
3D
3C
3B
3A
2D
2C
2B
2A
1D
1C
1B
1A
$2B_1$
$2B_2$
$2B_3$
$2B_4$
309

FIG. 3

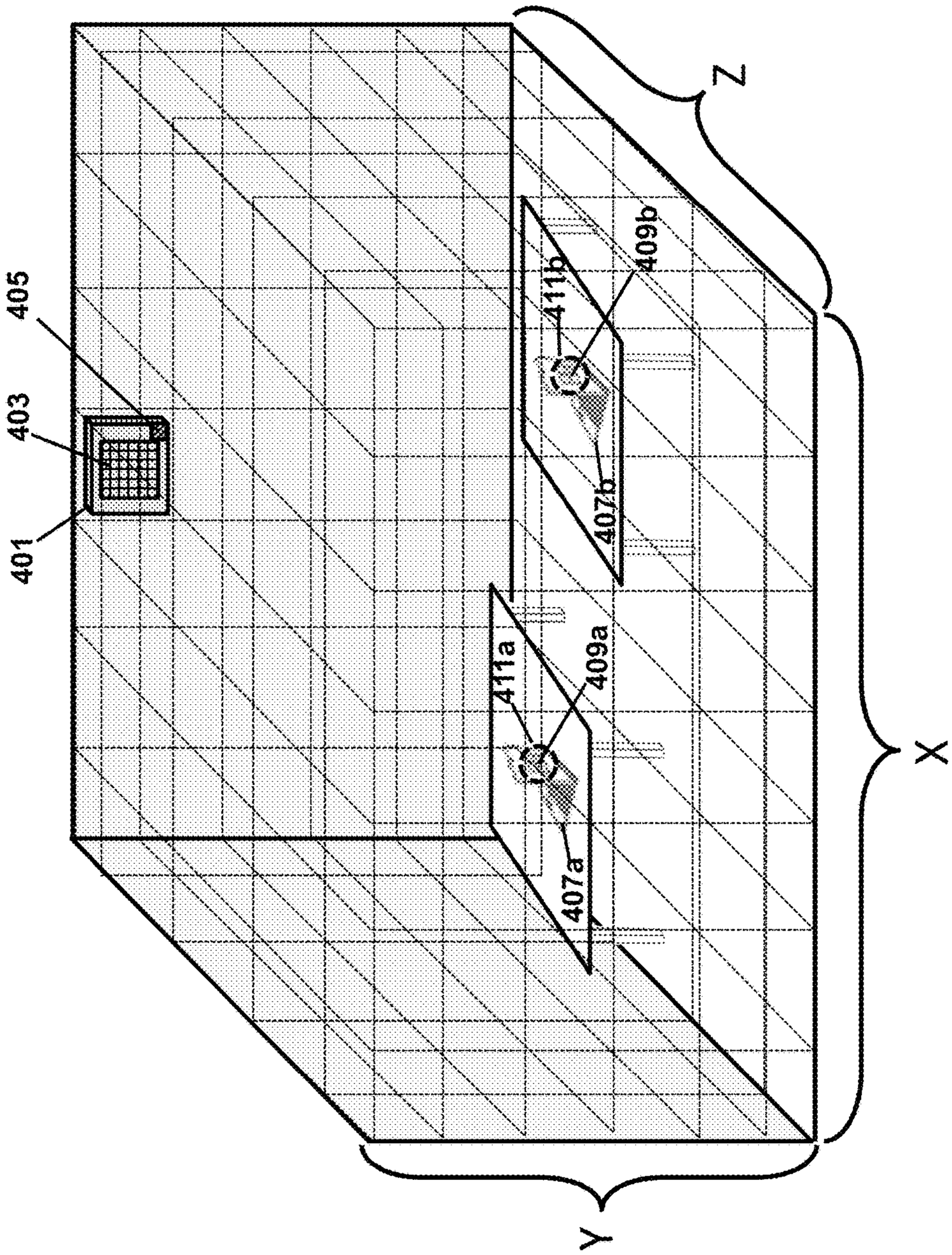

FIG. 4

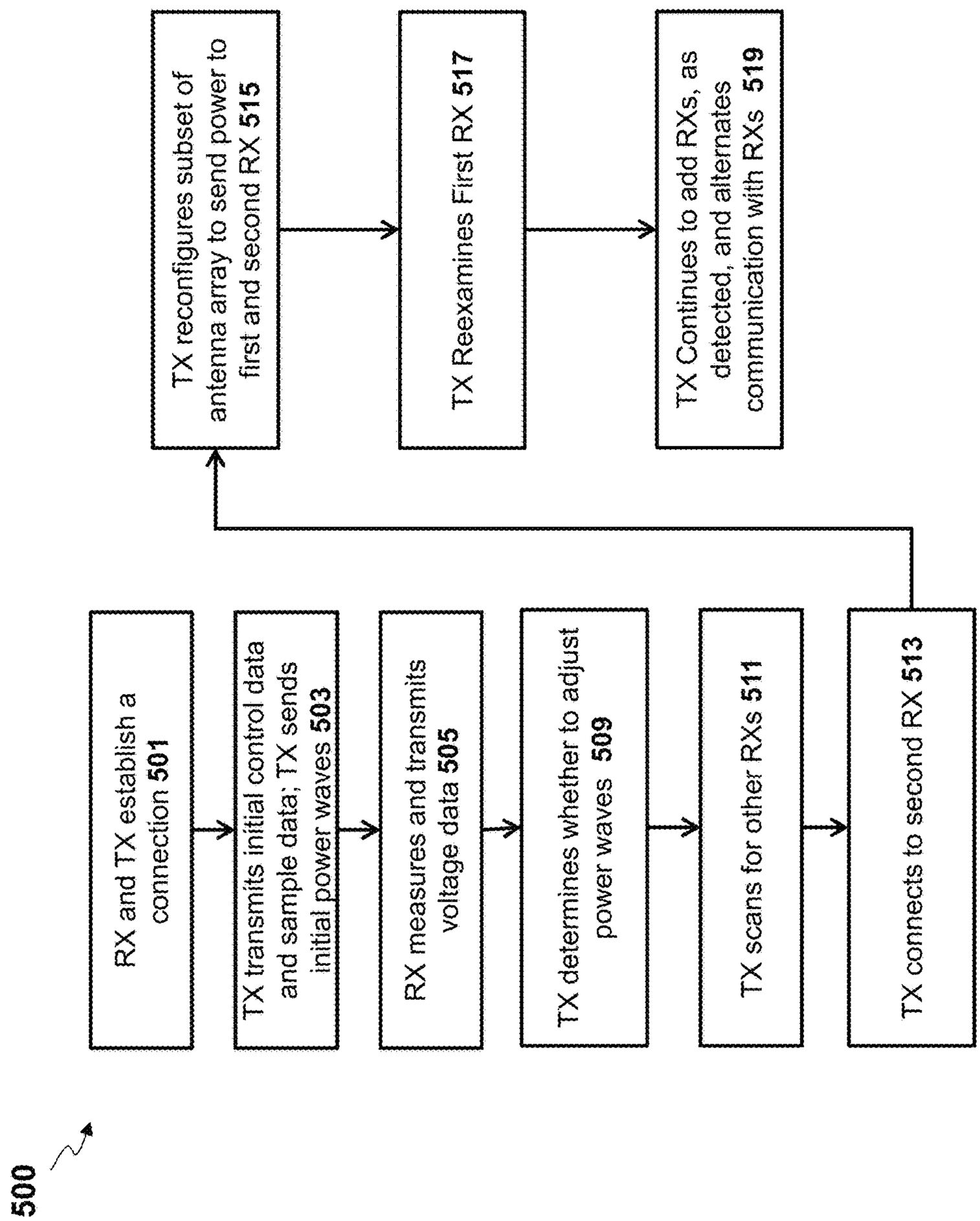
500
RX and TX establish a connection 501
TX transmits initial control data and sample data; TX sends initial power waves 503
RX measures and transmits voltage data 505
TX determines whether to adjust power waves 509
TX scans for other RXs 511
TX connects to second RX 513
TX reconfigures subset of antenna array to send power to first and second RX 515
TX Reexamines First RX 517
TX Continues to add RXs, as detected, and alternates communication with RXs 519

FIG. 5

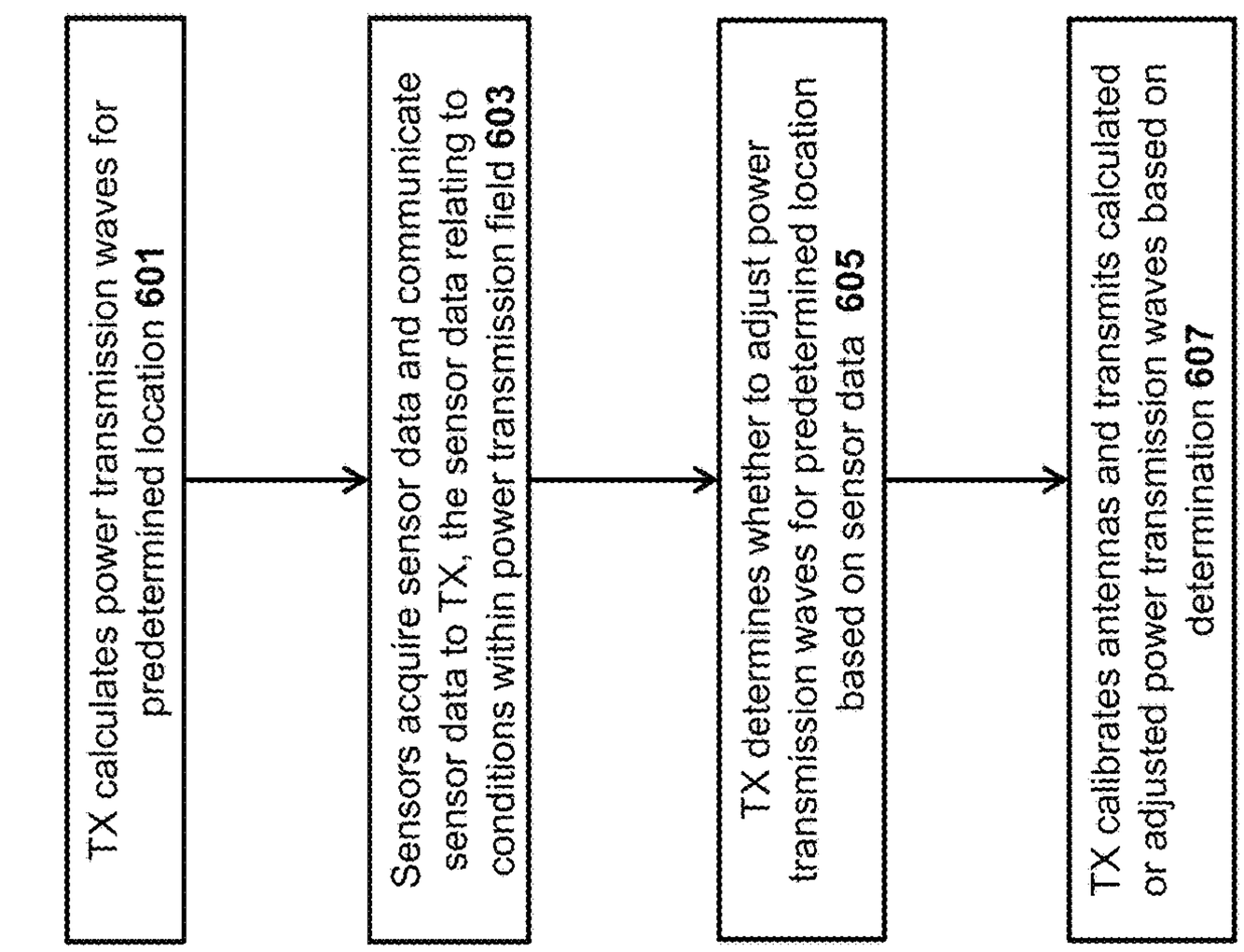
600
TX calculates power transmission waves for predetermined location 601
Sensors acquire sensor data and communicate sensor data to TX, the sensor data relating to conditions within power transmission field 603
TX determines whether to adjust power transmission waves for predetermined location based on sensor data 605
TX calibrates antennas and transmits calculated or adjusted power transmission waves based on determination 607

FIG. 6

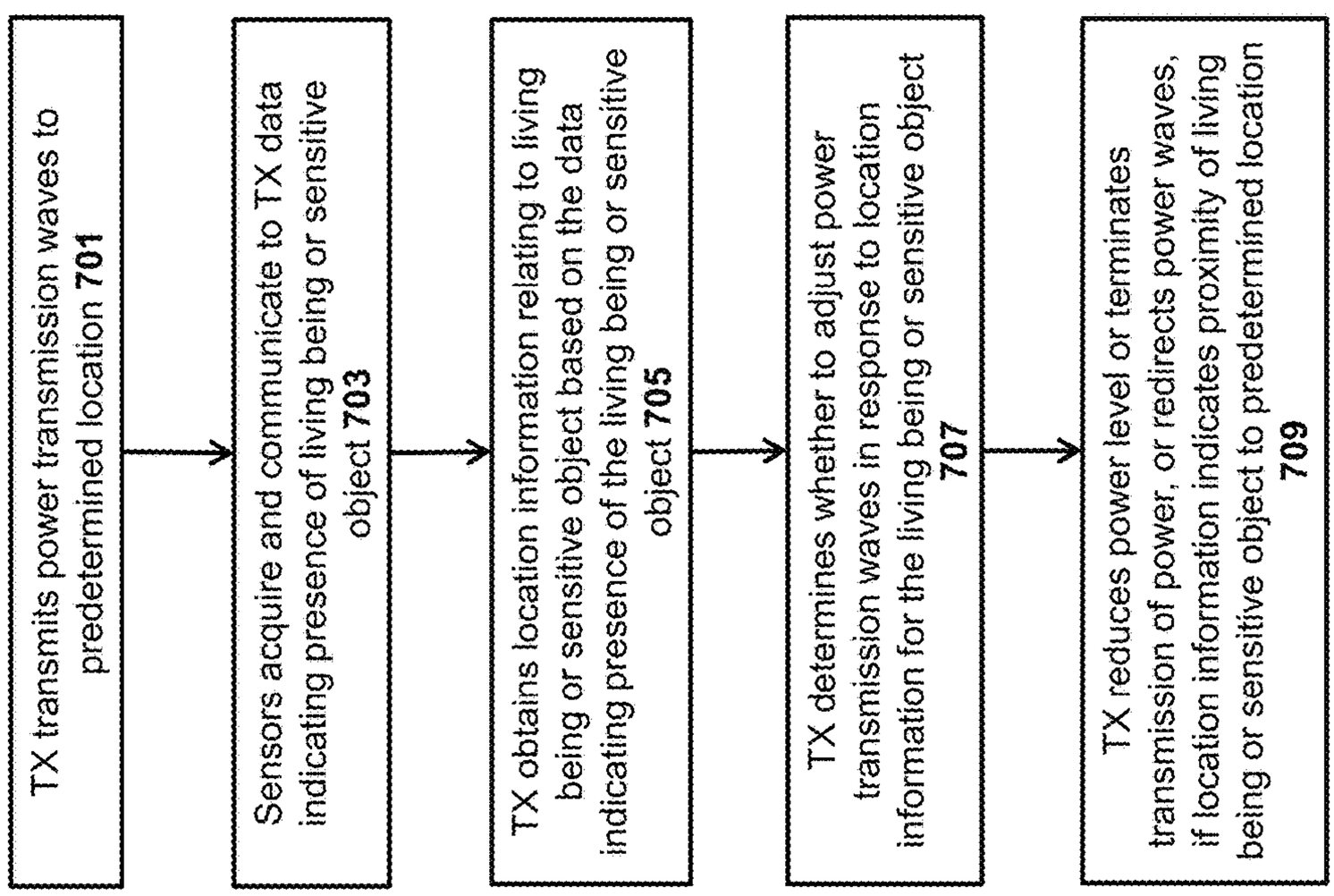
700
TX transmits power transmission waves to predetermined location 701
Sensors acquire and communicate to TX data indicating presence of living being or sensitive object 703
TX obtains location information relating to living being or sensitive object based on the data indicating presence of the living being or sensitive object 705
TX determines whether to adjust power transmission waves in response to location information for the living being or sensitive object 707
TX reduces power level or terminates transmission of power, or redirects power waves, if location information indicates proximity of living being or sensitive object to predetermined location 709

FIG. 7

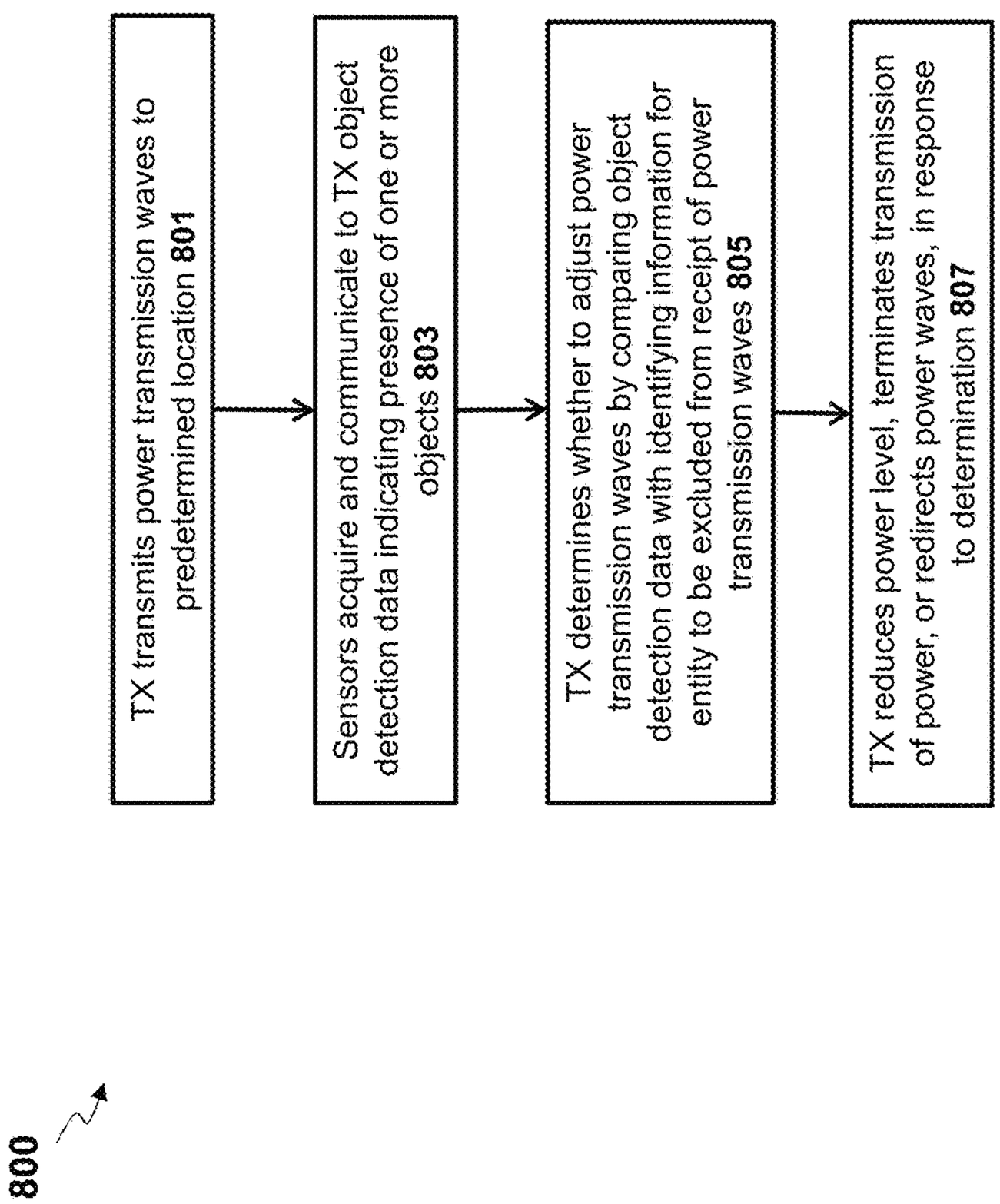
800
TX transmits power transmission waves to predetermined location 801
Sensors acquire and communicate to TX object detection data indicating presence of one or more objects 803
TX determines whether to adjust power transmission waves by comparing object detection data with identifying information for entity to be excluded from receipt of power transmission waves 805
TX reduces power level, terminates transmission of power, or redirects power waves, in response to determination 807

FIG. 8

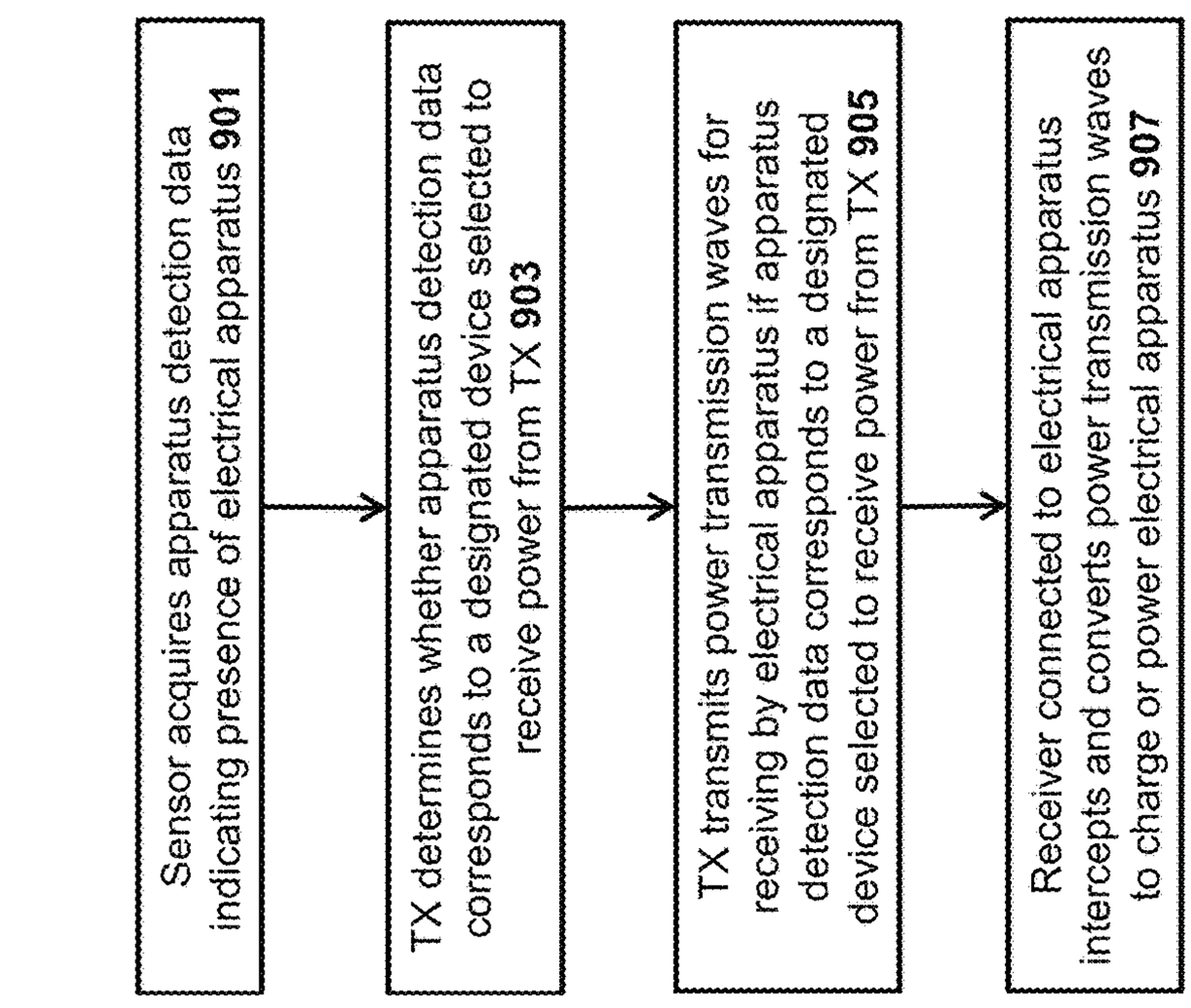
900
Sensor acquires apparatus detection data indicating presence of electrical apparatus 901
TX determines whether apparatus detection data corresponds to a designated device selected to receive power from TX 903
TX transmits power transmission waves for receiving by electrical apparatus if apparatus detection data corresponds to a designated device selected to receive power from TX 905
Receiver connected to electrical apparatus intercepts and converts power transmission waves to charge or power electrical apparatus 907

FIG. 9

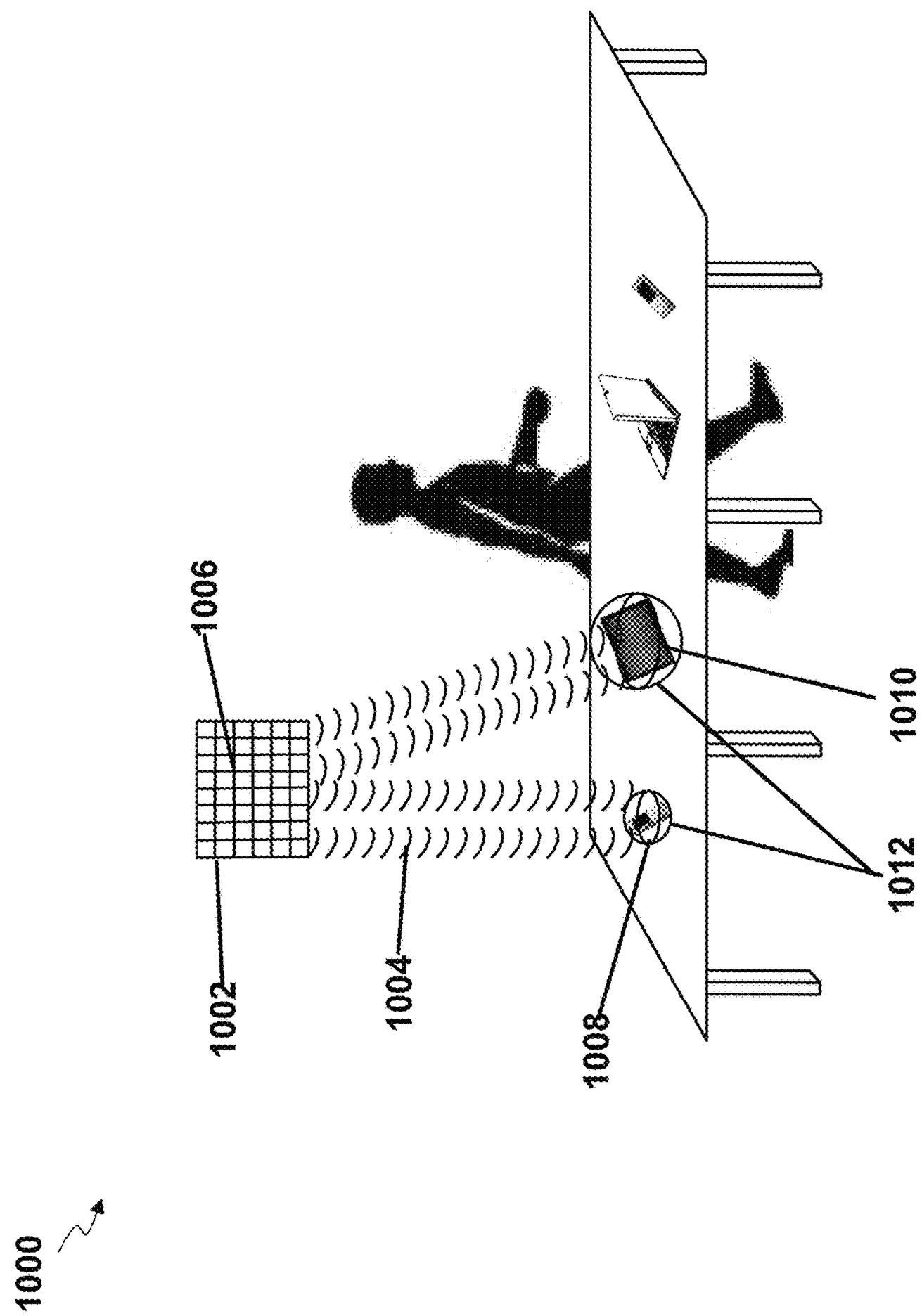

FIG. 10

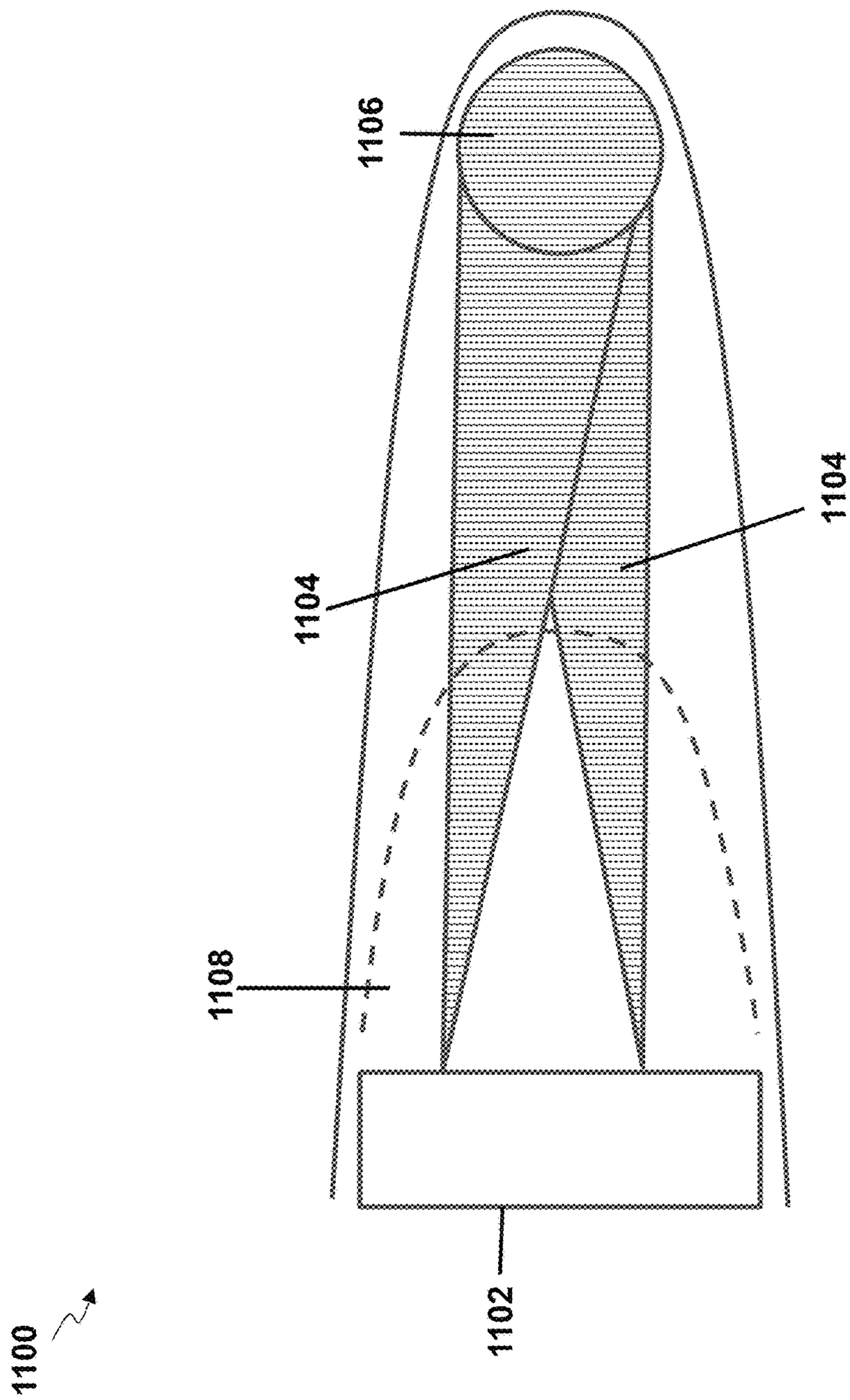

FIG. 11

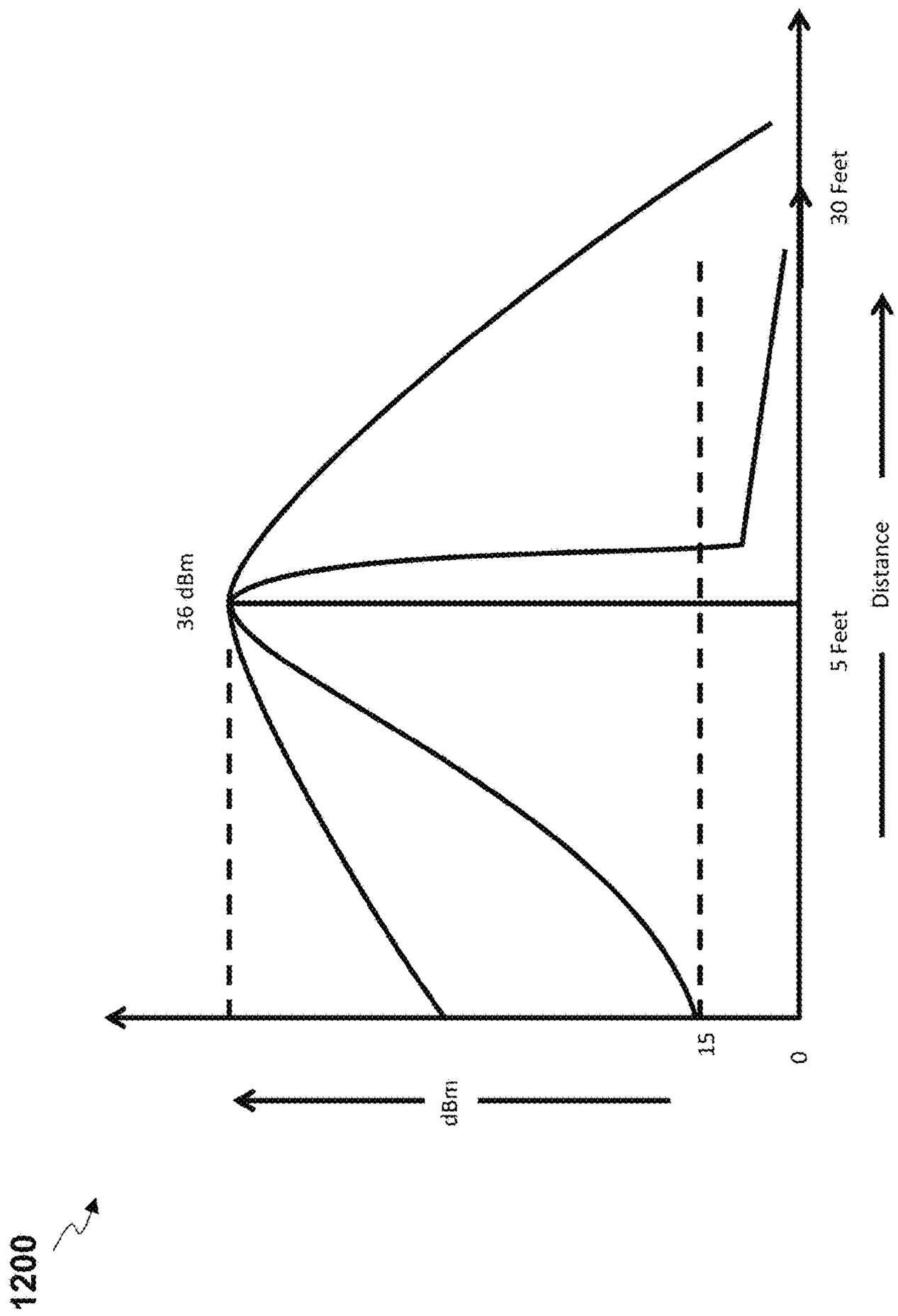

FIG. 12

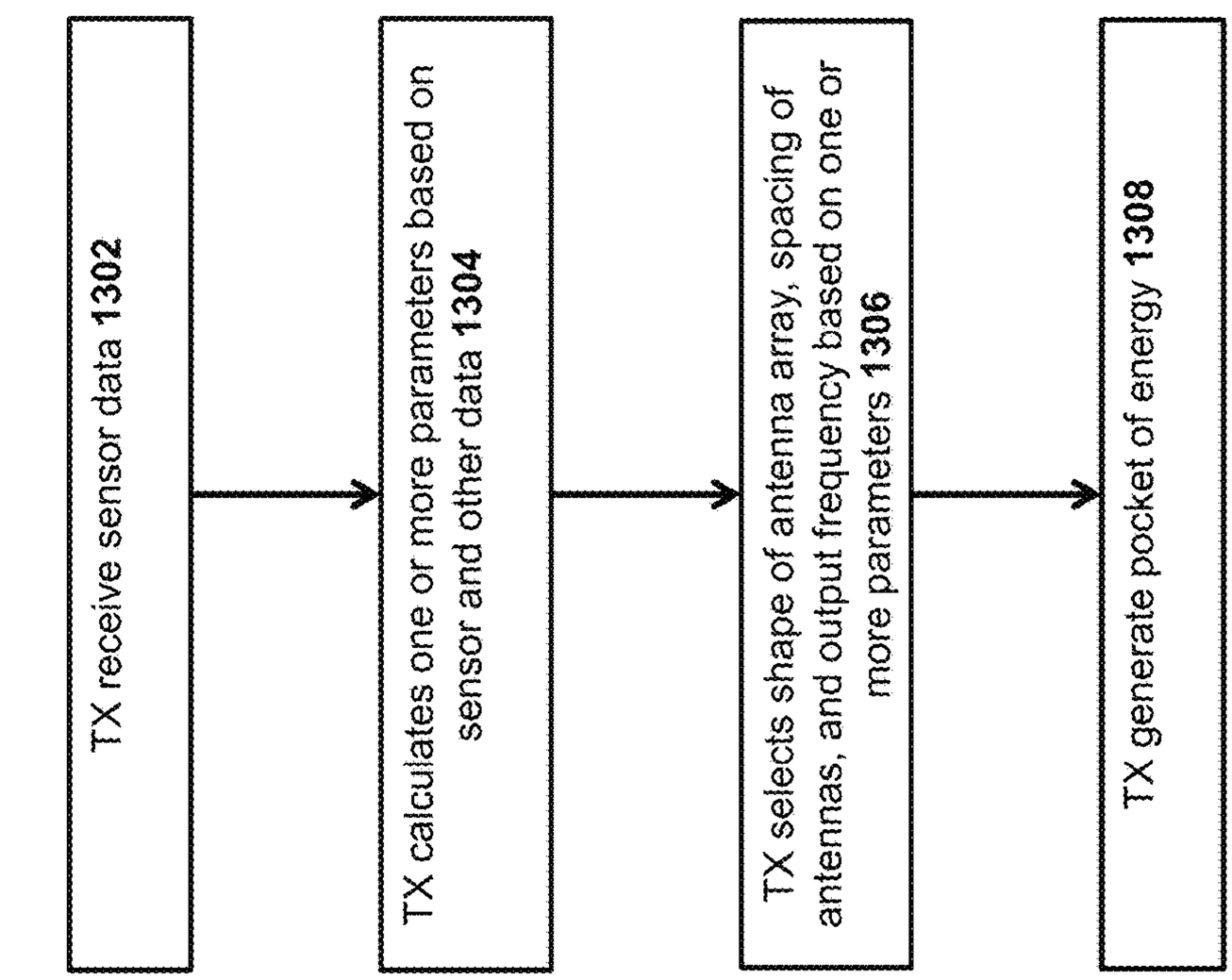
1300
TX receive sensor data 1302
TX calculates one or more parameters based on sensor and other data 1304
TX selects shape of antenna array, spacing of antennas, and output frequency based on one or more parameters 1306
TX generate pocket of energy 1308

FIG. 13

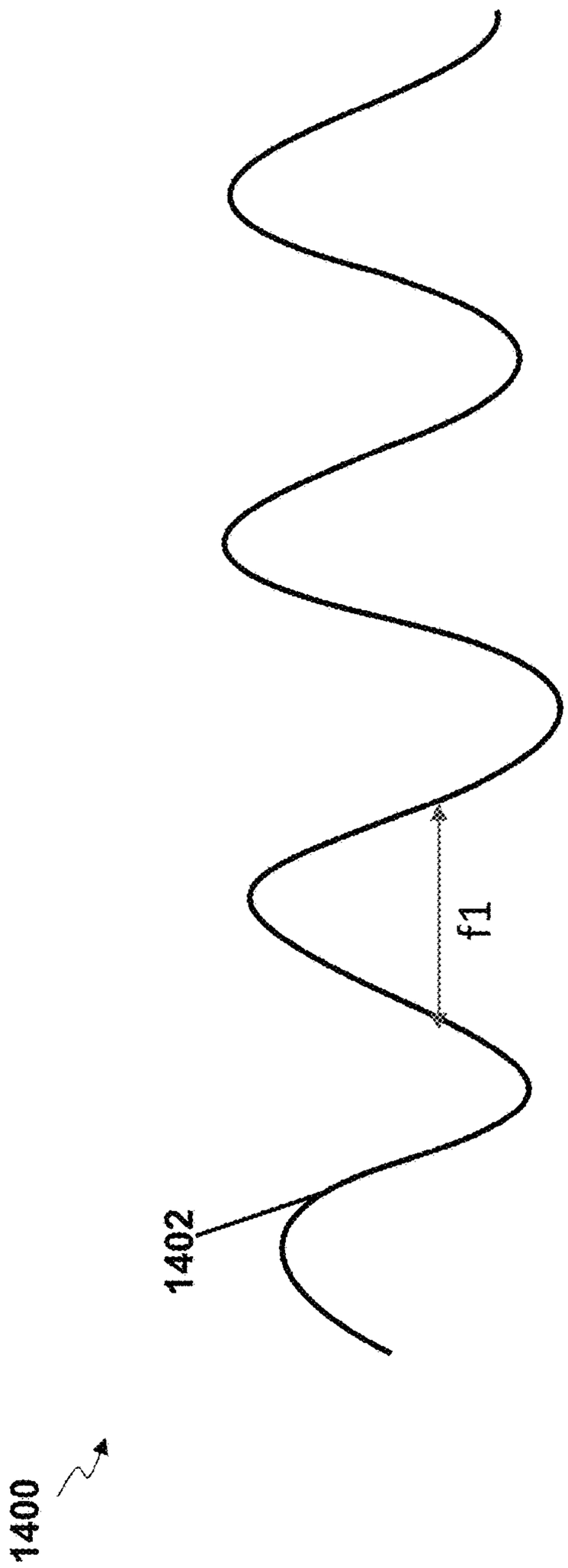

FIG. 14A

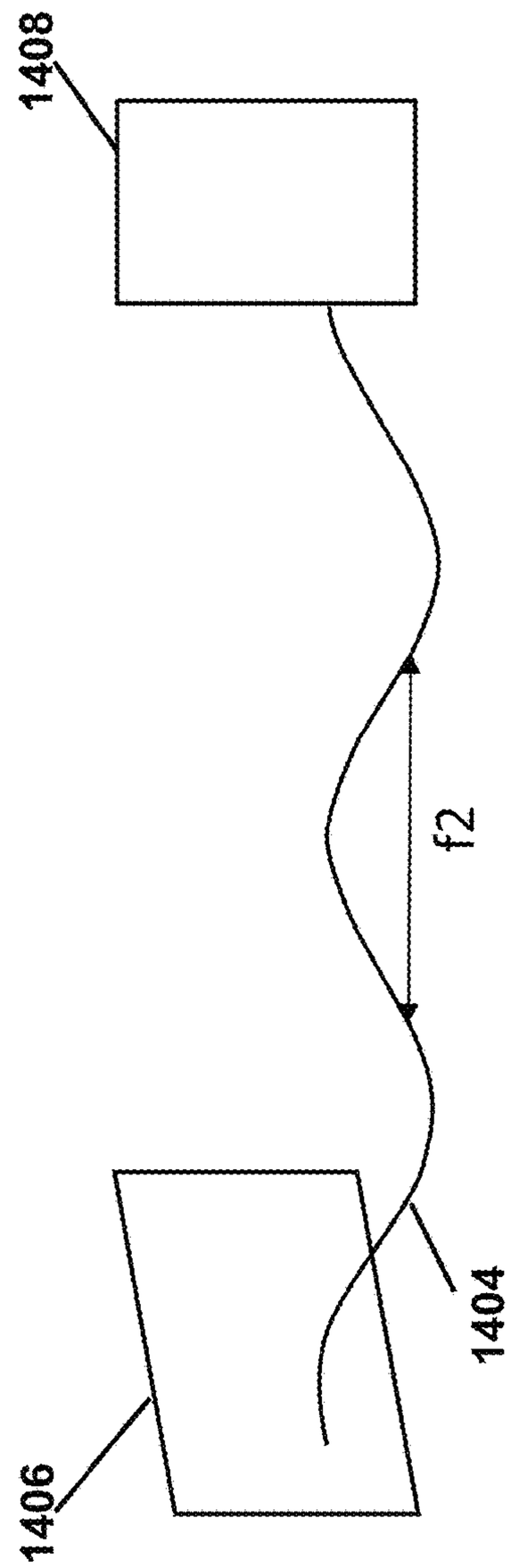

FIG. 14B

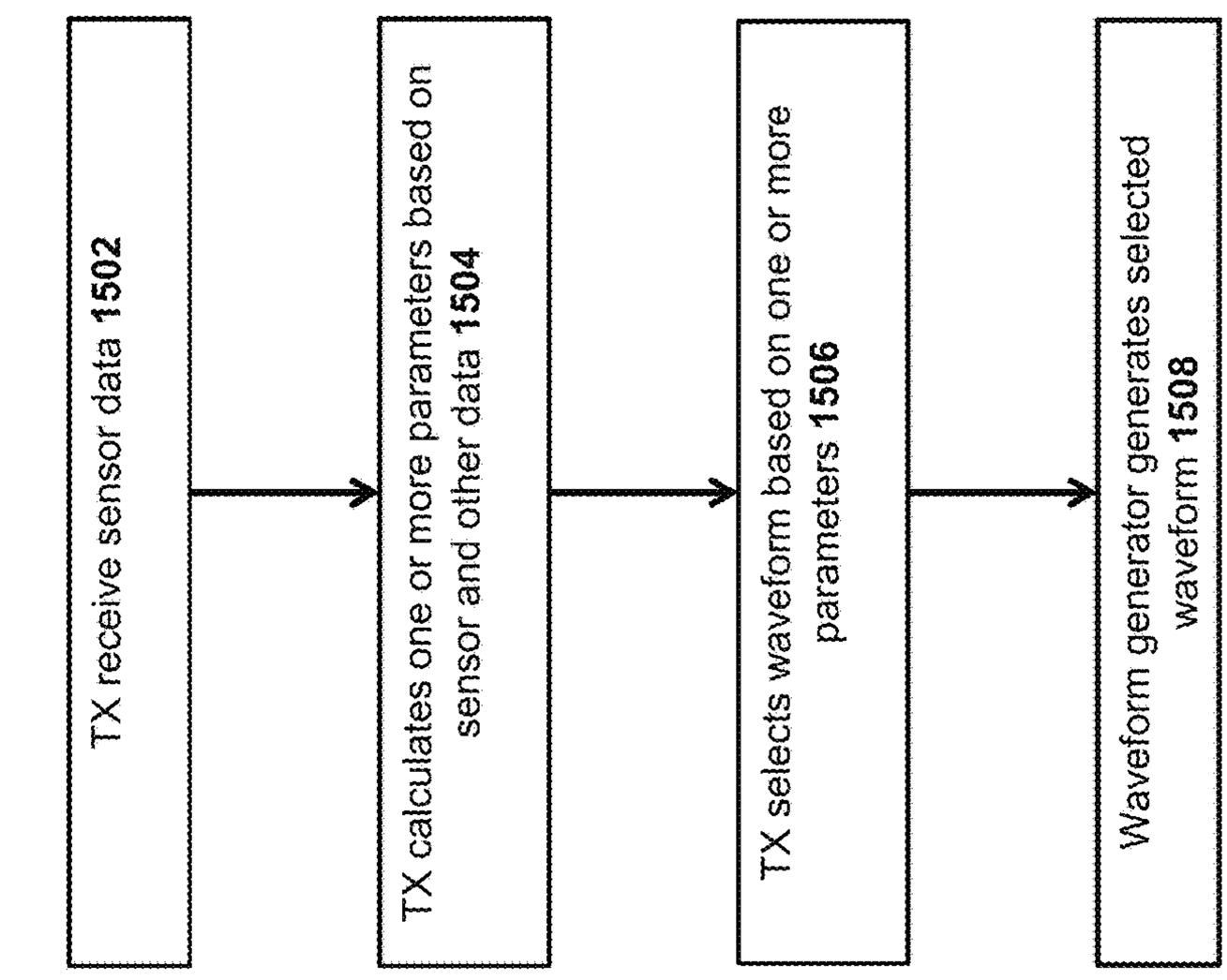
1500
TX receive sensor data 1502
TX calculates one or more parameters based on sensor and other data 1504
TX selects waveform based on one or more parameters 1506
Waveform generator generates selected waveform 1508

FIG. 15

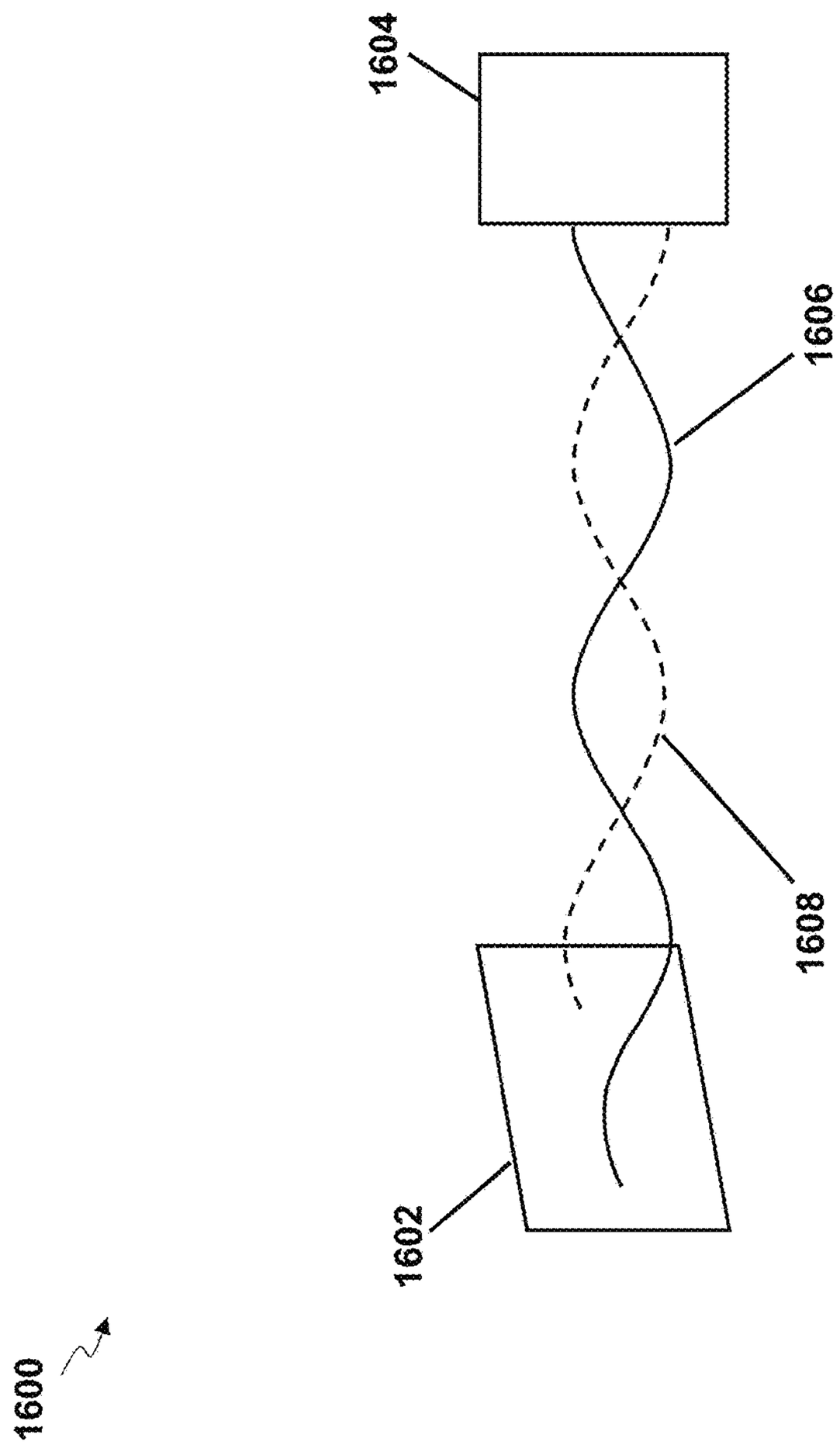

FIG. 16

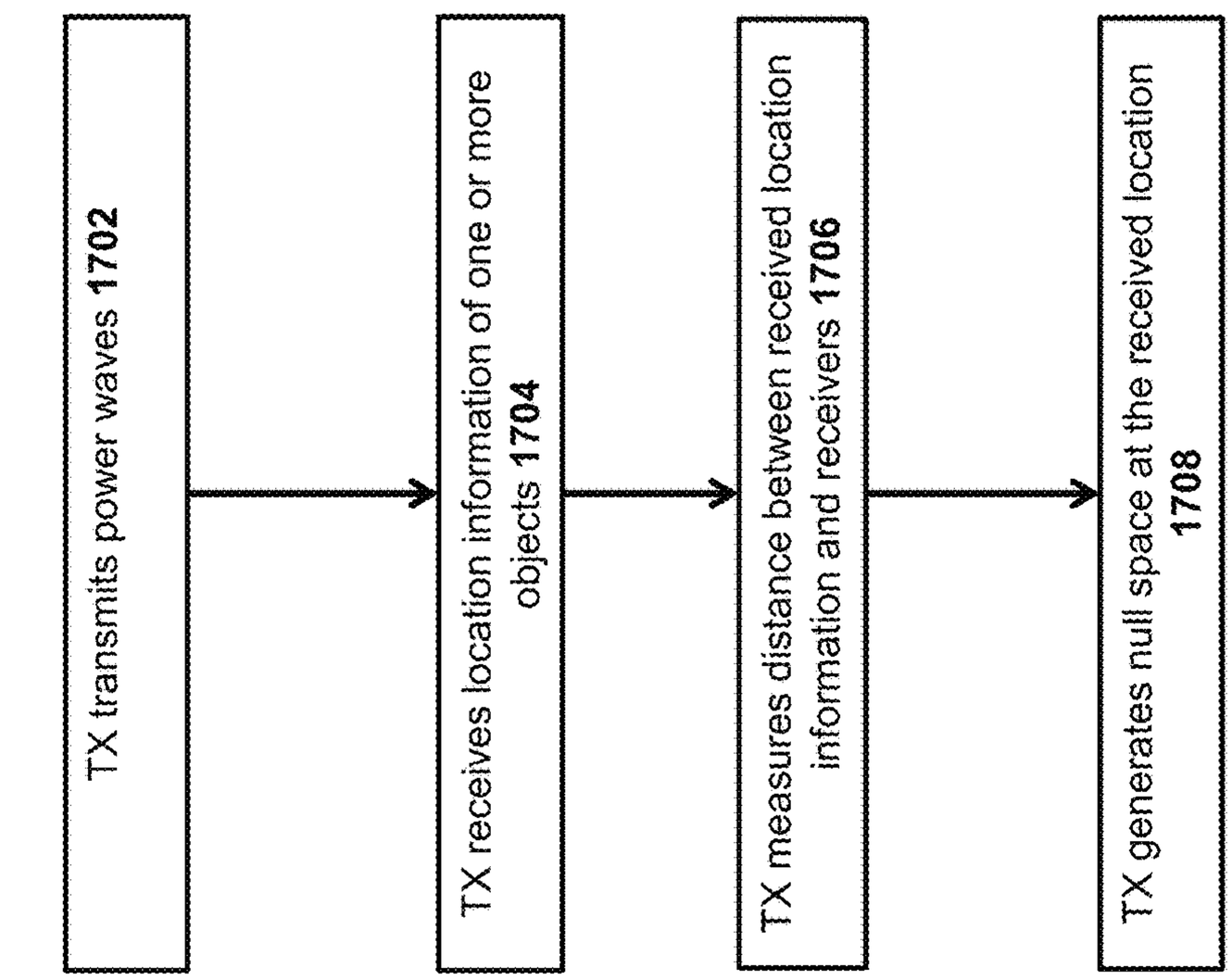
1700
TX transmits power waves 1702
TX receives location information of one or more objects 1704
TX measures distance between received location information and receivers 1706
TX generates null space at the received location 1708

FIG. 17

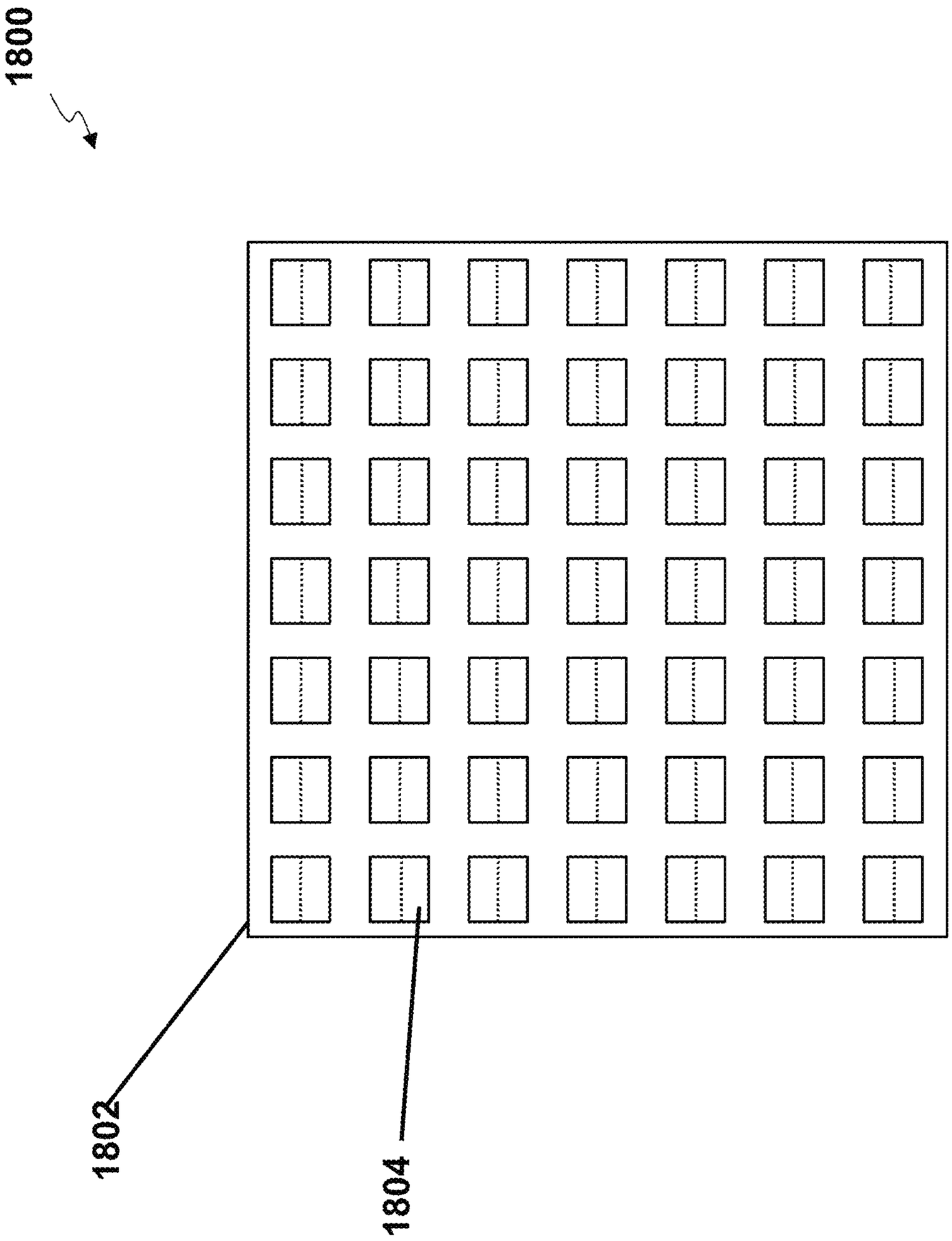

FIG. 18

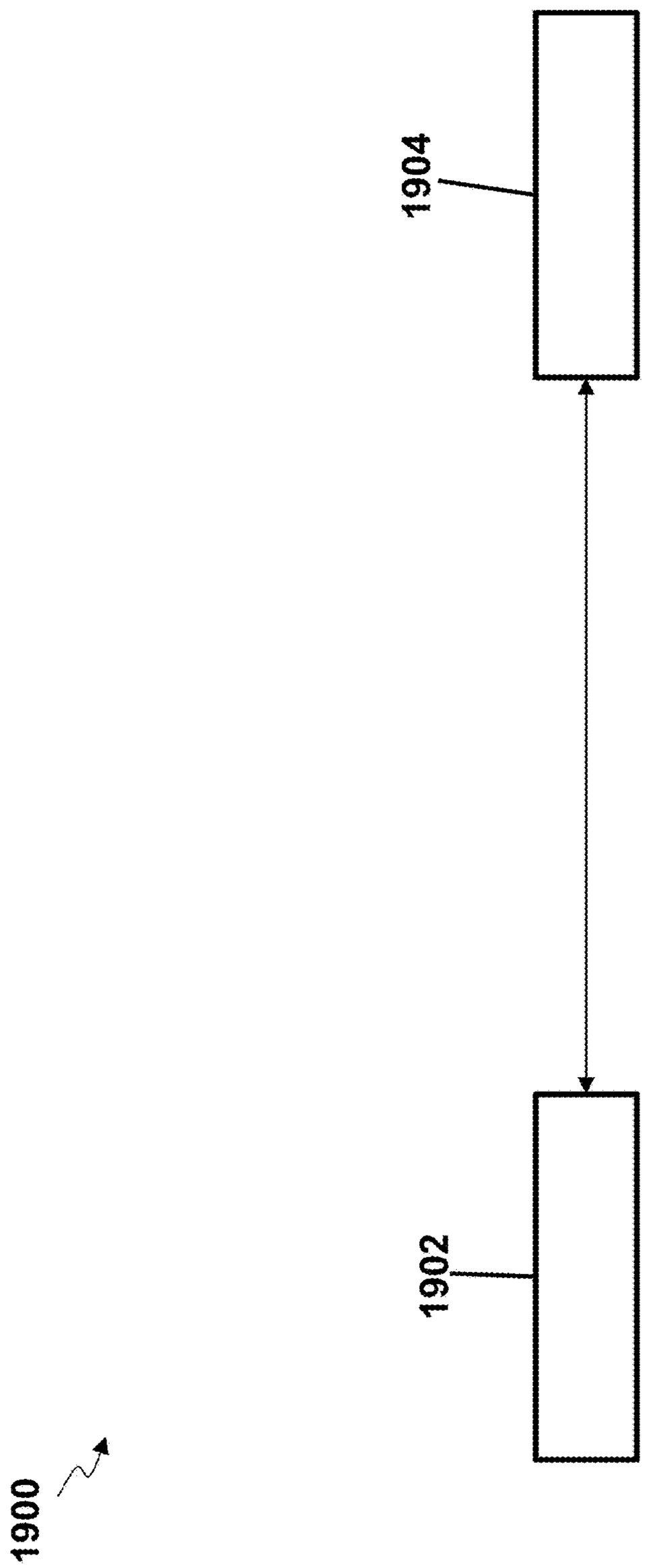

FIG. 19

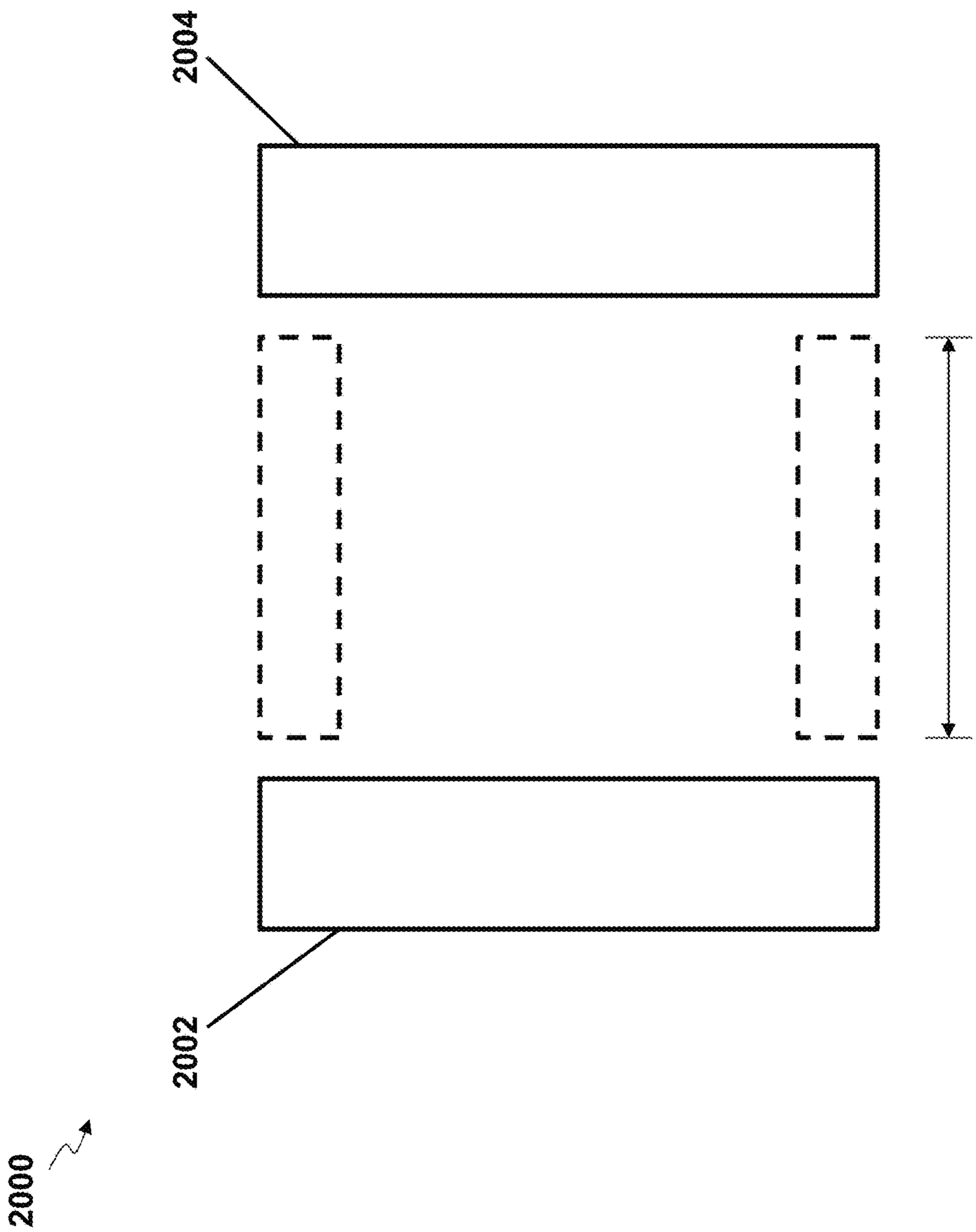

FIG. 20

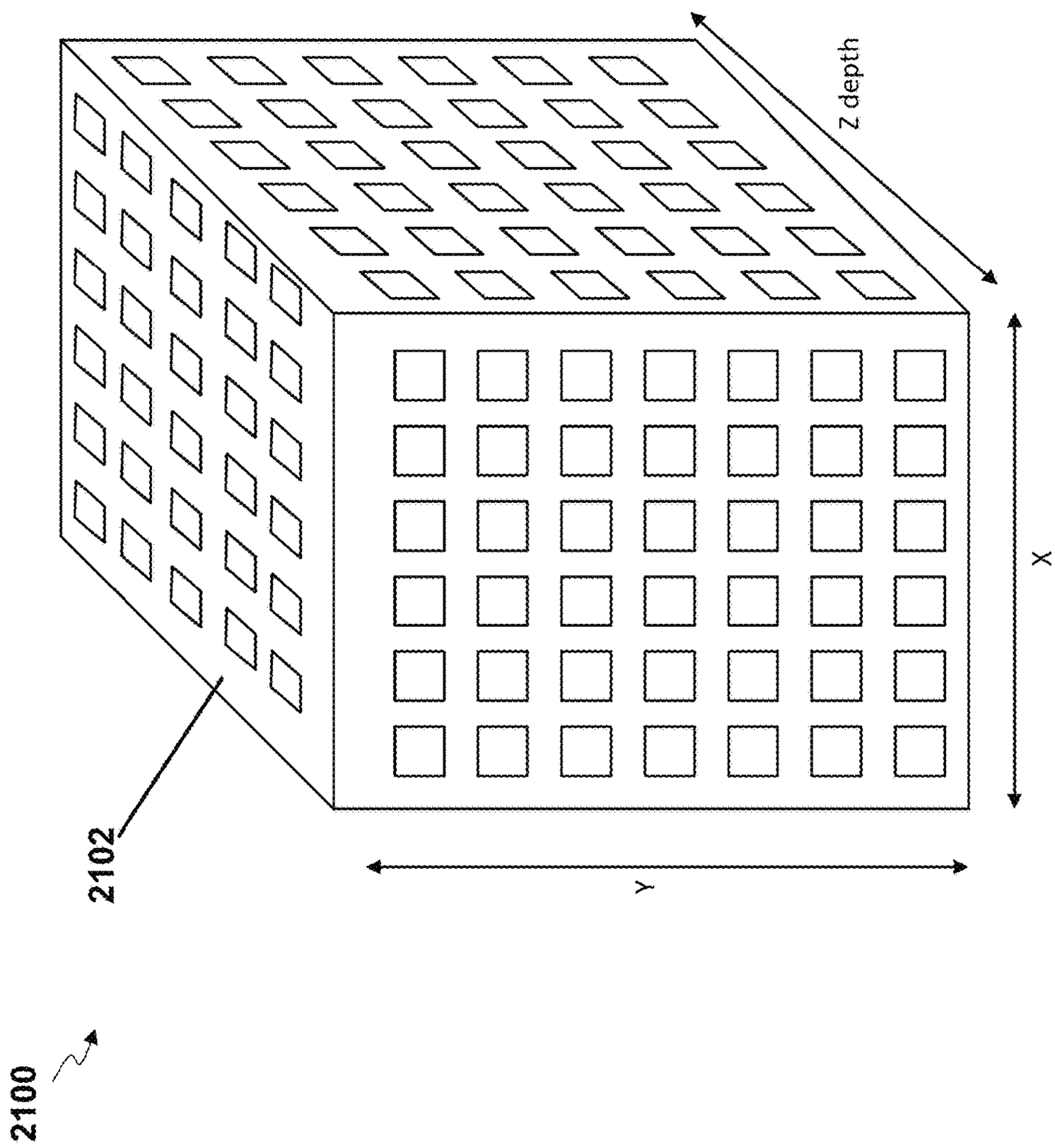

FIG. 21

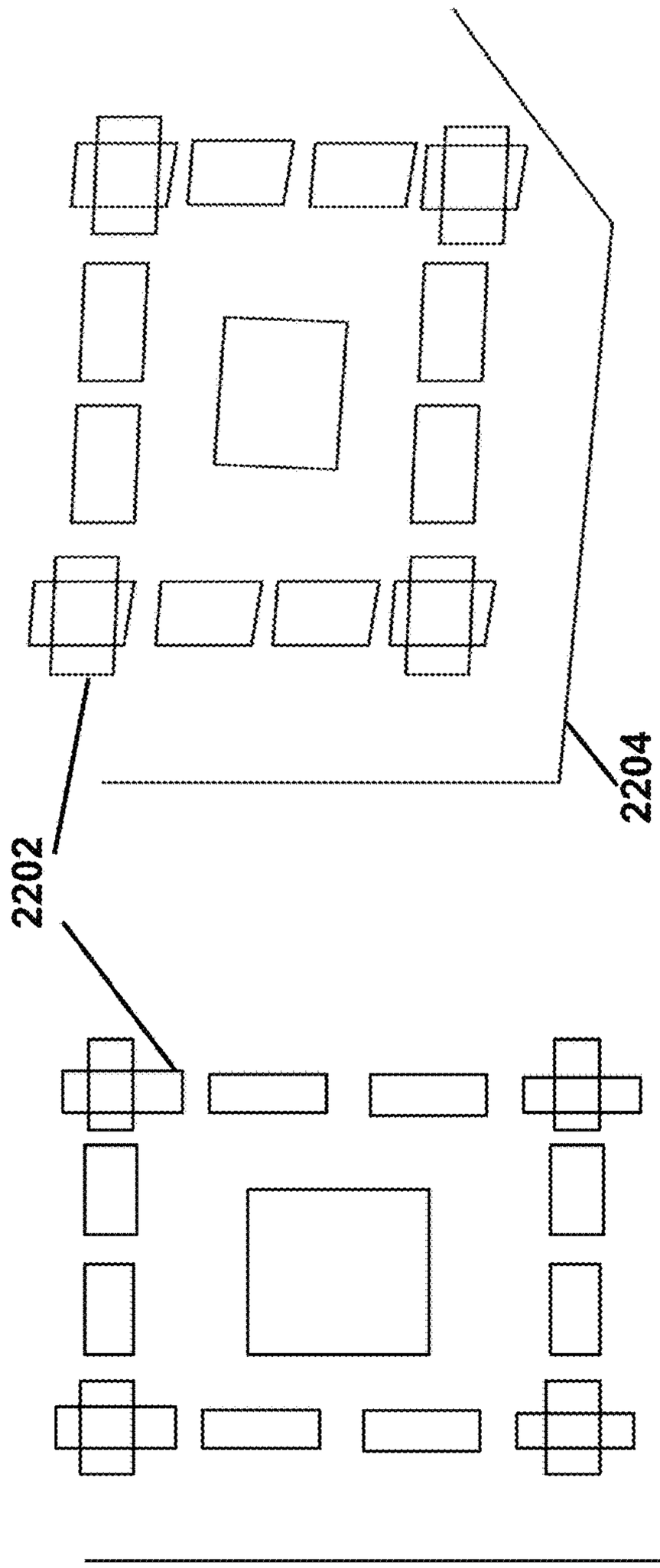

FIG. 22A

FIG. 22B

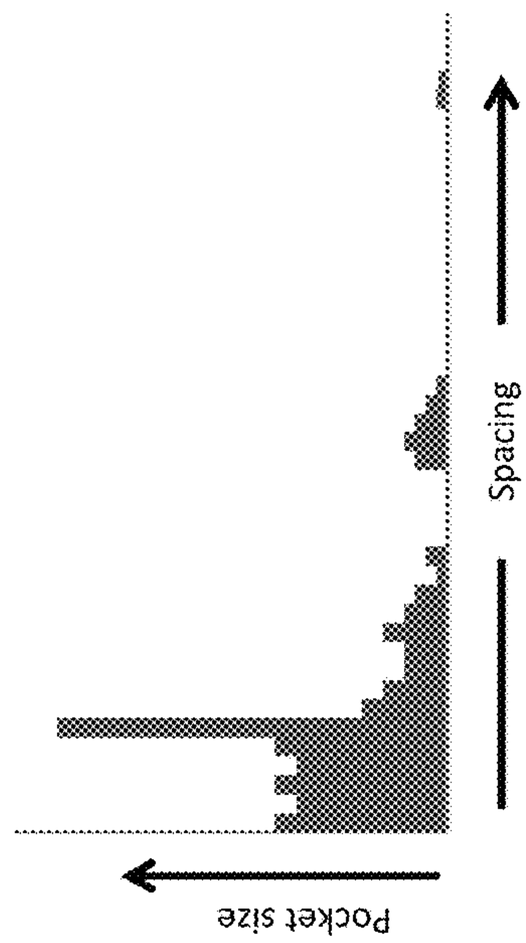

FIG. 22C

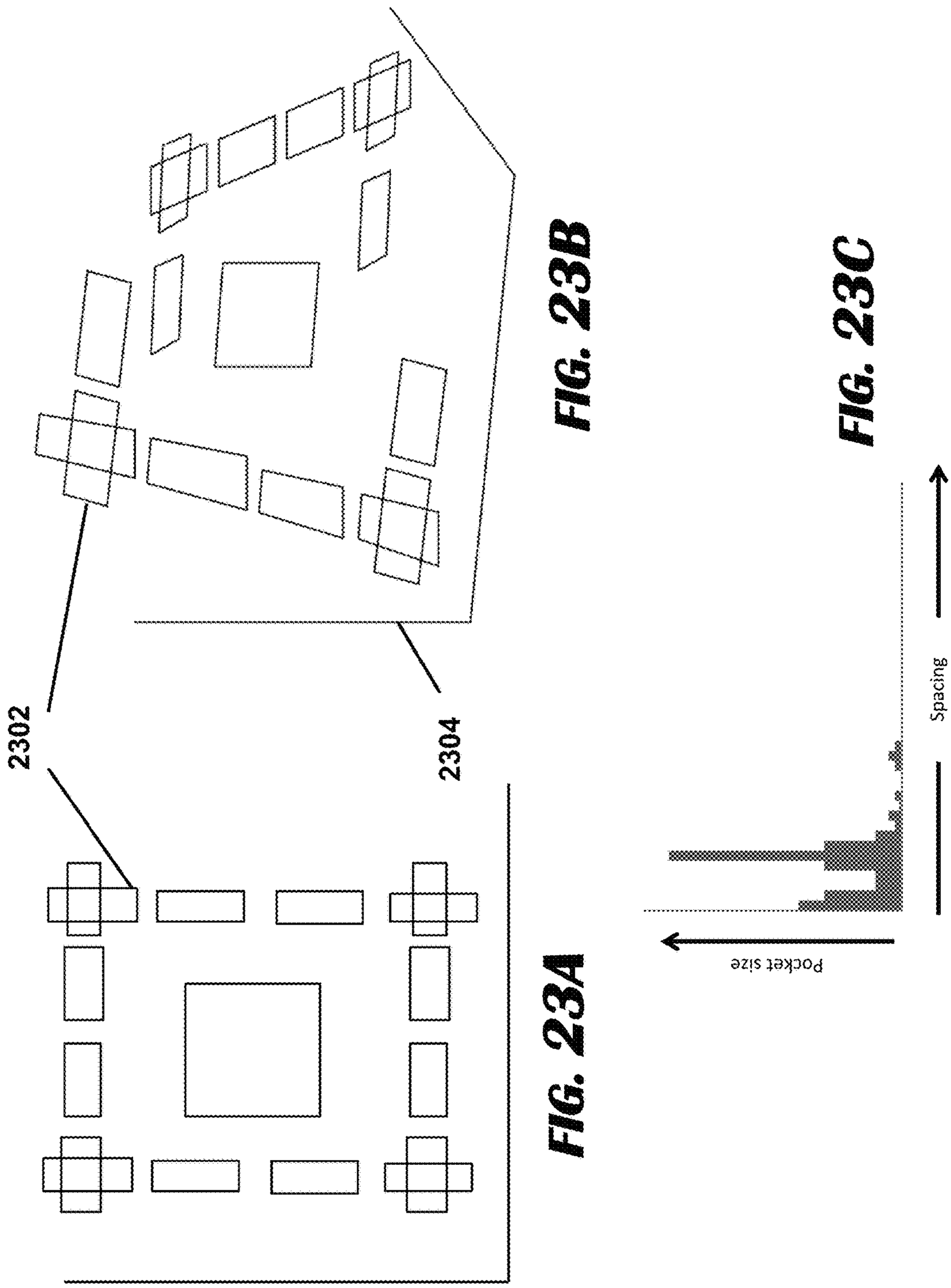

FIG. 23A

FIG. 23B

FIG. 23C

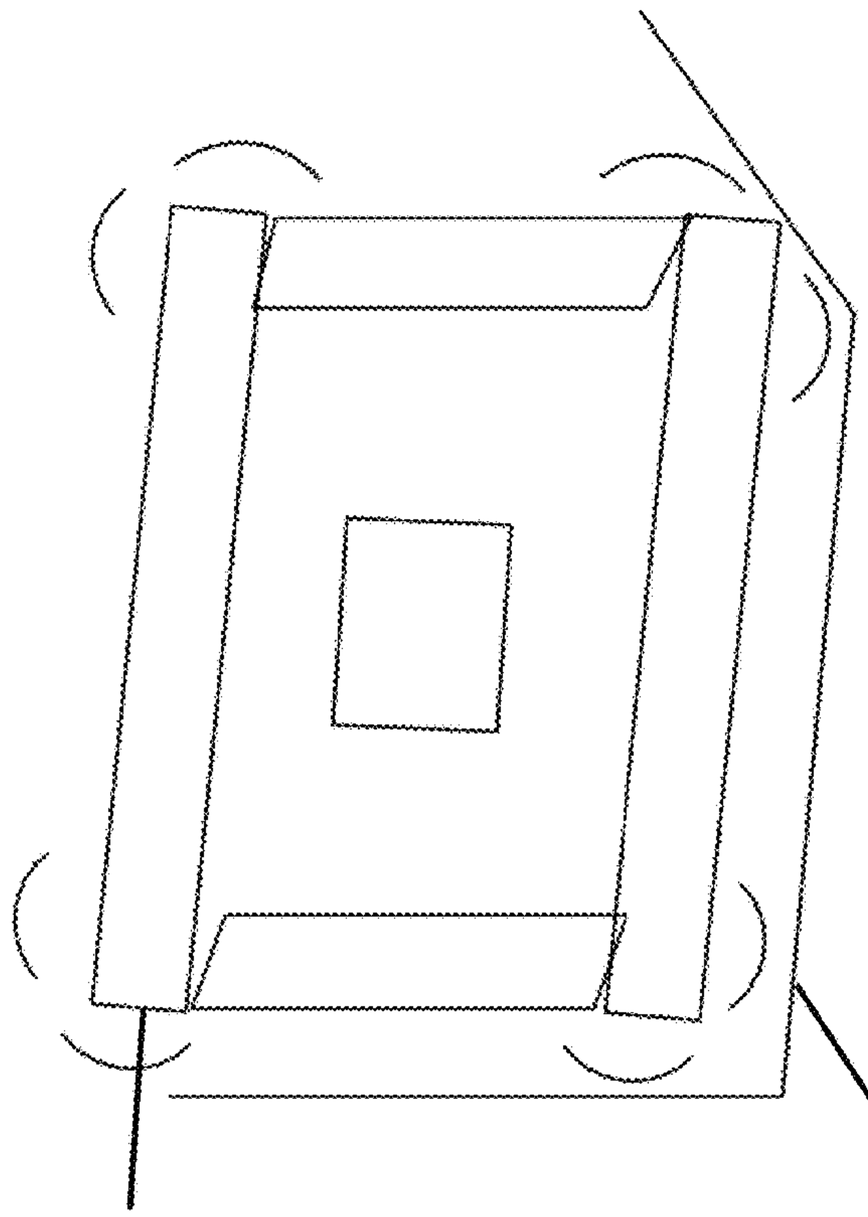

FIG. 24A

FIG. 24B

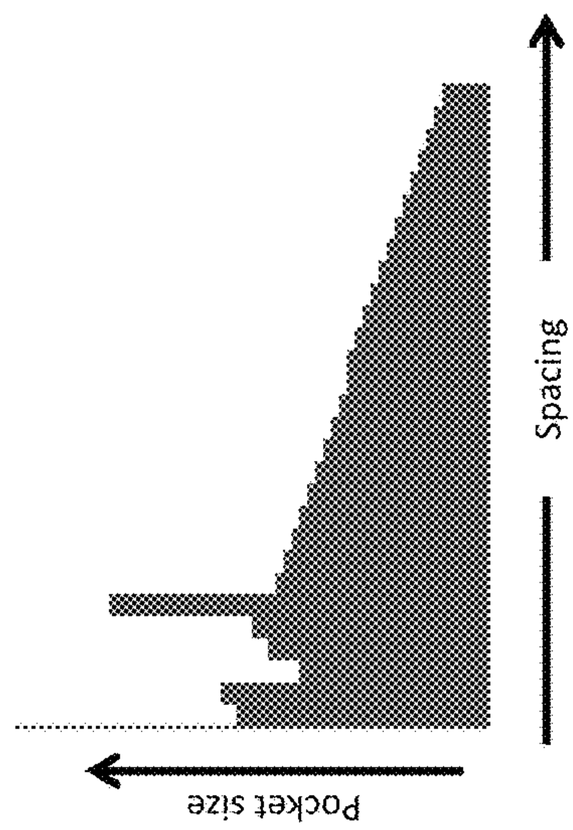

FIG. 24C

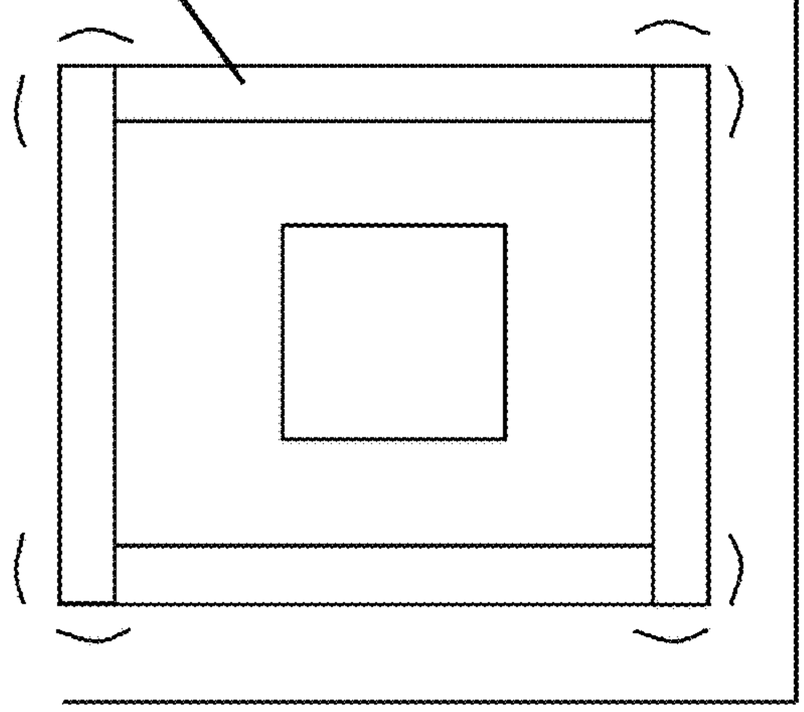

FIG. 25A

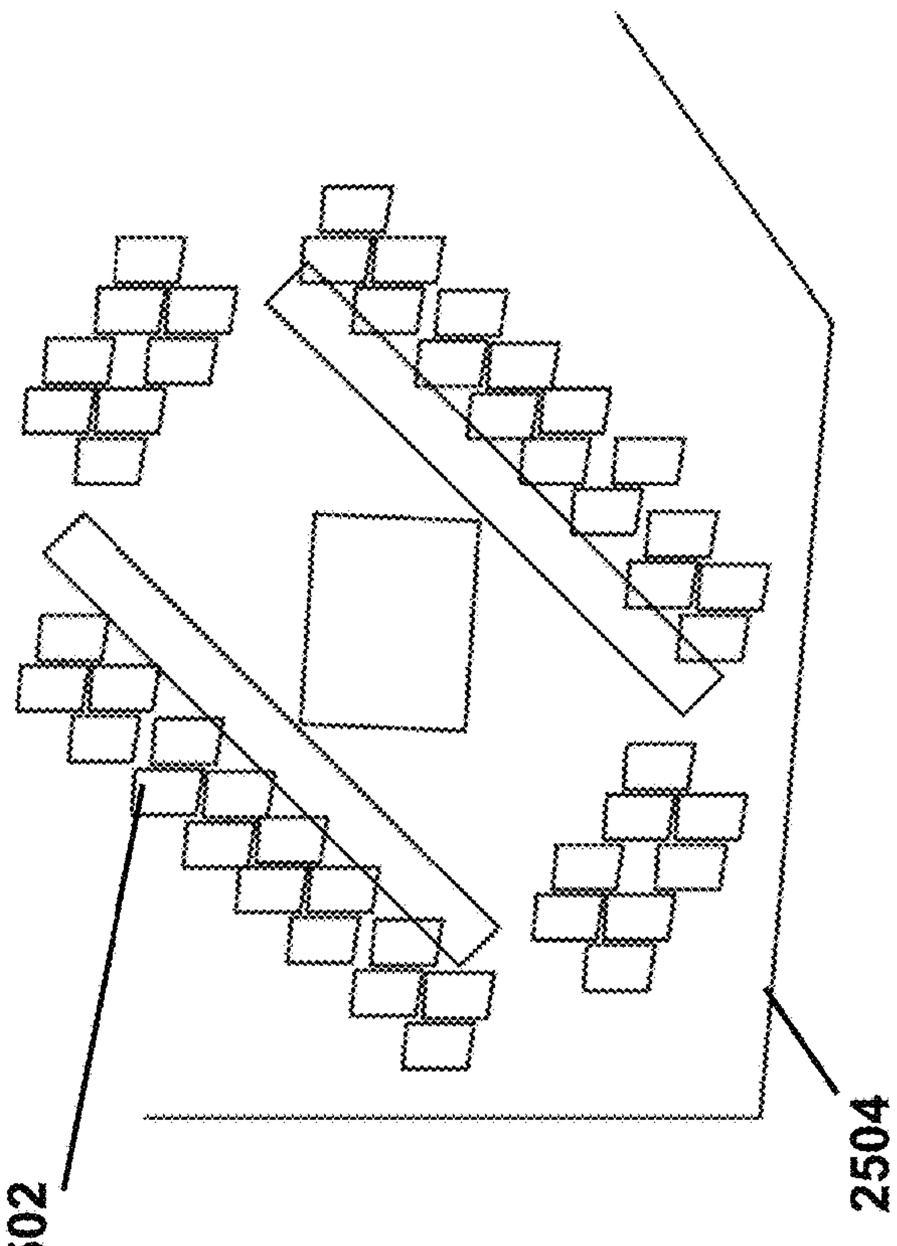

FIG. 25B

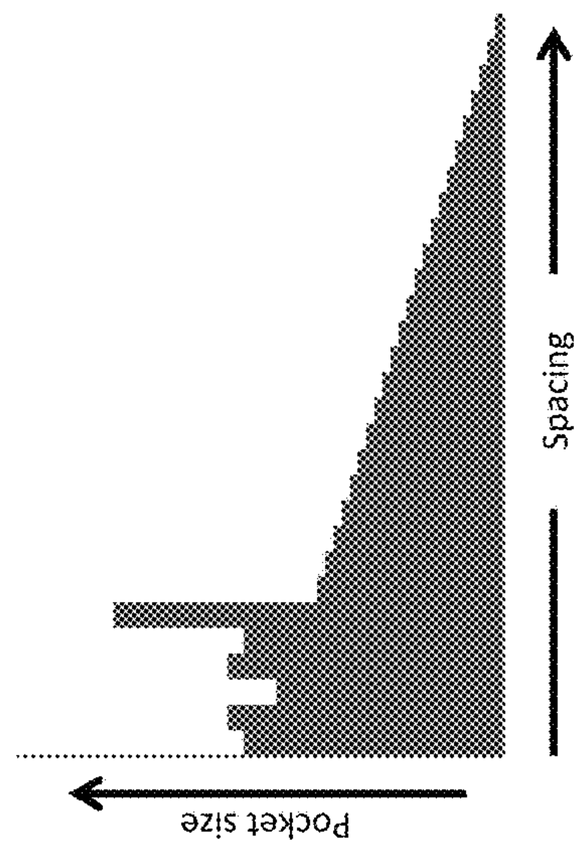

FIG. 25C

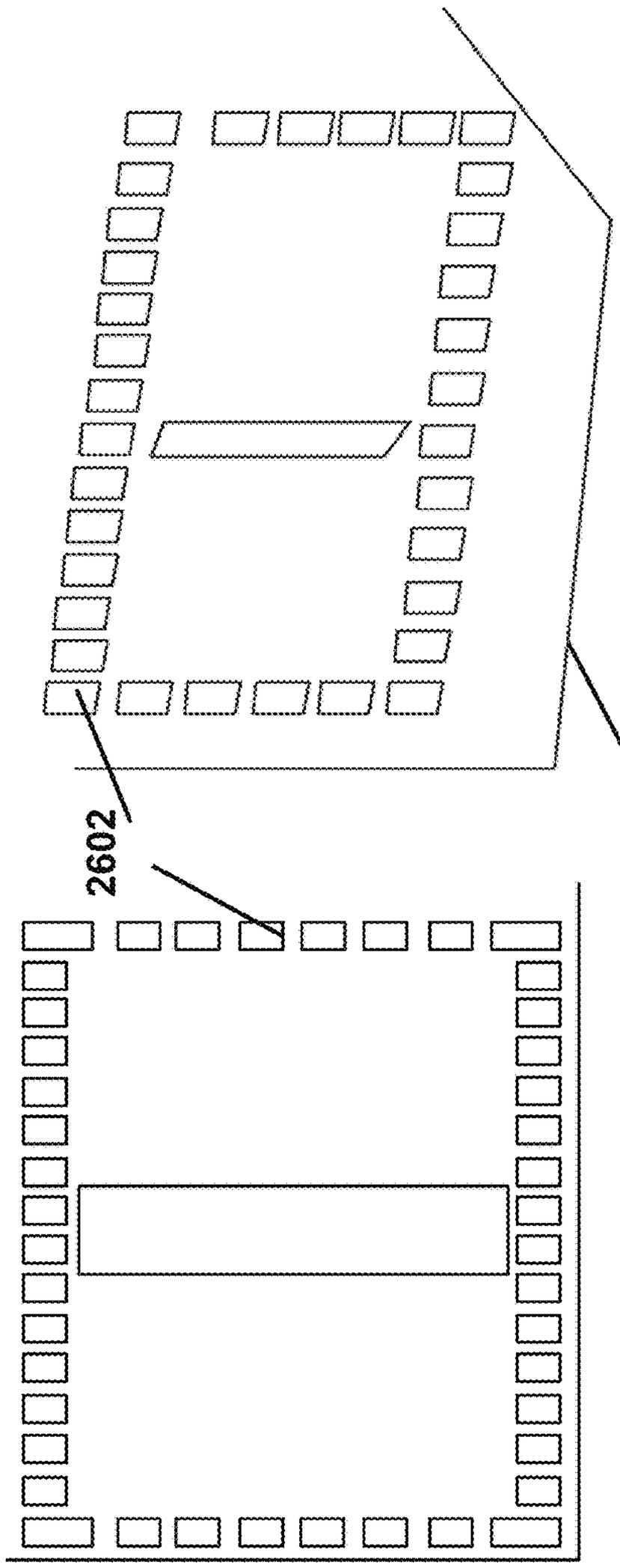

FIG. 26A

FIG. 26B

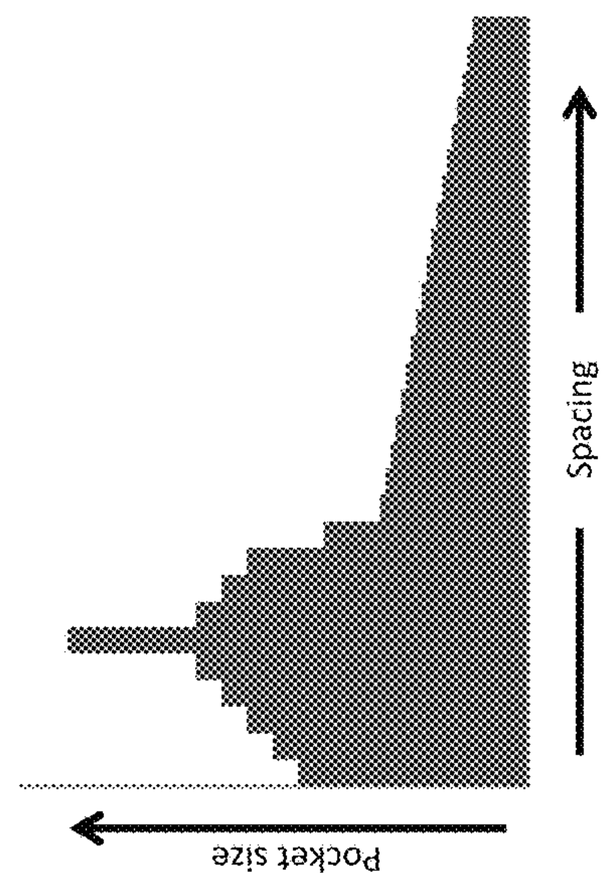

FIG. 26C

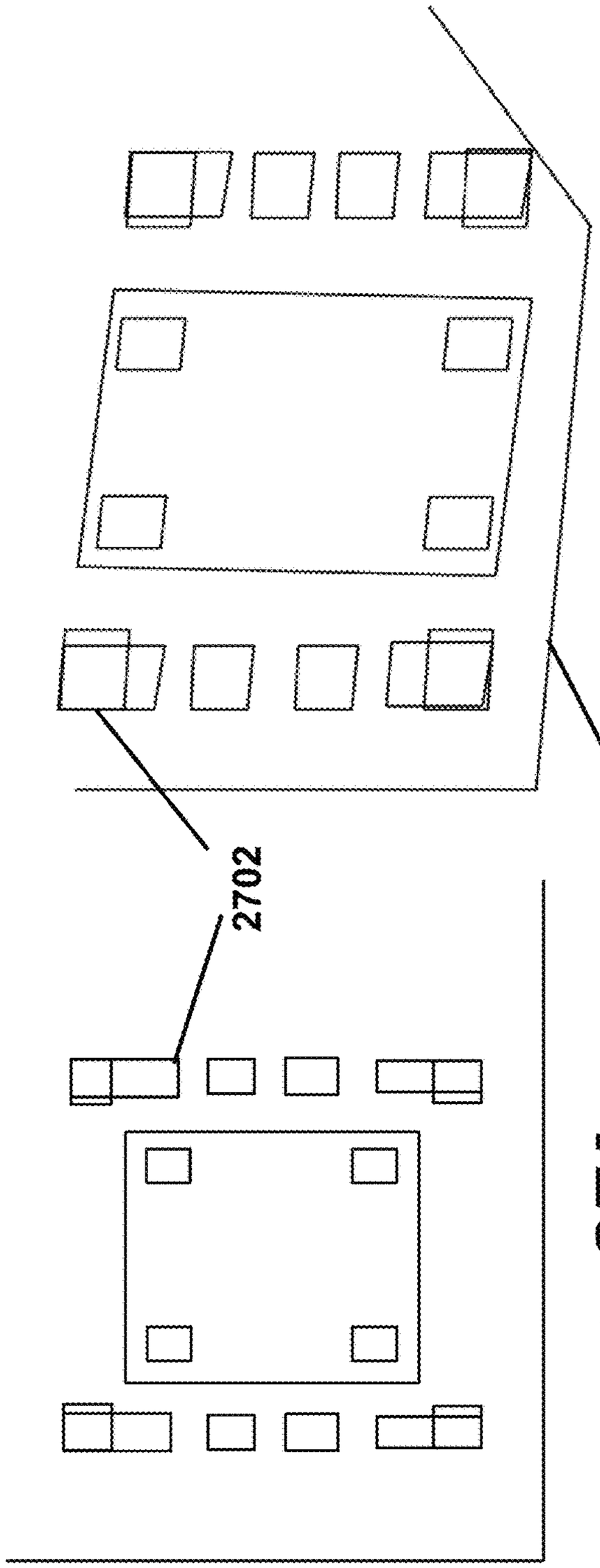

FIG. 27A

FIG. 27B

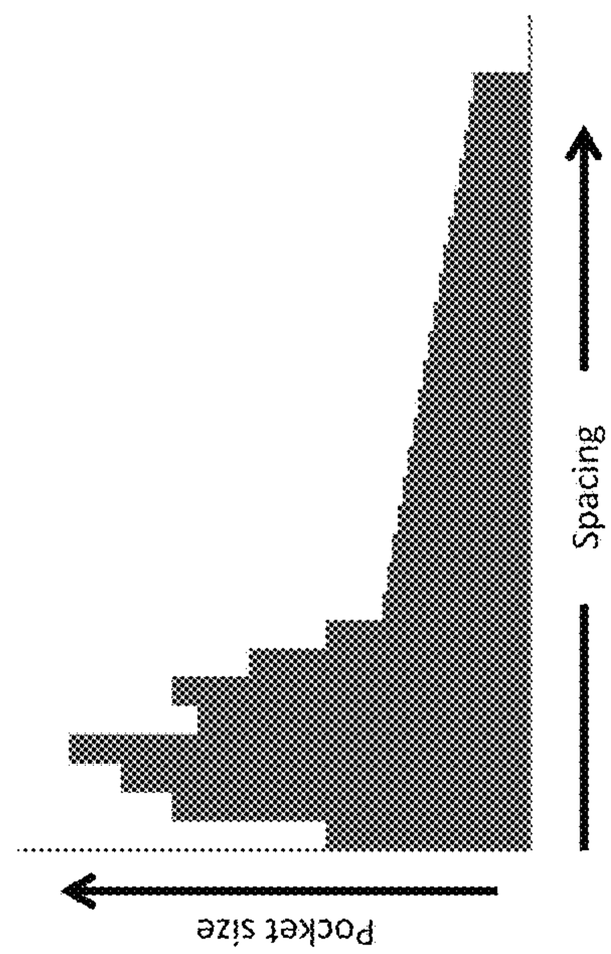

FIG. 27C

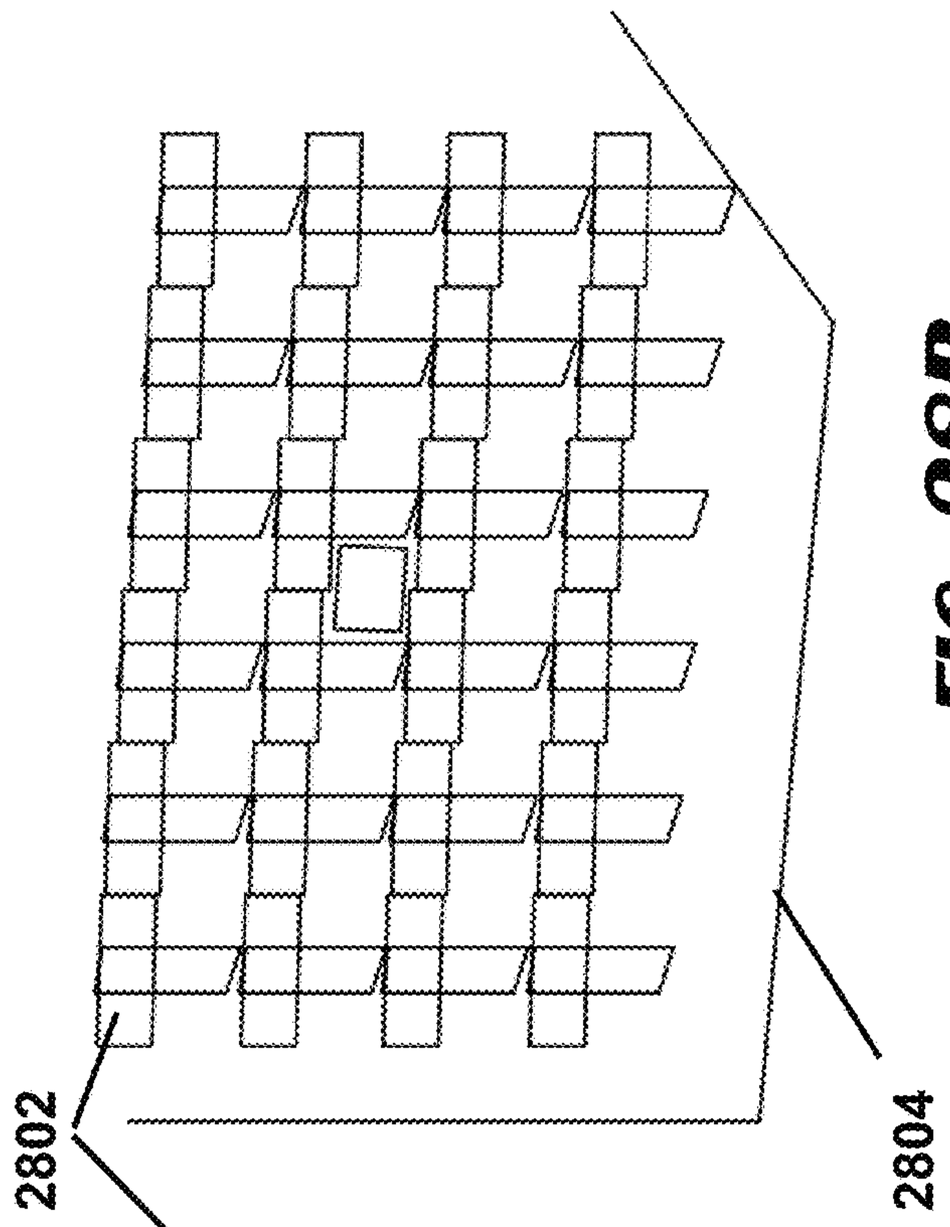

FIG. 28B

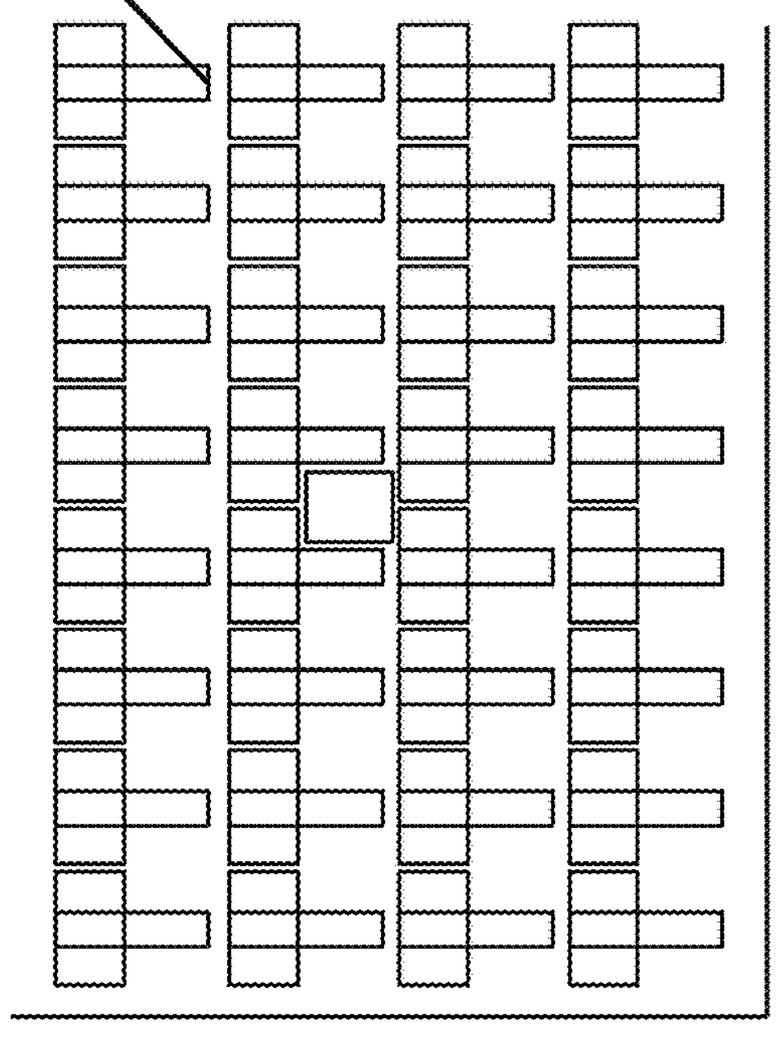

FIG. 28A

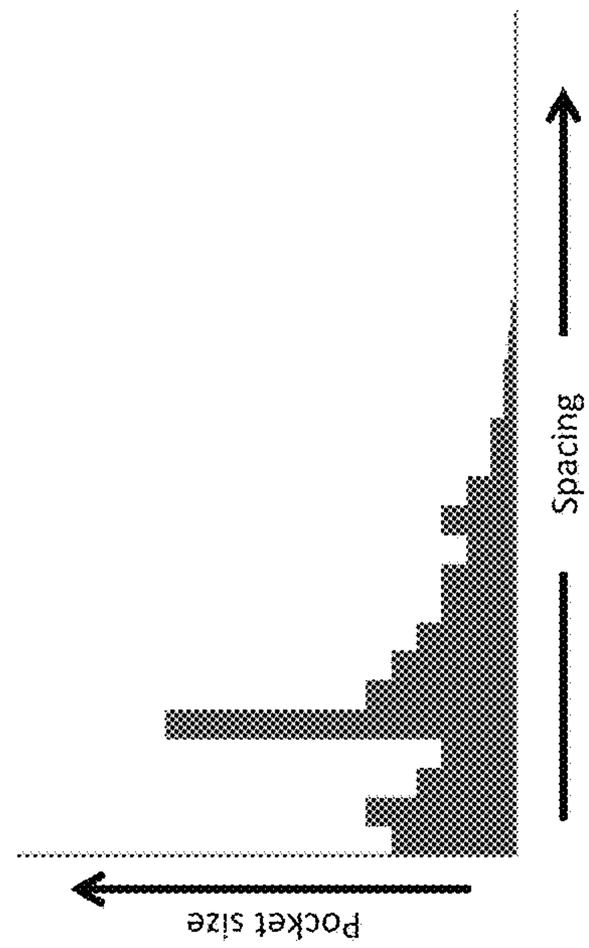

FIG. 28C

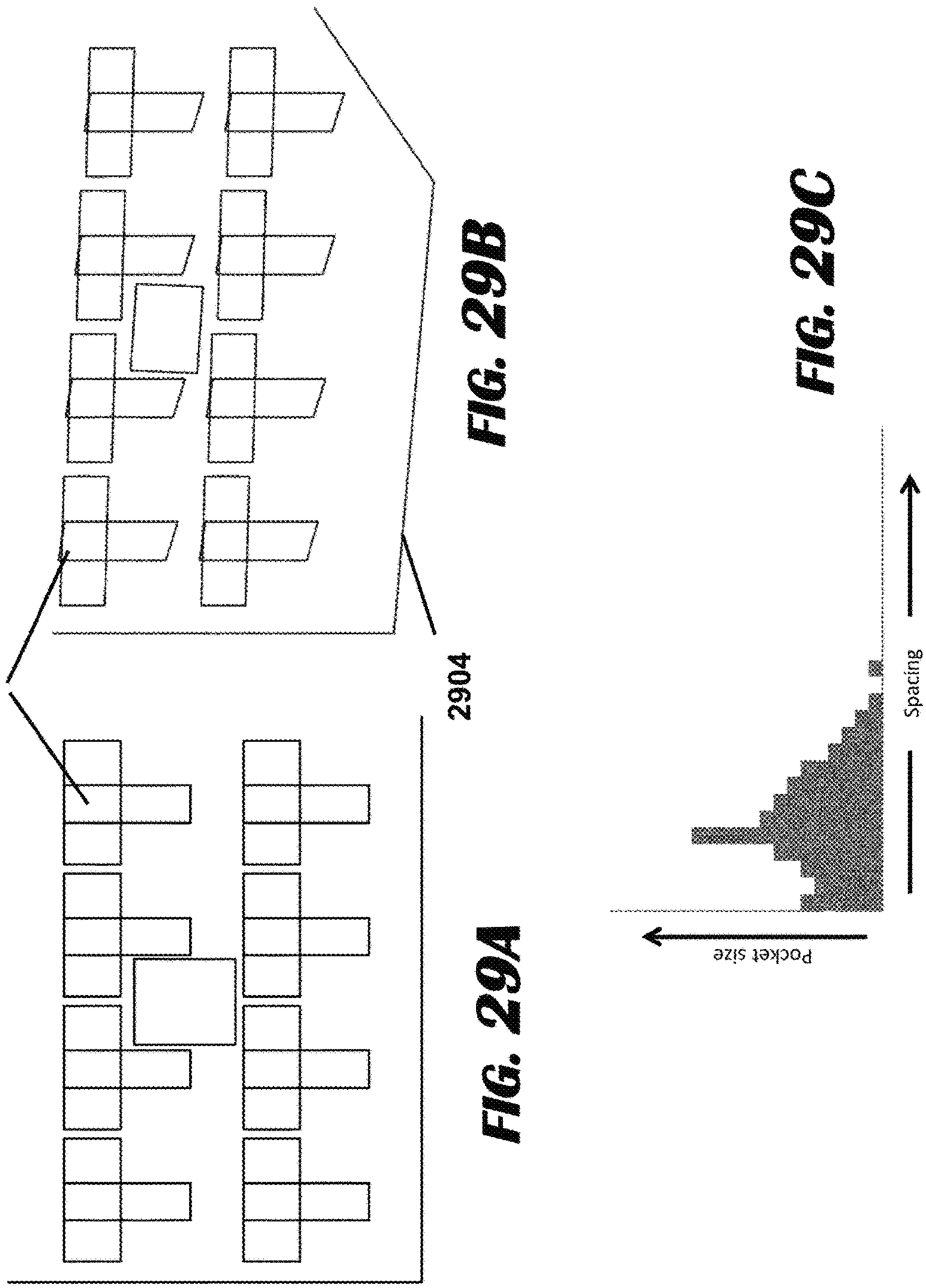

FIG. 29A

FIG. 29B

FIG. 29C

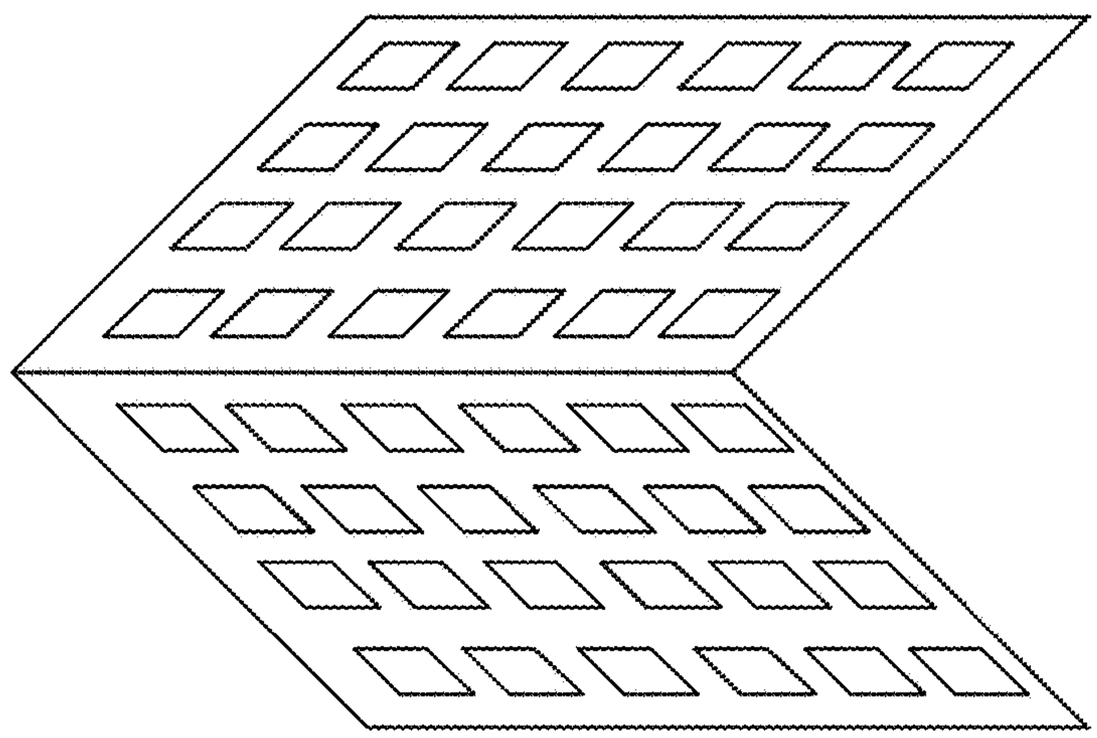

FIG. 30

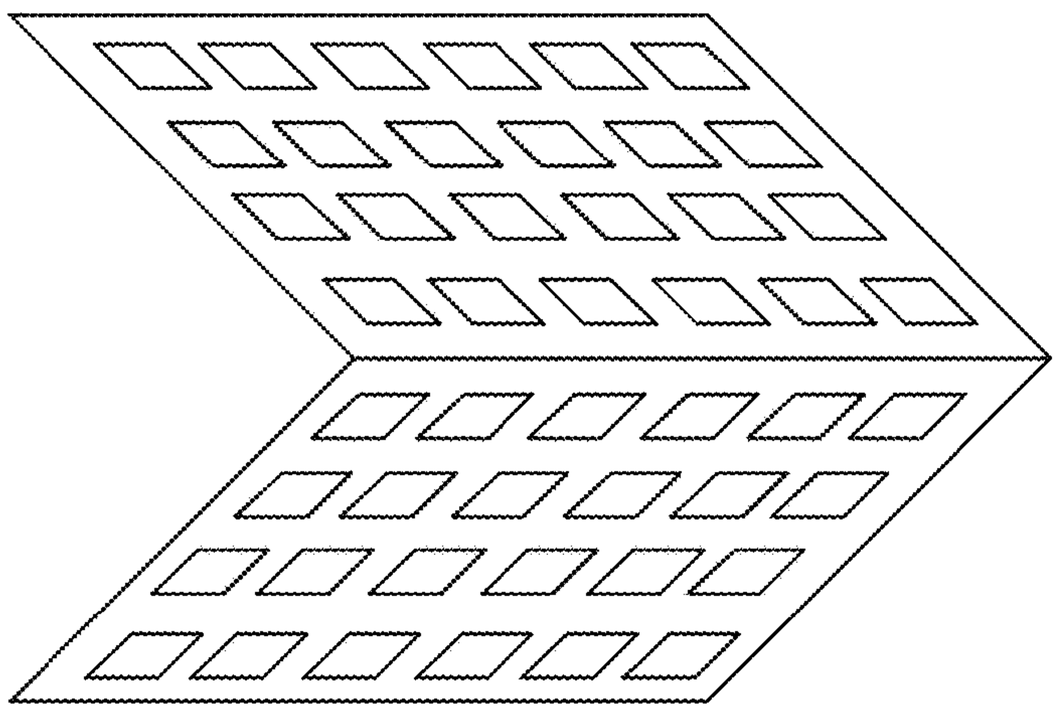

FIG. 31

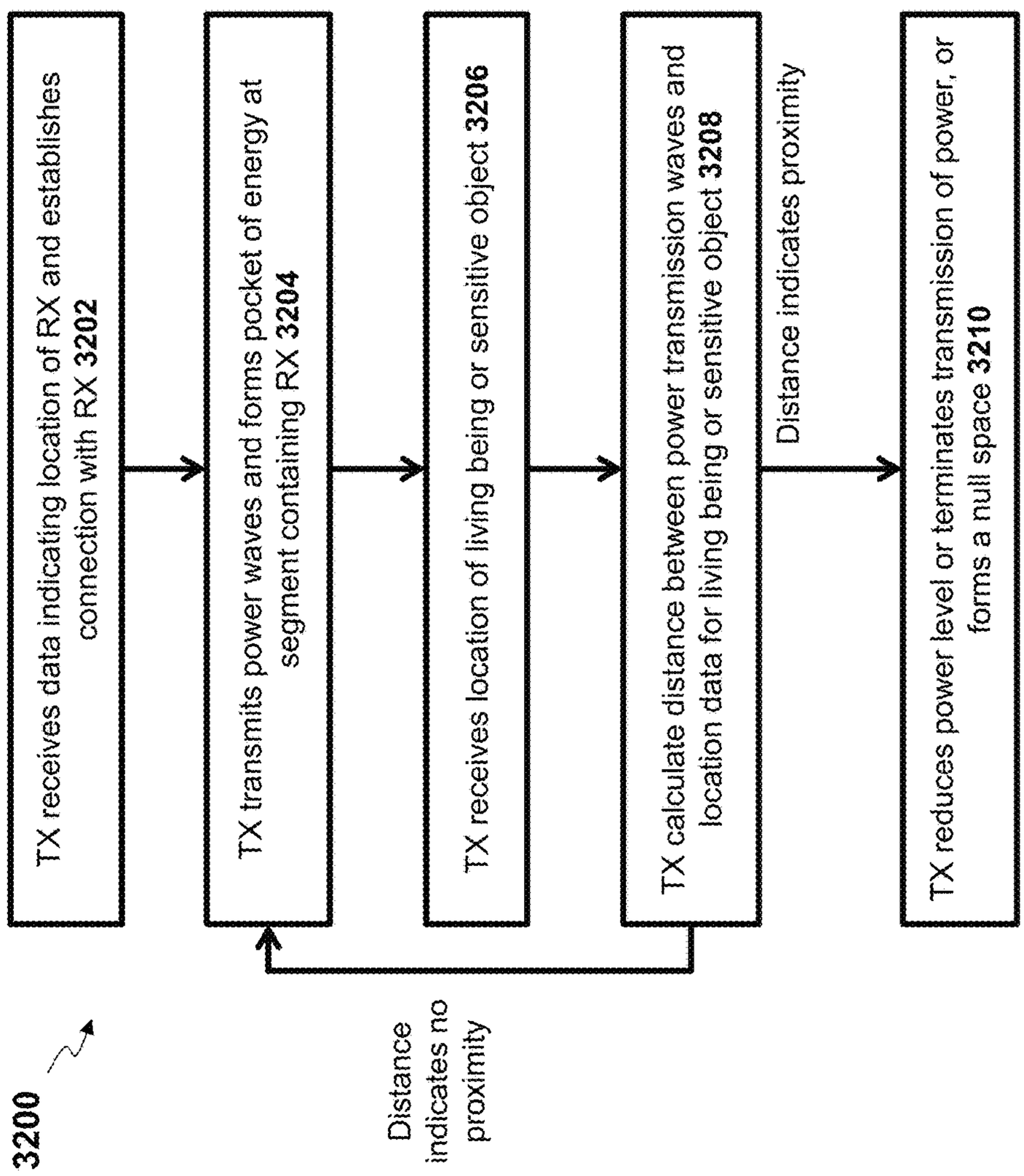
3200
TX receives data indicating location of RX and establishes connection with RX 3202
TX transmits power waves and forms pocket of energy at segment containing RX 3204
TX receives location of living being or sensitive object 3206
TX calculate distance between power transmission waves and location data for living being or sensitive object 3208
Distance indicates proximity
TX reduces power level or terminates transmission of power, or forms a null space 3210
Distance indicates no proximity

FIG. 32

SYSTEMS AND METHODS FOR NULLIFYING ENERGY LEVELS FOR WIRELESS POWER TRANSMISSION WAVES

TECHNICAL FIELD OF DISCLOSURE

This application generally relates to wireless charging systems and the hardware and software components used in such systems.

BACKGROUND

Numerous attempts have been made to wirelessly transmit energy to electronic devices, where a receiver device can consume the transmission and convert it to electrical energy. However, most conventional techniques are unable to transmit energy at any meaningful distance. For example, magnetic resonance provides electric power to devices without requiring an electronic device to be wired to a power resonator. However, the electronic device is required to be proximately located to a coil of the power resonator (i.e., within a magnetic field). Other conventional solutions may not contemplate user mobility for users who are charging their mobile devices or such solutions do not allow devices to be outside of a narrow window of operability.

Wirelessly powering a remote electronic device requires a means for identifying the location of electronic devices within a transmission field of a power-transmitting device. Conventional systems typically attempt to proximately locate an electronic device, so there are no capabilities for identifying and mapping the spectrum of available devices to charge, for example, in a large coffee shop, household, office building, or other three-dimensional space in which electrical devices could potentially move around. Moreover, what is needed is a system for managing power wave production, both for directionality purposes and power output modulation. Because many conventional systems do not contemplate a wide range of movement of the electronic devices they service, what is also needed is a means for dynamically and accurately tracking electronic devices that may be serviced by the power-transmitting devices.

Wireless power transmission may need to satisfy certain regulatory requirements. These devices transmitting wireless energy may be required to adhere to electromagnetic field (EMF) exposure protection standards for humans or other living beings. Maximum exposure limits are defined by US and European standards in terms of power density limits and electric field limits (as well as magnetic field limits). Some of these limits are established by the Federal Communications Commission (FCC) for Maximum Permissible Exposure (MPE), and some limits are established by European regulators for radiation exposure. Limits established by the FCC for MPE are codified at 47 CFR § 1.1310. For electromagnetic field (EMF) frequencies in the microwave range, power density can be used to express an intensity of exposure. Power density is defined as power per unit area. For example, power density can be commonly expressed in terms of watts per square meter (W/m2), milliwatts per square centimeter (mW/cm2), or microwatts per square centimeter (μW/cm2).

Accordingly, it is desirable to appropriately administer the systems and methods for wireless power transmission to satisfy these regulatory requirements. What is needed is a means for wireless power transmission that incorporates various safety techniques to ensure that humans or other living beings within a transmission field are not exposed to EMF energy near or above regulatory limits or other nominal limits. What is needed is a means for monitoring and tracking objects within a transmission field in real-time and providing a means for controlling the production of power waves to adaptively adjust to the environment within the transmission field.

SUMMARY

Disclosed herein are systems and methods intended to address the shortcomings in the art and may provide additional or alternative advantages as well. Embodiments disclosed herein may generate and transmit power waves that, as result of their physical waveform characteristics (e.g., frequency, amplitude, phase, gain, direction), converge at a predetermined location in a transmission field to generate a pocket of energy. Receivers associated with an electronic device being powered by the wireless charging system, may extract energy from these pockets of energy and then convert that energy into usable electric power for the electronic device associated with a receiver. The pockets of energy may manifest as a three-dimensional field (e.g., transmission field), where energy may be harvested by receivers positioned within or nearby a pocket of energy. In some embodiments, transmitters may perform adaptive pocket forming by adjusting transmission of the power waves in order to regulate power levels based on inputted sensor data from sensors or to avoid certain objects. A technique for identifying receivers in the transmission field may be employed to determine where pockets of energy should be formed and where power waves should be transmitted. This technique may result in heat-map data, which is a form of mapping data that may be stored into a mapping memory for later reference or computations. The sensors may generate sensor data that may identify areas that the power waves should avoid. This sensor data may be an additional or alternative form of mapping data, which may also be stored into a mapping memory for later reference or computation.

In one embodiment, a processor-implemented method comprises determining, by a transmitter, a location within a transmission field to transmit one or more power waves based upon sensor data from a sensor indicating a region to avoid and heat-map data from a communications signal indicating a region containing a receiver; and transmitting, by the transmitter, the one or more power waves into the transmission field based upon the location, wherein the one or more power waves converge at the location.

In another embodiment, a processor-implemented method comprises, in response to a transmitter receiving sensor data from one or more sensors: identifying, by the transmitter, a location of a sensitive object in a transmission field based upon the sensor data; in response to receiving from a receiver a feedback signal indicating a location of the receiver in the transmission field; determining, by the transmitter, a pocket location within the transmission field, wherein the pocket location exceeds a threshold distance from the location of the sensitive object and is at least proximate to the location of the receiver; and transmitting, by the transmitter, the one or more power waves to the pocket location within the transmission field.

In another embodiment, a system comprises a transmitter comprising a sensor configured to detect a sensitive object in a transmission field and generate sensor data indicating a location of the sensitive object, and a communications component configured to communicate one or more communication signals with one or more receivers, wherein the transmitter is configured to: identify a location of a sensitive object in the transmission field upon receiving sensor data

from the sensor, determine a pocket location within the transmission field in response to the transmitter receiving from a receiver a feedback communication signal indicating a location of the receiver in the transmission field, the pocket location exceeding a threshold distance from the location of the sensitive object and is at least proximate to the location of the receiver, and transmit the one or more power waves to the pocket location within the transmission field.

In another embodiment, a computer-implemented method comprises receiving, by a communications component of a user device and from a transmitter, a communications signal indicating one or more characteristics of one or more power waves transmitted by the transmitter, at least one characteristic is a power level for the one or more power waves; identifying, by the user device located at a receiver location, an amount of energy received from the one or more power waves; determining, by the user device, a pocket location for a pocket of energy, wherein the pocket location is where the one or more power waves having the one or more characteristics converge in the transmission field; and when the pocket location has a higher power level than the receiver location, generating and displaying, by the user device, a user interface having an indicator indicating a direction to the pocket location relative to the receiver location.

In another embodiment, a user device comprises a wireless communications component configured to receive from a transmitter a communications signal containing one or more parameters indicating one or more characteristics for one or more power waves; one or more antennas configured to gather power from a pocket of energy formed by the one or more power waves converging at a pocket location; and a receiver processor configured to: identify an amount of energy received from the one or more power waves; identify an amount of energy transmitted in the one or more power waves, based upon one or more parameters received in the communications signal; determine the pocket location; and generate and display a user interface having an indicator that indicates a direction to the pocket location relative to a receiver location.

In another embodiment, a computer-implemented method comprises transmitting, by a transmitter, a low power wave to each of a plurality of segments in a transmission field; in response to the transmitter receiving a communications signal from a receiver containing data indicating a segment containing the receiver: transmitting, by the transmitter, one or more power waves configured to converge at the segment containing the receiver.

A computer-implemented method comprises transmitting, by a transmitter device, into a transmission field associated with the transmitter device one or more power waves and a communications signal, the communications signal containing a first set of transmission parameters defining one or more characteristics of the one or more power waves; in response to the transmitter receiving via the communications signal from a receiver device, device data indicating a location of the receiver in the transmission field: transmitting, by the transmitter device, a second set of transmission parameters into a sub-segment of the transmission field in accordance with the device data, the second set of transmission parameters defining the one or more characteristics of the one or more power waves; determining, by the transmitter device, one or more refined characteristics for the one or more power waves, based upon a set of one or more refined parameters defining the one or more refined characteristics, the refined parameters based upon refined location data received from the receiver device indicating a refined location within the sub-segment; generating, by the transmitter device, the one or more refined power waves having the one or more refined characteristics, according to the set of refined parameters; and transmitting, by the transmitter, the one or more refined power waves into the sub-segment of the transmission field, thereby forming a pocket of energy at the refined location.

In another embodiment, a wireless power system comprises a mapping memory comprising non-transitory machine-readable storage media configured to store one or more receiver records containing data for one or more receivers; one or more transmitters associated with a transmission field, a transmitter comprising: an antenna array configured to transmit an exploratory power wave into one or more segments of a transmission field; a communications component configured to: transmit to each respective segment of the transmission field a set of parameters indicating one or more characteristics of the exploratory power wave transmitted into the respective segment, and transmit to a sub-segment of a first segment a second set of parameters indicating one or more refined characteristics of a second exploratory power wave transmitted into the sub-segment, upon receiving location data indicating the receiver is in the first segment from a receiver device at a location in a first segment; and a transmitter processor configured to determine the one or more characteristics for the exploratory wave based upon one or more parameters for each respective segment of the transmission field, and determine the one or more refined characteristics for the second exploratory power wave upon receiving the first segment location data from the receiver.

In another embodiment, a device-implemented method comprises receiving, by a transmitter and from a receiver, a communication signal via a communication channel, the communication signal containing one or more parameters identifying a first location of the receiver within a transmission field associated with the transmitter; upon receiving the one or more parameters: storing, by the transmitter, the one or more parameters for the receiver into a mapping memory comprising non-transitory machine-readable storage media configured to store the one or more parameters; and transmitting, by the transmitter, the one or more power waves to the first location in accordance with the one or more parameters; and upon receiving one or more updated parameters from the receiver: transmitting, by the transmitter, the one or more power waves to a second location in accordance with the one or more updated parameters.

In another embodiment, a wireless charging system comprises a mapping memory database hosted in non-transitory machine-readable storage media configured to store one or more records of one or more locations in a transmission field associated with one or more transmitters; and a transmitter comprising: a communications component configured to receive from a receiver a communications signal containing one or more parameters identifying a first location of the receiver; and an antenna array comprising one or more antennas configured to transmit one or more power waves to the first location in the transmission field, and transmit the one or more power waves to the second location in the transmission field in accordance with one or more updated parameters, upon the communications component receiving the one or more updated parameters.

In another embodiment, a device-implemented method comprises transmitting, by a transmitter, an exploratory wave to a first segment of a transmission field comprising a plurality of segments; determining, by the transmitter, a sub-segment of the first segment containing a receiver upon receiving a communications signal from the receiver indi-

cating that the receiver received the exploratory wave in the sub-segment of the first segment.

In another embodiment, a method comprises transmitting, by a transmitter, to a plurality of segments of a transmission field sequentially, an exploratory power wave and a communications signal for each respective segment in the transmission field, wherein the communications signal transmitted to each respective segment contains data indicating the respective segment to which the exploratory power wave is transmitted; upon receiving a response message from a receiver at a first location within a first segment of the transmission field: transmitting, by the transmitter, sequentially to one or more sub-segments of the first segment, an exploratory power wave and a communications signal, for each respective sub-segment in the first segment, wherein the communications signal transmitted to each respective sub-segment contains data indicating the respective sub-segment to which the exploratory power wave is transmitted; determining, by the transmitter, a set of one or more characteristics of one or more power waves to transmit to the receiver at the first location; and generating, by the transmitter, the one or more power waves having the one or more characteristics.

In another embodiment, a wireless charging system comprises a mapping database comprising non-transitory machine-readable storage media configured to store one or more records of one or more receivers in a transmission field; and a transmitter comprising: an array of one or more antennas configured to transmit one or more power waves having one or more characteristics according to a transmitter processor; a communications component configured to communicate one or more communications signals with one or more receivers according to the transmitter processor; and the transmitter processor comprising instructions for the transmitter to: transmit a plurality of segments of a transmission field sequentially, an exploratory power wave and a communications signal, for each respective segment in the transmission field, wherein the communications signal transmitted to each respective segment contains data indicating the respective segment to which the exploratory power wave is transmitted; upon receiving a response message from a receiver at a first location within a first segment of the transmission field, transmit sequentially to one or more sub-segments of the first segment, an exploratory power wave and a communications signal, for each respective sub-segment in the first segment, wherein the communications signal transmitted to each respective sub-segment contains data indicating the respective sub-segment to which the exploratory power wave is transmitted; determine a set of one or more characteristics of one or more power waves to transmit to the receiver at the first location; and generate the one or more power waves having the one or more characteristics.

In another embodiment, a computer-implemented method comprises receiving, by a receiver device, from a transmitter device, an exploratory power wave and a communications signal requesting a feedback communications signal based upon the exploratory power wave; transmitting, by the receiver, the feedback communications signal containing data indicating a location of the receiver relative to the transmitter within a transmission field; receiving, by the receiver, a second exploratory power wave and a second communications signal requesting a second feedback communications signal based upon the second exploratory power wave; and transmitting, by the receiver, the second feedback communications signal containing data indicating a comparatively more granular location of the receiver relative to the transmitter within the transmission field.

In another embodiment, a receiver device comprises an antenna array comprising one or more antennas, an antenna configured to receive one or more power waves and capture energy from the one or more power waves; a communications component configured to receive one or more communications signals from a transmitter; and a receiver processor instructing the receiver to: receive from a transmitter device an exploratory power wave and a communications signal requesting a feedback communications signal based upon the exploratory power wave; transmit the feedback communications signal containing data indicating a location of the receiver relative to the transmitter within a transmission field; receive a second exploratory power wave and a second communications signal requesting a second feedback communications signal based upon the second exploratory power wave; and transmit the second feedback communications signal containing data indicating a comparatively more granular location of the receiver relative to the transmitter within the transmission field.

In another embodiment, a method for wireless power transmission comprises acquiring, by at least one sensor in communication with a transmitter, data indicating a presence of an electrical apparatus; determining, by the transmitter, whether the electrical apparatus is a receiver designated to receive power from the transmitter according to data stored in a record stored in a database; and transmitting, by the transmitter, one or more power waves to the electrical apparatus upon determining the electrical apparatus is designated to receive power from the transmitter, wherein the one or more power waves are transmitted to converge in a three dimensional space to form one or more pockets of energy at a location associated with the electrical apparatus.

In another embodiment, a transmitter for wireless power transmission comprises at least two antennas; a controller configured to control power waves broadcast by the transmitter through the at least two antennas that converge in a three dimensional space to form one or more pockets of energy; a database operatively coupled to the controller, including identifying information for a device designated to receive power from the transmitter; and at least one sensor configured to sense the presence of an electrical apparatus and communicate to the controller data indicating the presence of the electrical apparatus; wherein the controller compares the data indicating the presence of the electrical apparatus with the identifying information to determine whether that device is designated to receive power from the transmitter, and if the device is designated to receive power from the transmitter, then the transmitter broadcasts through the at least two antennas the power waves that converge in the three dimensional space to form the one or more pockets of energy for receiving by the electrical apparatus to charge or power the electrical apparatus.

A method for wireless power transmission, comprising acquiring, by at least one sensor in communication with a transmitter, data indicating the presence of an electrical apparatus; matching, by the transmitter, the data indicating the presence of the electrical apparatus to identifying information for a device designated to receive power from the transmitter; and transmitting, by the transmitter, power waves that converge in a three dimensional space to form one or more pockets of energy to charge or power the electrical apparatus.

In another embodiment, a device-implemented method comprises receiving, by a transmitter, from a tagging device, a device tag containing data indicating a first location of a

first receiver device; determining, by the transmitter, one or more characteristics of one or more power waves to transmit to the first receiver device based upon the first location as indicated by the device tag; and transmitting, by the transmitter, the one or more power waves having the one or more characteristics to the first location indicated by the device tag.

In another embodiment, a system comprises a mapping memory configured to store one or more records of one or more receivers, each respective record containing data indicating a location of a receiver; a tagging device configured to generate a device tag containing tagging data for a receiver, the tagging data configured to generate data indicating a location of the receiver and instructions for one or more transmitters to transmit one or more power waves to the location of the receiver; and a transmitter comprising an array of antennas configured to transmit one or more power waves to the location of the receiver as indicated by the device tag for the receiver in the memory database.

In another embodiment, a system comprises a transmitter configured to receive sensor data from a sensor device coupled to the transmitter, determine whether the sensor data identifies an object to avoid, and transmit one more power waves that avoid the object.

In another embodiment, a method for wireless power transmission comprises transmitting, by a transmitter, power waves that converge in a three dimensional space to form one or more first pockets of energy at a predetermined location for receiving by an antenna element of a receiver, wherein the receiver is configured to harvest power from the one or more first pockets of energy at the predetermined location; acquiring, by at least one sensor in communication with the transmitter, data indicating presence of a living being or a sensitive object; obtaining, by the transmitter, information relating to a location of the living being or the sensitive object based upon the data indicating the presence of the living being or the sensitive object; and determining, by the transmitter, whether to adjust a power level of the power waves that converge in the three dimensional space to form the one or more first pockets of energy at the predetermined location in response to the information relating to the location of the living being or the sensitive object.

In another embodiment, a transmitter for wireless power transmission comprises at least two antennas; a controller that controls power waves broadcast by the transmitter through the at least two antennas that converge in a three dimensional space to form one or more pockets of energy at a predetermined location for receiving by an antenna element of a receiver; a transmitter housing containing the at least two antennas; and at least one sensor located on the transmitter housing to sense presence of a living being or a sensitive object, and to communicate to the controller data relating to the presence of the living being or the sensitive object; wherein the controller determines whether to adjust a power level of the power waves that converge in the three dimensional space to form the one or more pockets of energy at the predetermined location in response to the data relating to the presence of the living being or the sensitive object.

In another embodiment, a method for wireless power transmission, comprises transmitting, by a transmitter, power waves that converge in a three dimensional space to form a one or more pockets of energy at a predetermined location for receiving by antenna elements of a receiver, wherein the receiver harvests power from the one or more pockets of energy at the predetermined location; acquiring, by a plurality of sensors in communication with the transmitter, data indicating presence of a living being or a sensitive object; obtaining, by the transmitter, information relating to a location of the living being or the sensitive object based upon the data indicating the presence of the living being or the sensitive object; and at least reducing, by the transmitter, the power level of the power waves that converge in the three dimensional space to form the one or more pockets of energy at the predetermined location, when the data relating to the presence of the living being or the sensitive object indicates that the living being or the sensitive object is proximate to the three dimensional space at the predetermined location.

In another embodiment, a method for wireless power transmission, comprises determining, by a transmitter, whether to transmit one or more power waves to a receiver location by comparing the receiver location and a path of the one or more power waves with a stored location of an entity to be excluded from receipt of the power waves; and upon determining that the entity to be excluded is not at the receiver location and not in the path, transmitting, by the transmitter, the one or more power waves to converge at the receiver location.

In another embodiment, a transmitter for wireless power transmission comprises at least two antennas; a database operatively coupled to a controller, including a stored location indicating a location in transmission field for an entity to be excluded from receiving one or more power waves; and the controller configured to control the one or more power waves broadcast by the transmitter through the at least two antennas that converge in a three dimensional space to form one or more pockets of energy at a receiver location, whereby the controller is configured to determine whether the stored location for the entity to be excluded is at the receiver location or in a path of the one or more power waves when transmitted to the receiver location, and transmit the one or more power waves upon determining that the entity to be excluded is not at the receiver location or in the path to the receiver location.

In another embodiment, a method for wireless power transmission comprises receiving, by a transmitter, from a tagging device, a device tag containing data indicating a first location of an entity to be excluded from receipt of power waves; determining, by the transmitter, a second location of a receiver and a path of one or more power waves to the receiver; determining, by the transmitter, whether the first location as indicated by the device tag is the same as the second location or in the path of the one more power waves; and transmitting, by the transmitter, the one or more power waves when the first location is not the same as the second location or in the path of the one or more power waves.

In another embodiment, a method in wireless power transmission system, the method comprising: determining, by a transmitter, one or more parameters indicated by sensor data and mapping data; determining, by the transmitter, an output frequency of the one or more power waves based on the one or more parameters; selecting, by the transmitter, one or more antennas in one or more antenna arrays of the transmitter based upon the one or more parameters and a spacing between the one or more antennas in each of the one or more antenna arrays; and transmitting, by the transmitter, one or more power waves using the output frequency and the selected antennas.

In another embodiment, a system for wireless power transmission, the system comprising: one or more transmitters, each of the one or more transmitters comprising: one or more antenna arrays, each of the one or more antenna arrays comprising one or more antennas configured to transmit power waves; a microprocessor is configured to, based on

one or more parameters, adjust a transmission of power waves by selecting one or more additional transmitters, varying an output frequency of power waves, varying a selection of antennas in one or more antenna arrays, or selecting antennas to adjust spacing between the one or more antennas in each of the one or more antenna array, to form a pocket of energy to power an electronic device.

In another embodiment, a method for wireless power transmission, the method comprising: determining, by a transmitter, one or more transmission parameters based upon mapping data and sensor data; determining, by the transmitter, one or more characteristics of power waves corresponding to the one or more transmission parameters, wherein the one or more characteristics includes an amplitude and a frequency; generating, by a waveform generator of the transmitter, one or more power waves having the one or more characteristics according to the one or more transmission parameters, wherein the one or more power waves are non-continuous waves; and adjusting, by the waveform generator of the transmitter, the frequency and the amplitude of the one or more power waves based on one or more updates to the one or more transmission parameters corresponding to the one or more characteristics of the one or more power waves.

In another embodiment, a system for wireless power transmission, the system comprising: one or more transmitters configured to determine one or more transmission parameters based on mapping data and sensor data, each of the one or more transmitters comprising: one or more antenna arrays configured to transmit power waves, each of the one or more antenna arrays comprising one or more antennas; and a waveform generator configured to generate one or more power waves, wherein the one or more power waves are non-continuous waves, and wherein the waveform generator is further configured to adjust a frequency and an amplitude that increases and decreases based on the one or more transmission parameters.

In another embodiment, a method for wireless power transmission, the method comprising: receiving, by the transmitter, location data about a location associated with one or more objects within a transmission field of the transmitter; transmitting, by the transmitter, one or more power waves to converge to form a pocket of energy at a location of a target electronic device; and transmitting, by the transmitter, one or more power waves to converge to form a null space at the location of the one or more objects.

In another embodiment, a system for wireless power transmission, the system comprising: one or more transmitters, each of the one or more transmitters comprising one or more antenna arrays, each of the one or more antenna arrays comprising one or more antennas to transmit one or more power waves to generate a null space at a location based on received location data that the location of one or more objects is within a transmission field of the one or more transmitters.

In another embodiment, a system for wireless power transmission, the system comprising: one or more transmitters, each of the one or more transmitters comprising one or more antenna arrays configured to transmit one or more power waves, wherein a first antenna of a first antenna array is located at a distance from a second antenna of a second antenna array such that the one or more power waves transmitted by the plurality of antennas are directed to form a pocket of energy to power an targeted electronic device, wherein the transmitter is configured to determine the distance between the first and second antennas based upon one or more parameters received in a communication signal from the targeted electronic device.

In another embodiment, a system for wireless power transmission, the system comprising: a transmitter comprising: one or more antenna arrays, each of the one or more antenna arrays comprises a plurality of antennas, each of the antennas configured to transmit one or more power waves; and a microprocessor configured to activate a first set of antennas of the plurality of antennas based on a target for directing a pocket of energy using the one or more power waves, wherein the first set of antennas are selected from the plurality of antennas based on a distance between antennas of the first set of antennas.

In another embodiment, a system for wireless power transmission, the system comprising: a transmitter comprising at least two antenna arrays, wherein each of the at least two antenna arrays comprises at least one row or at least one column of antennas configured to transmit one or more power waves; and a microprocessor configured to control transmissions of power waves from one or more antennas of the two antenna arrays, wherein a first array of the at least two arrays is positioned at a first plane spaced to be offset at a pre-defined distance behind a second array of in a second plane in a 3-dimensional space.

In another embodiment, a system for wireless power transmission, the system comprising: a transmitter comprising one or more antennas configured to transmit one or more power waves for forming a pocket of energy to power a targeted electronic device, wherein the one or more antennas are positioned on a non-planar shaped antenna array surface of a three dimensional array selected from the group consisting of a concave shape and a convex shape.

In another embodiment, a system for wireless power transmission, the system comprising: a transmitter comprising one or more antennas configured to transmit one or more power waves, wherein the one or more antennas are positioned on a non-planar shaped antenna array surface of a three dimensional array selected from the group consisting of a concave shape and a convex shape, and wherein the one or more antennas are positioned at a depth between 3 to 6 inches with respect to each other such that the one or more power waves transmitted by each of the one or more antennas are directed to form a pocket of energy to power a targeted electronic device.

BRIEF DESCRIPTION OF THE DRAWINGS

The accompanying drawings constitute a part of this specification and illustrate embodiments of the invention. The present disclosure can be better understood by referring to the following figures. The components in the figures are not necessarily to scale, emphasis instead being placed upon illustrating the principles of the disclosure.

FIG. **1** shows components of an exemplary wireless charging system, according to an exemplary embodiment.

FIG. **2** shows an exemplary method for transmitters to locate receivers within a transmission field, according to an exemplary embodiment.

FIG. **3** shows components of a wireless charging system for tracking and updating mapping data for a transmission field of the exemplary system, where the exemplary system executes an exemplary method for locating receivers according to an exemplary embodiment.

FIG. **4** shows an exemplary wireless power system that employs heat-mapping, for identifying receivers, according to an exemplary embodiment.

FIG. **5** shows an exemplary method for transmitting power wirelessly, according to an exemplary embodiment.

FIG. **6** illustrates steps of wireless power transmission using sensors, according to an exemplary embodiment.

FIG. **7** illustrates steps of wireless power transmission using sensors, according to an exemplary embodiment.

FIG. **8** illustrates steps of wireless power transmission using sensors, according to an exemplary embodiment.

FIG. **9** illustrates steps of wireless power transmission using sensors, according to an exemplary embodiment.

FIG. **10** illustrates generation of pocket of energy to power one or more electronic devices in a wireless power transmission system, according to an exemplary embodiment.

FIG. **11** illustrates generation of pocket of energy in a wireless power transmission system, according to an exemplary embodiment.

FIG. **12** illustrates a graphical representation of formation of pocket of energy in a wireless power transmission system, according to an exemplary embodiment.

FIG. **13** illustrates a method of formation of pocket of energy for one or more devices in a wireless power transmission system, according to an exemplary embodiment.

FIG. **14**A illustrates a waveform to form a pocket of energy in a wireless power transmission system, according to an exemplary embodiment.

FIG. **14**B illustrates a waveform to form a pocket of energy in a wireless power transmission system, according to an exemplary embodiment.

FIG. **15** illustrates a method to generate a waveform in a wireless power transmission system, according to an exemplary embodiment.

FIG. **16** illustrates formation of a null space in a wireless power transmission system, according to an exemplary embodiment.

FIG. **17** illustrates a method for forming a null space in a wireless power transmission system, according to an exemplary embodiment.

FIG. **18** illustrates arrangement of antennas in an antenna array of a wireless power transmission system, according to an exemplary embodiment.

FIG. **19** illustrates arrangement of a plurality of antenna arrays in a wireless power transmission system, according to an exemplary embodiment.

FIG. **20** illustrates arrangement of a plurality of antenna arrays in a wireless power transmission system, according to an exemplary embodiment.

FIG. **21** illustrates an antenna array configuration in a wireless power transmission system, according to an exemplary embodiment.

FIGS. **22**A and **22**B illustrate an antenna array configuration in a wireless power transmission system, according to an exemplary embodiment.

FIG. **22**C illustrates a graph depicting a size of a pocket of energy because of the antenna array configuration represented in FIGS. **22**A and **22**B in a wireless power transmission system, according to an exemplary embodiment.

FIGS. **23**A and **23**B illustrate an antenna array configuration in a wireless power transmission system, according to an exemplary embodiment.

FIG. **23**C illustrates a graph depicting a size of a pocket of energy because of the antenna array configuration represented in FIGS. **23**A and **22**B in a wireless power transmission system, according to an exemplary embodiment.

FIGS. **24**A and **24**B illustrate an antenna array configuration in a wireless power transmission system, according to an exemplary embodiment.

FIG. **24**C illustrates a graph depicting a size of a pocket of energy because of the antenna array configuration represented in FIGS. **24**A and **24**B in a wireless power transmission system, according to an exemplary embodiment.

FIGS. **25**A and **25**B illustrate an antenna array configuration in a wireless power transmission system, according to an exemplary embodiment.

FIG. **25**C illustrates a graph depicting a size of a pocket of energy because of the antenna array configuration represented in FIGS. **25**A and **25**B in a wireless power transmission system, according to an exemplary embodiment.

FIGS. **26**A and **26**B illustrate an antenna array configuration in a wireless power transmission system, according to an exemplary embodiment.

FIG. **26**C illustrates a graph depicting a size of a pocket of energy because of the antenna array configuration represented in FIGS. **26**A and **26**B in a wireless power transmission system, according to an exemplary embodiment.

FIGS. **27**A and **27**B illustrate an antenna array configuration in a wireless power transmission system, according to an exemplary embodiment.

FIG. **27**C illustrates a graph depicting a size of a pocket of energy because of the antenna array configuration represented in FIGS. **27**A and **27**B in a wireless power transmission system, according to an exemplary embodiment.

FIGS. **28**A and **28**B illustrate an antenna array configuration in a wireless power transmission system, according to an exemplary embodiment.

FIG. **28**C illustrates a graph depicting a size of a pocket of energy because of the antenna array configuration represented in FIGS. **28**A and **28**B in a wireless power transmission system, according to an exemplary embodiment.

FIGS. **29**A and **29**B illustrate an antenna array configuration in a wireless power transmission system, according to an exemplary embodiment.

FIG. **29**C illustrates a graph depicting a size of a pocket of energy because of the antenna array configuration represented in FIGS. **29**A and **29**B in a wireless power transmission system, according to an exemplary embodiment.

FIG. **30** illustrates an antenna array configuration in a wireless power transmission system, according to an exemplary embodiment.

FIG. **31** illustrates an antenna array configuration in a wireless power transmission system, according to an exemplary embodiment.

FIG. **32** illustrates a method for forming a pocket of energy in a wireless power transmission system, according to an exemplary embodiment.

DETAILED DESCRIPTION

The present disclosure is here described in detail with reference to embodiments illustrated in the drawings, which form a part here. Other embodiments may be used and/or other changes may be made without departing from the spirit or scope of the present disclosure. The illustrative embodiments described in the detailed description are not meant to be limiting of the subject matter presented here.

Reference will now be made to the exemplary embodiments illustrated in the drawings, and specific language will be used here to describe the same. It will nevertheless be understood that no limitation of the scope of the invention is thereby intended. Alterations and further modifications of the inventive features illustrated here, and additional applications of the principles of the inventions as illustrated here, which would occur to one skilled in the relevant art and

having possession of this disclosure, are to be considered within the scope of the invention.

In the following description, the "transmitter" may refer to a device, including a chip that may generate and transmit one or more power waves (e.g., radio-frequency (RF) waves), whereby at least one RF wave is phase shifted and gain adjusted with respect to other RF waves, and substantially all of the waves pass through one or more antennas, such that focused RF waves are directed to a target. A "receiver" may refer to a device including at least one antenna, at least one rectifying circuit, and at least one power converter, which may utilize a pocket of energy for powering or charging the electronic device. "Pocket-forming" may refer to generating one or more RF waves that converge in a transmission field, forming controlled pocket of energy and null space. A "pocket of energy" may refer to an area or region of space where energy or power may accumulate based on a convergence of waves causing constructive interference at that area or region. The "null-space" may refer to areas or regions of space where pockets of energy do not form, which may be caused by destructive interference of waves at that area or region.

A pocket of energy may be formed at locations of constructive interference patterns of power waves transmitted by the transmitter. The pockets of energy may manifest as a three-dimensional field where energy may be harvested by receivers located within or proximate to the pocket of energy. The pocket of energy produced by transmitters during pocket-forming processes may be harvested by a receiver, converted to an electrical charge, and then provided to an electronic device (e.g., laptop computer, smartphone, rechargeable battery) associated with the receiver. In some embodiments, multiple transmitters and/or multiple receivers may power various electronic devices. The receiver may be separable from the electronic device or integrated with the electronic device.

In some embodiments, transmitters may perform adaptive pocket-forming processes by adjusting transmission of the power waves in order to regulate power levels based on inputted sensor data from sensors. In one embodiment, adaptive pocket forming reduces the power level (measured, for example, as power density) of power waves at a given location. For example, adaptive pocket-forming may reduce the power level of power waves converging at a 3D location or region in space, thereby reducing or altogether eliminating the amount of energy used to form one or more pockets of energy at that location, in response to sensor readings indicating a living being or sensitive object in proximity to that location. In other embodiment, adaptive pocket forming uses "destructive interference" to diminish, reduce, or prevent the energy of power waves concentrated at that location. For example, transmitter may use "destructive inference" to diminish the energy of power waves concentrated at the location of an object, as sensed by one or more sensors, wherein the object is identified or "tagged" in a database of transmitter to be excluded from receipt of power. In a further embodiment, adaptive pocket forming terminates power waves converging at a 3D location or region in space to form one or more pockets of energy at that location, in response to sensor readings indicating a living being or sensitive object in proximity to that location.

Adaptive pocket forming may use a combination of these techniques in response to data from sensors. For example, using sensors that can detect presence and/or motion of objects, living beings, and/or a sensitive object, based on a series of sensor readings at different times, and, in response, a transmitter may reduce the power level of power waves when presence and/or motion data from sensors indicate the presence and/or movement of an object to be avoided, such as a living being and/or sensitive object, as those power waves are transmitted toward a 3D region in space to produce one or more pockets of energy having a high power density. In some cases, the transmitter may terminate or adjust the power waves when location data from sensors indicates arrival or anticipated arrival of the living being or sensitive object within the 3D region of space with pockets of energy.

Communications signals may be produced by the receiver or the transmitter using an external power supply and a local oscillator chip, which in some cases may include using a piezoelectric material. Communications signals may be RF waves or any other communication medium or protocol capable of communicating data between processors, such as Bluetooth®, wireless fidelity (Wi-Fi), radio-frequency identification (RFID), infrared, near-field communication (NFC), ZigBee, and others. Such communications signals may be used to convey information between the transmitter and the receiver used to adjust the power waves, as well as contain information related to status, efficiency, user data, power consumption, billing, geo-location, and other types of information.

Transmitters and receivers may use communications signals to communicate information relating to the receivers and/or the transmission field more generally, in the form of wireless signals carrying digital data, which may include mapping data, heat-map data, and data that is specific to the particular wireless protocol, among other types of data. A transmitter may use the information in the data communicated via the communications signal as input parameters, which the transmitter uses to determine how the transmitter should produce and transmit power waves for receivers in the transmission field. That is, the transmitter may use the data about a transmission field, gathered from one or more receivers, to determine, e.g., where receivers are in a transmission field, where or where not to transmit power waves, where to generate pockets of energy, the physical waveform characteristics for the power waves, and which antennas or antenna arrays should be used to transmit the power waves. A person having ordinary skill in the art would appreciate that any number of possible wave-based technologies may be used to for generating power waves to provide energy to a receiver, including RF waves, ultrasound, microwave, laser light, infrared, and others. It would also be appreciated that the power waves would have physical waveform characteristics, such as amplitude, frequency, direction, power level, and others. In order to produce a pocket of energy at a particular location in the transmission field, the transmitter may generate power waves having a particular set of characteristics that cause the power waves to converge and form a pocket of energy at the desired location. In determining the appropriate characteristics, the transmitter may refer to the input parameters received as data from the receivers (via the communications signal), or from other sources, such as a mapping database or sensors. As previously mentioned, the transmitter may also use the input parameters to make additional or alternative determinations related to power wave transmission and receiver identification, such as determining which antennas or antenna arrays should be used for generating and transmitting the power waves.

Although the exemplary embodiments described herein mention the use of RF-based wave transmission technologies, it should be appreciated that the wireless charging techniques that might be employed are not be limited to such RF-based technologies and techniques. Rather, it should be

appreciated there are additional or alternative wireless charging techniques, which may include any number of technologies and techniques for wirelessly transmitting energy to a receiver that is capable of converting the transmitted energy to electrical power. Non-limiting exemplary transmission techniques for energy that can be converted by a receiving device into electrical power may include: ultrasound, microwave, laser light, infrared, or other forms of electromagnetic energy. In the case of ultrasound, for example, one or more transducer elements may be disposed so as to form a transducer array that transmits ultrasound waves toward a receiving device that receives the ultrasound waves and converts them to electrical power. In addition, although the exemplary transmitter is shown as a single unit comprising potentially multiple transmitters (transmitter antenna array), both for RF transmission of power and for other power transmission methods mentioned in this paragraph, the transmit arrays can comprise multiple transmitters that are physically spread around a room rather than being in a compact regular structure.

I. Components of an Exemplary Wireless Charging System

FIG. **1** shows components of an exemplary wireless power transmission system **100**. The exemplary system **100** may comprise transmitters **101**, an external mapping memory **117**, a receiver **103**, and an electronic device **121** to be charged. Transmitters **101** may send various types of waves **131**, **133**, **135**, such as communication signals **131**, sensor waves **133**, and power waves **135**, into a transmission field, which may be the two or three-dimensional space into which transmitters **101** may transmit power waves **135**.

In operation, transmitters **101** may transmit power transmission signals comprising power waves **135**, which may be captured by receivers **103** configured to convert the energy of the power waves **135** into electrical energy, for an electronic device **121** associated with the receiver **103**. That is, the receivers **103** may comprise antennas, antenna elements, and other circuitry that may convert the captured power waves **135** into a useable source of electrical energy on behalf of electronic devices **121** associated with the receivers **103**. In some embodiments, transmitters **101** may intelligently transmit the power waves **135** into a transmission field, by manipulating characteristics of the power waves **135** (e.g., phase, gain, direction, frequency) and/or by selecting a subset of transmitter antennas **115** from which to transmit the power waves **135**. In some implementations, the transmitters **101** may manipulate the characteristics of power waves **135** so that the trajectories of the power waves **135** cause the power waves **135** to converge at a predetermined location within a transmission field (e.g., a 3D location or region in space), resulting in constructive or destructive interference.

Constructive interference may be a type of waveform interference that may be generated at the convergence of the power waves **135** at a particular location within a transmission field associated with one or more transmitters **101**. Constructive interference may occur when power waves **135** converge and their respective waveform characteristics coalesce, thereby augmenting the amount of energy concentrated at the particular location where the power waves **135** converge. The constructive interference may be the result of power waves **135** having particular waveform characteristics that constructive interference results in a field of energy or "pocket of energy" **137** at the particular location in the transmission field where the power waves **135** converge.

Destructive interference may be another type of waveform interference that may be generated at the convergence of the power waves **135** at a particular location within a transmission field associated with one or more transmitters **101**. Destructive interference may occur when power waves **135** converge at particular location and their respective waveform characteristics are opposite each other (i.e., waveforms cancel each other out), thereby diminishing the amount of energy concentrated at the particular location. Where constructive interference may result in generating pockets of energy when enough energy is present, destructive interference may result in generating a negligible amount of energy or "null" at the particular location within the transmission field where the power waves **135** converge to form destructive interference.

A. Transmitters

Transmitters **101** may comprise or be associated with a processor (not shown), a communications component **111**, a sensor **113**, and an antenna array **115**. Processors may control, manage, and otherwise govern the various processes, functions, and components of the transmitters **101**. Additionally or alternatively, transmitters **101** may comprise an internal mapping memory (not shown), and/or may be wired or wirelessly coupled to an external mapping memory **117**.

i. Transmitter Processors

Transmitters **101** may comprise one or more transmitter processors that may be configured to process and communicate various types of data (e.g., heat-mapping data, sensor data). Additionally or alternatively, a transmitter processor of a transmitter **101** may manage execution of various processes and functions of the transmitter, and may manage the components of the transmitter **101**. For example, the transmitter processor may determine an interval at which a beacon signal may be broadcast by a communications component **111**, to identify receivers **103** that may inhabit the transmission field. As another example, the processor may generate heat-mapping data from communications signals **131** received by the communications component **111**, and then, based upon sensor data received from a sensor **113** or sensor processor, the transmitter processor may determine the safest and most effective characteristics for power waves **135**. In some cases, a single transmitter **101** may comprise a single transmitter processor. However, it should be appreciated that, in some cases, a single transmitter processor may control and govern multiple transmitters **101**. For example, the transmitters **101** may be coupled to a server computer (not shown) comprising a processor that executes software modules instructing the processor of the server to function as a transmitter processor capable of controlling the behavior of the various transmitters **101**. Additionally or alternatively, a single transmitter **101** may comprise multiple processors configured to execute or control specified aspects of the transmitter's **101** behavior and components. For example, the transmitter **101** may comprise a transmitter processor and a sensor processor, where the sensor processor is configured to manage a sensor **113** and generate sensor data, and where the transmitter processor is configured to manage the remaining functions of the transmitter **101**.

It should be appreciated that an exemplary system **100** may comprise any number of transmitters **101**, such as a first transmitter **101***a* and a second transmitter **101***b*, which may transmit waves **131**, **133**, **135** into one or more transmission fields. As such, the system **100** may comprise multiple discrete transmission fields associated with the transmitters **101**, where the transmission field may or may not overlap, but may be managed discretely by transmitter processors. Additionally or alternatively, the system **100** may comprise

transmission fields that may or may not overlap, but may be managed by the transmitter processors as a unitary transmission field.

ii. Communications Component of a Transmitter

Communications components **111** may effectuate wired and/or wireless communications to and from receivers **103** of the system **100**. In some cases, a communications component **111** may be an embedded component of a transmitter **101**; and, in some cases, the communications component **111** may be attached to the transmitter **101** through any wired or wireless communications medium. In some embodiments, the communications component **111** may be shared among a plurality of transmitters **101**, such that each of the transmitters **101** coupled to the communications component **111** may use the data received within a communications signal **131**, by the communications component **111**.

The communications component **111** may comprise electromechanical components (e.g., processor, antenna) that allow the communications component **111** to communicate various types of data with one or more receivers **103**, other transmitters **101** of the system **100**, and/or other components of the transmitter **101**. In some implementations, these communications signals **131** may represent a distinct channel for hosting communications, independent from the power waves **135** and/or the sensor waves **133**. The data may be communicated using communications signals **131**, based on predetermined wired or wireless protocols and associated hardware and software technology. The communications component **111** may operate based on any number of communication protocols, such as Bluetooth®, Wireless Fidelity (Wi-Fi), Near-Field Communications (NFC), ZigBee, and others. However, it should be appreciated that the communications component **111** is not limited to radio-frequency based technologies, but may include radar, infrared, and sound devices for sonic triangulation of the receiver **103**.

The data contained within the communications signals **131** may be used by the wireless-charging devices **101**, **103** to determine how the transmitter **101** may transmit safe and effective power waves **135** that generate a pocket of energy **137**, from which the receiver **103** may capture energy and convert it to useable alternating current (AC) or direct current (DC) electricity. Using a communications signal **135**, the transmitter **101** may communicate data that may be used, e.g., to identify receivers **103** within a transmission field, determine whether electronic devices **121** or users are authorized to receive wireless charging services from the system **100**, determine safe and effective waveform characteristics for power waves **135**, and hone the placement of pockets of energy **137**, among other possible functions. Similarly, a communications component (not shown) of a receiver **103** may use a communications signal **135** to communicate data that may be used to, e.g., alert transmitters **101** that the receiver **103** has entered or is about to enter a transmission field, provide information about the user or the electronic device **121** being charged by the receiver **103**, indicate the effectiveness of the power waves **135**, and provide updated transmission parameters that the transmitters **101** may use to adjust the power waves **135**, as well as other types of useful data. As an example, the communications component **111** of the transmitter **101** may communicate (i.e., send and receive) different types of data (e.g., authentication data, heat-mapping data, transmission parameters) containing various types of information. Non-limiting examples of the information may include a beacon message, a transmitter identifier (TX ID), a device identifier (device ID) for an electronic device **121**, a user identifier (user ID), the battery level for the device **121**, the receiver's **103** location in the transmission field, the device's **121** location in the transmission field, and other such information.

iii. Transmitter Sensors

Sensors **113** may be physically associated with transmitters **101** (i.e., connected to, or a component of), or devices may be configured to detect and identify various conditions of the system **100** and/or transmission field, and sensor data may then be generated for the transmitter **101**, which may contribute to the generation and transmission of power waves **135** by the transmitters **101**. The sensor data may help the transmitters **101** determine various modes of operation and/or how to appropriately generate and transmit power waves **135**, so that the transmitters **101** may provide safe, reliable, and efficient wireless power to receivers **103**. As detailed herein, sensors **113** may transmit sensor data collected during sensor operations for subsequent processing by a transmitter processor of a transmitter **101**. Additionally or alternatively, one or more sensor processors may be connected to or housed within the sensors **113**. Sensor processors may comprise a microprocessor that executes various primary data processing routines, whereby the sensor data received at the transmitter processor has been partially or completely pre-processed as useable mapping data for generating power waves **135**.

Sensors **113** transmit sensor data to the transmitter **101**. Although described in the exemplary embodiment as raw sensor data, it is intended that the sensor data is not limited to raw sensor data and can include data that is processed by a processor associated with the sensor, processed by the receiver, processed by the transmitter, or any other processor. The sensor data can include information derived from the sensor, and processed sensor data can include determinations based upon the sensor data. For example, a gyroscope of a receiver may provide raw data such as an orientation in X-plane, Y-plane, and Z planes, and processed sensor data from the gyroscope may include a determination of the location of the receiver or a location of a receiver antenna based upon the orientation of the receiver. In another example, raw sensor data from an infrared sensor of a receiver may provide thermal imaging information, and processed sensor data may include an identification of the person **141***a* based upon the thermal imaging information. As used herein, any reference to sensor data or raw sensor data can include data processed at the sensor or other device. In some implementations, a gyroscope and/or an accelerometer of the receiver **103** or electronic device associated with the receiver **103** may provide sensor data indicating the orientation of the receiver **103** or electronic device **121**, which the transmitter **101** may use to determine whether to transmit power waves **135** to the receiver **103**. For example, the receiver **103** may be embedded or attached to an electronic device **121** (e.g., smartphone, tablet, laptop) comprising a gyroscope and/or an accelerometer that generates sensor data indicating the orientation of the electronic device **121**. The receiver **103** may then transmit this sensor data to the transmitter **101**, via communications waves **131**. In such implementations, the transmitter **101** may transmit power waves **135** to the location of the receiver **103** until the transmitter **101** receives, via communications waves **131**, the sensor data produced by the gyroscope and/or accelerometer, indicating that the receiver **103** or electronic device is in motion or has an orientation suggesting that the electronic device **121** is in use or nearby a person **141***a*. As an example, a receiver **103** may be attached to or embedded within a smartphone comprising a gyroscope and an accelerometer. In this example, while the smartphone is flat on a table **141***b* for a time, the transmitter **101** may transmit

power waves **135** to the smartphone. But when the person **141***a* lifts the smartphone to his or her head, the accelerometer then generates sensor data indicating that the smartphone is in motion and the gyroscope generates sensor data indicating that the smartphone has a planar-orientation indicating that the smartphone is against the person's **141***a* ear. The transmitter **101** may then determine from this sensor data produced by the gyroscope and accelerometer that the smartphone is against the person's **141***a* head, and thus the transmitter **101** ceases the power waves **131** transmitted to the receiver **103** associated with the smartphone. The transmitter **101** may make this determination according to any number of preset threshold values regarding data produced by gyroscopes and/or accelerometers.

Sensors **113** may be devices configured to emit sensor waves **133**, which may be any type of wave that may be used to identify sensitive objects **141**, **143** in a transmission field (e.g., a person **141**, a piece of furniture **143**). Non-limiting examples of sensor technologies for the sensors **113** may include: infrared/pyro-electric, ultrasonic, laser, optical, Doppler, accelerometer, microwave, millimeter, and RF standing-wave sensors. Other sensor technologies that may be well-suited to secondary and/or proximity-detection sensors may include resonant LC sensors, capacitive sensors, and inductive sensors. Based upon the particular type of sensor waves **133** used and the particular protocols associated with the sensor waves **133**, a sensor **113** may generate sensor data. In some cases, the sensor **113** may comprise a sensor processor that may receive, interpret, and process sensor data, which the sensor **113** may then provide to a transmitter processor.

Sensors **113** may be passive sensors, active sensors, and/or smart sensors. Passive sensors, such as tuned LC sensors (resonant, capacitive, or inductive) are a simple type of sensor **113** and may provide minimal but efficient object discrimination. Such passive sensors may be used as secondary (remote) sensors that may be dispersed into the transmission field and may be part of a receiver **103** or otherwise independently capture raw sensor data that may be wirelessly communicated a sensor processor. Active sensors, such as infrared (IR) or pyro-electric sensors, may provide efficient and effective target discrimination and may have minimal processing associated with the sensor data produced by such active sensors. Smart sensors may be sensors **113** having on-board digital signal processing (DSP) for primary sensor data (i.e., prior to processing by the transmitter processor). Such processors are capable of fine, granular object discrimination and provide transmitter processors with pre-processed sensor data that is more efficiently handled by the transmitter processor when determining how to generate and transmit the power waves **135**.

Sensors **113** may have the capability to operate and generate different types of sensor data and may generate location-related information in various formats. Active and smart sensors may be categorized by sensor type, characteristic hardware and software requirements, and capabilities for distance calculation and motion detection, as seen in the following Table 1:

TABLE 1

Active and Smart Sensor Attributes Active and Smart Sensor Attributes				
Sensor Type	Hardware Requirements	Software Requirements	Distance Calculation	Motion Detection
One dimensional	Simple circuits	Minimal	Rough	None

TABLE 1-continued

Active and Smart Sensor Attributes Active and Smart Sensor Attributes				
Sensor Type	Hardware Requirements	Software Requirements	Distance Calculation	Motion Detection
Smart one dimensional	Simple circuits	Limited	Good	None
Two dimensional (2D)	Simple circuits	Limited	Good	Possible
Smart two dimensional	Complex circuits	Moderate	Good	Possible
Three dimensional (3D)	Complex circuits	Intensive	Good	Good
Smart three dimensional	DSP (primary processing)	Intensive	Precise	Excellent

In some implementations, sensors **113** may be configured for human recognition, and thus may discriminate a person **141***a* from other objects, such as furniture **141***b*. Non-limiting examples of sensor data processed by human recognition-enabled sensors **113** may include: body temperature data, infrared range-finder data, motion data, activity recognition data, silhouette detection and recognition data, gesture data, heart rate data, portable devices data, and wearable device data (e.g., biometric readings and output, accelerometer data).

In an embodiment, control systems of transmitters **101** adhere to electromagnetic field (EMF) exposure protection standards for human subjects. Maximum exposure limits are defined by US and European standards in terms of power density limits and electric field limits (as well as magnetic field limits). These include, for example, limits established by the Federal Communications Commission (FCC) for MPE, and limits established by European regulators for radiation exposure. Limits established by the FCC for MPE are codified at 47 CFR § 1.1310. For electromagnetic field (EMF) frequencies in the microwave range, power density can be used to express an intensity of exposure. Power density is defined as power per unit area. For example, power density can be commonly expressed in terms of watts per square meter (W/m2), milliwatts per square centimeter (mW/cm2), or microwatts per square centimeter (μW/cm2).

In an embodiment, the present methods for wireless power transmission incorporate various safety techniques to ensure that human occupants **141***a* in or near a transmission field are not exposed to EMF energy near or above regulatory limits or other nominal limits. One safety method is to include a margin of error (e.g., about 10% to 20%) beyond the nominal limits, so that human subjects are not exposed to power levels at or near the EMF exposure limits. A second safety method can provide staged protection measures, such as reduction or termination of wireless power transmission if humans **141***a* (and in some embodiments, other living beings or sensitive objects) move toward a pocket of energy **137** with power density levels exceeding EMF exposure limits. A further safety method is redundant safety systems, such as use of power reduction methods together with alarms **119**.

In operation, sensors **113** may detect whether objects, such as person **141** or furniture **143**, enter a predetermined proximity of a transmitter **101**, power waves **135**, and/or a pocket of energy **137**. In one configuration, the sensor **113** may then instruct the transmitter **101** or other components of the system **100** to execute various actions based upon the detected objects. In another configuration, the sensor **113**

may transmit sensor data to the transmitter **101**, and the transmitter **101** may determine which actions to execute (e.g., adjust a pocket of energy, cease power wave transmission, reduce power wave transmission). For example, after a sensor **113** identifies that a person **141** has entered the transmission field, and then determines that the person **141** is within the predetermined proximity of the transmitter **101**, the sensor could provide the relevant sensor data to the transmitter **101**, causing the transmitter **101** to reduce or terminate transmission of the power waves **135**. As another example, after identifying the person **141** entering the transmission field and then determining that the person **141** has come within the predetermined proximity of a pocket of energy **137**, the sensor **113** may provide sensor data to the transmitter **101** that causes the transmitter **101** to adjust the characteristics of the power waves **135**, to diminish the amount of energy concentrated at the pockets of energy **137**, generate a null, and/or reposition the location of the pocket energy **137**. In another example, the system **100** may comprise an alarm device **119**, which may produce a warning, and/or may generate and transmit a digital message to a system log or administrative computing device configured to administer the system **100**. In this example, after the sensor **113** detects the person **141** entering the predetermined proximity of a transmitter **101**, power wave **135**, and/or pocket of energy **137**, or otherwise detects other unsafe or prohibited conditions of system **100**, the sensor data may be generated and transmitted to the alarm device **119**, which may activate the warning, and/or generate and transmit a notification to the administrator device. A warning produced by the alarm **119** may comprise any type of sensory feedback, such as audio feedback, visual feedback, haptic feedback, or some combination.

In some embodiments, such as the exemplary system **100**, a sensor **113** may be a component of a transmitter **101**, housed within the transmitter **101**. In some embodiments, a sensor **113** may be external to the transmitter **101** and may communicate, over a wired or wireless connection, sensor data to one or more transmitters **101**. A sensor **113**, which may be external to one or more transmitters **101** or part of a single transmitter **101**, may provide sensor data to the one or more transmitters **101**, and the processors of the transmitters **101** may then share this sensor data to determine the appropriate formulation and transmission of power waves **135**. Similarly, in some embodiments, multiple sensors **113** may share sensor data with multiple transmitters **101**. In such embodiments, sensors **113** or host transmitters **101** may send and receive sensor data with other sensors **113** or host transmitters in the system **100**. Additionally or alternatively, the sensors **113** or the host transmitters **101** may transmit or retrieve sensor data, to or from one or more mapping memories **117**.

As an example, as seen in the exemplary system **100** of FIG. **1**, a first transmitter **101***a* may comprise a first sensor **113***a* that emits sensor waves **133***a* and generates sensor data, which may be stored on the first transmitter **101***a* and/or a mapping memory **117**; the system **100** may also have a second transmitter **101***b* comprising a second sensor **113***a* that emits sensor waves **113***b* and generates sensor data, which may be stored on the second transmitter **101***b* and/or the mapping memory **117** of the system **100**. In this example, both of the transmitters **101***a*, **101***b* may comprise processors that may receive sensor data from the sensors **113***a*, **113***b*, and/or fetch stored sensor data from the particular storage locations; thus, the sensor data produced by the respective sensors **113***a*, **113***b* may be shared among the respective transmitters **101***a*, **101***b*. The processors of each of the transmitters **101***a*, **101***b* may then use the shared sensor data, to then determine the characteristics for generating and transmitting power waves **133***a*, **133***b*, which may include determining whether to transmit power waves **133***a*, **133***b* when a sensitive object **141**, **143** is detected.

As mentioned, a transmitter **101** may comprise, or otherwise be associated with, multiple sensors **113** from which the transmitter **101** receives sensor data. As an example, a single transmitter **101** may comprise a first sensor located at a first position of the transmitter **101** and a second sensor located at a second position on the transmitter **101**. In this example, the sensors **113** may be binary sensors that may acquire stereoscopic sensor data, such as the location of a sensitive object **141** to the sensors **113**. In some embodiments, such binary or stereoscopic sensors may be configured to provide three-dimensional imaging capabilities, which may be transmitted to an administrator's workstation and/or other computing device. In addition, binary and stereoscopic sensors may improve the accuracy of receiver **103** or object **141** location detection and displacement, which is useful, for example, in motion recognition and tracking.

To enable transmitter **101**, to detect and confirm objects **141** that the user wishes to exclude from receipt of wireless energy (i.e., power waves **135**, pockets of energy **137**), the user may communicate to transmitter **101** tagging information to be recorded in a mapping memory of transmitter **101**. For example, the user may provide tagging information via a user device **123** in communication with the controller of transmitter **101** via a graphical user interface (GUI) of the user device **123**. Exemplary tagging information includes location data for an electrical device **121**, which may include one-dimensional coordinates of a region in space containing the object **141**, two-dimensional (2D) coordinates of a region in space containing the object **141**, or three-dimensional (3D) coordinates of a region in space containing the object **141**.

In some embodiments, tags may be assigned to particular objects **141** and/or locations within a transmission field. During a tagging process, tagging data may be generated and stored into a mapping database, and may inform the transmitter **101** about how the transmitter **101** should behave with regards to specific objects **141** or locations in the transmission field. Tagging data generated during a tagging process may inform transmitters **101** whether to transmit power waves to an object **141** or location, and/or where within a transmission field to transmit power waves **135** or generate pockets of energy **137**. For example, a record for a location in the mapping database may be updated or generated with tagging data instructing the transmitter **101** to never transmit power waves **137** to the particular location. Likewise, in another example, tagging data may be populated into a record for a location, instructing the transmitter **101** to always transmit power waves **137** to that location. In other words, in some implementations, the process of tagging may be as simple as pre-populating tagging data into the mapping database, via a user interface of some kind. Although tags may be generated by merely inputting the tagging data into the mapping database of the transmitter **101**, in some cases, the tagging data may be automatically generated by a sensor processor, transmitter processor, or other computing device, when the mapping database or other device receives a tagging indicator from a wireless tagging device **123**, such as a smartphone or other mobile device. For example, say a user wants to prohibit power waves **137** from being transmitted to a table **141** in a child's playroom because the child has a habit of hiding under the table **141***b*. The user in this

example may interact with a graphical interface on their smartphone **123** to generate and transmit tagging data containing the coordinates of the table **141***b* to the transmitter's **101** mapping database. In some cases, the user may place their mobile tagging device **123** next to the table **141***b* or outline coordinates of the table **141***b*, and then press an indicator button on the user interface, to transmit the relevant location data to the transmitter **101** or mapping database. If necessary, the transmitter **101** or mapping database may then convert the location data into useable coordinates of the transmission field. The generated transmission field coordinates may then be stored into the mapping database and referenced later when the transmitter **101** is determining where to generate a pocket of energy **137**.

In some implementations, sensors **113** may detect sensitive objects **141** within a transmission field that have been predetermined or "tagged" as being sensitive. In some cases, it may be desirable to avoid particular obstacles in the transmission field, such as furniture **141***b* or walls, regardless of whether a sensor **113** has identified a person **141***a* or other sensitive object **141**, entering within proximity to the particular obstacle. As such, an internal or external mapping memory **117** may store mapping data and/or sensor identifying the particular location of the particular obstacle, thereby effectively "tagging" the location of the particular location as being off-limits to power waves **135**. Additionally or alternatively, the particular object may be digitally or physically associated with a digital or physical tag that produces a signal or physical manifestation (e.g. heat-signature) detectable by the sensor **113**, communications components **111**, or other component of the transmitter **101**. For example, as part of generating sensor data for the transmitter **101**, the sensor **113** may access an internal mapping memory (i.e., internal to the transmitter **101** housing the sensor **113**) that stores records of tagged obstacles to avoid, such as a table **141***b*. In this example, the sensor **113** would detect the table **141***b* as a tagged obstacle, and generate sensor data **113** that causes the transmitters **101** to reduce the amount of energy provided by the power waves **135** where table **141***b* is located, terminate the power waves **135** being sent to the table **141***b*, or redirect the power waves **135**.

Additionally or alternatively, in some implementations, sensors **113** may detect electrical devices **121** that have been tagged (i.e., previously recorded in an internal mapping memory or external mapping memory **117** or received a digital or physical tag detectable by the sensors **113**) to receive wireless power waves **137**. Under these circumstances, after detecting a tag or tagged object, or otherwise determining that a tag or tagged object should receive wireless energy, a sensor **113** may generate sensor data that causes a transmitter **101** to transmit power waves **135** to the tagged object to form a pocket of energy **137** at the location of the identified tag or tagged object.

iv. Antenna Array, Antenna Elements, and Antennas

Transmitters **101** may comprise an antenna array **115**, which may be a set of one or more antennas configured to transmit one or more types of waves **131**, **133**, **135**. In some embodiments, an antenna array **115** may comprise antenna elements, which may be configurable "tiles" comprising an antenna, and zero or more integrated circuits controlling the behavior of the antenna in that element, such as generating power waves **135** having predetermined characteristics (e.g., amplitude, frequency, trajectory, phase). An antenna of the antenna array **115** may transmit a series of power waves **135** having the predetermined characteristics, such that the series of power waves **135** arrive at a given location within a transmission field, and exhibit those characteristics. Taken together, the antennas of the antenna array **115** may transmit power waves **135** that intersect at the given location (usually where a receiver **103** is detected), and due to their respective characteristics, form a pocket of energy **137**, from which the receiver **103** may collect energy and generate electricity. It should be appreciated that, although the exemplary system **100** describes radio-frequency based power waves **135**, additional or alternative transmitter antennas, antenna arrays, and/or wave-based technologies may be used (e.g., ultrasonic, infrared, magnetic resonance) to wirelessly transmit power from the transmitter **101** to the receiver **103**.

A transmitter **101** may use mapping data to determine where and how an antenna array **115** should transmit power waves **135**. The mapping data may indicate for the transmitter **101** where power waves **135** should be transmitted and the pockets of energy **137** should be formed, and, in some cases, where the power waves **135** should not be transmitted. The mapping data may be captured, queried, and interpreted by processors associated with the transmitter **101**, from which the transmitter **101** may determine how the antennas of the antenna array **115** should form and transmit the power waves **135**. When determining how the power waves should be formed, the transmitter **101** determines the characteristics for each of the power waves **135** to be transmitted from each of the respective antennas of the antenna array **115**. Non-limiting examples of characteristics for the power waves **135** may include: amplitude, phase, gain, frequency, and direction, among others. As an example, to generate a pocket of energy **137** at a particular location, the transmitter **101** identifies a subset of antennas from the antenna array, **115** transmits power waves **135** to the predetermined location, and then the transmitter **101** generates the power waves **135**. The power waves **135** transmitted from each antenna of the subset have a comparatively different, e.g., phase and amplitude. In this example, a waveform-generating integrated circuit (not shown) of the transmitter **101** can form a phased array of delayed versions of the power waves **137**, apply different amplitudes to the delayed versions of the power waves **137**, and then transmit the power waves **137** from appropriate antennas. For a sinusoidal waveform, such as an RF signal, ultrasound, microwave, and others, delaying the power waves **137** is effectively similar to applying a phase shift to power waves **135**. In some cases, one or more transmitter processors (not shown) control the formation and transmission of power waves **135** broadcast by the transmitter **101** through the antenna array **115**.

Antenna arrays **115** may comprise one or more integrated circuits that are associated with the antennas to generate the power waves **135**. In some embodiments, integrated circuits are found on antenna elements that house an integrated circuit and antenna associated with the integrated circuit. An integrated circuit may function as a waveform generator for an antenna associated with the integrated circuit, providing the appropriate circuitry and instructions to the associated antenna so that the antenna may formulate and transmit the power waves **135** in accordance with the predetermined characteristics identified for the power waves **135**. The integrated circuits may receive instructions from a microprocessor (e.g., transmitter processor) that determines how the power waves **135** should be emitted into the transmitter's **101** transmission field. The transmitter processor, for example, may determine where to form a pocket of energy **137** based on mapping data and then may instruct the integrated circuits of the antenna array **115** to generate power waves **135** with a set of waveform characteristics.

The integrated circuits may then formulate the power waves **135** and instruct their respectively associated antennas to transmit the power waves **135** into the transmission field accordingly.

As mentioned, the mapping data may be based upon heat-map data collected by the communications component **111** and generated by a transmitter processor, and/or sensor data collected by a sensor **113** and generated by a sensor processor. The heat-map data may contain data useful for identifying receivers **103** within the transmission field and their location within the transmission field relative to the transmitter **101**. For example, the heat-map data may include data representative of a location of a receiver in a communication signal that the transmitter receives from the receiver identifying the location where the receiver detected a low power wave from the transmitter **101**, and/or identifying whether or not the power level of the low power wave detected by the receiver exceeded a particular threshold. The sensor data may contain data useful for identifying sensitive objects **141**, **143**, which are objects found at locations within the transmission field where power waves **135** should exhibit minimal energy or should not be transmitted at all. In other words, the mapping data may represent input parameters used by the transmitter **101** to determine the characteristics with which to generate and transmit the power waves **135**. As the mapping data (i.e., heat-map data and/or sensor data) is updated and queried by the transmitter **101**, the transmitter **101** may adjust how the antenna array **115** is producing and transmitting the power waves **135** to account for changes of the environment within the transmission field, such as receiver **103** or people **141** movements.

In some cases, a transmitter **101** may split the antenna array **115** into groups of antennas, such that the constituent antennas perform different tasks. For example, in an antenna array **115** comprising ten antennas, nine antennas may transmit power waves **135** that form a pocket of energy **137** at a receiver **103**, and a tenth antenna may operate in conjunction with the communications component **111** to identify new receivers (not shown) in the transmission field, by continuously and sequentially transmitting low levels of energy to discrete locations within the transmission field, which a new receiver may capture along with a communications signal **131** to then determine the new receiver's location relative to the transmitter **101** within the transmission field. In another example, the antenna array **115** having ten antennas may be split into two groups of five, each of which may transmit power waves **135** to two different receivers **103** in the transmission field.

v. Mapping Memory

Transmitters **101** may be associated with one or more mapping-memories, which may be non-transitory machine-readable storage media configured to store mapping data, which may be data describing aspects of transmission fields associated with the transmitters **101**. Mapping data may comprise heat-map data and sensor data. The heat-map data may be generated by transmitter processors to identify receivers **103** located in a transmission field; and the sensor data may be generated by transmitter processors and/or sensor processors to identify sensitive objects **141**, **143** located in the transmission field. Thus, mapping data stored in a mapping memory of the system **100** may include information indicating the location of receivers **103**, the location of sensitive objects **141**, **143**, transmission parameters for power waves **135**, and other types of data, which can be used by the transmitters **101** to generate and transmit safe and effective power waves **135** (e.g., location of tagged objects, tracking parameters). Transmitters **101** may query the mapping data stored in the records of a mapping memory, or the records may be "pushed" to the transmitters **101** in real-time, so that the transmitters **101** may use the mapping data as input parameters for determining the characteristics for transmitting the power waves **135** and where to generate pockets of energy **137**. In some implementations, transmitters **101** may update the mapping data of a mapping memory as new, up-to-date mapping data is received, from the processors governing the communications components **111** or sensors **113**.

In some embodiments, a wireless-charging system **100** may comprise an external mapping memory **117**, which may be a database or a collection of machine-readable computer files, hosted by non-transitory machine-readable storage media of one or more server computers. In such embodiments, the external mapping memory **117** may be communicatively coupled to one or more transmitters **101** by any wired or wireless communications protocols and hardware. The external mapping memory **117** may contain mapping data for one or more transmission fields that are associated with one or more transmitters **101** of the system **100**. The records of the external mapping memory **117** may be accessed by each transmitter **101**, which may update the mapping data when scanning a transmission field for receivers **103** or sensitive objects **141**, **143**, and/or query the mapping data when determining safe and effective characteristics for the power waves **135** that the transmitter **101** is going to generate.

In some embodiments, a transmitter **101** may comprise non-transitory machine-readable storage media configured to host an internal mapping memory, which may store the mapping data within the transmitter **101**. A processor of the transmitter **101**, such as a transmitter processor or a sensor processor, may update the records of the internal mapping memory as new mapping data is identified and stored. In some embodiments, the mapping data stored in the internal mapping memory may be transmitted to additional transmitters **101** of the system **100**, and/or the mapping data in the internal mapping memory may be transmitted and stored into an external mapping memory **117** at a regular interval or in real-time.

B. Receivers

Receivers **103** may be used for powering or charging an associated electronic device **121**, which may be an electrical device **121** coupled to or integrated with one or more receivers **103**. A receiver **103** may comprise one or more antennas (not shown) that may receive power waves **135** from one or more power waves **135** originating from one or more transmitters **101**. The receiver **103** may receive one or more power waves **135** produced by and transmitted directly from the transmitter **101**, or the receiver **103** may harvest power waves **135** from one or more pockets of energy **137**, which may be a three-dimensional field in space resulting from the convergence of a plurality of power waves **135** produced by one or more transmitters **101**.

In some embodiments, the receiver **103** may comprise an array of antennas configured to receive power waves **135** from a power transmission wave. Receiver **103** antennas may harvest energy from one or more power waves **135** or from a pocket of energy **137**, which may be formed from the resulting accumulation of power waves **135** at a particular location within a transmission field. After the power waves **135** are received and/or energy is gathered from a pocket of energy **137**, circuitry (e.g., integrated circuits, amplifiers, rectifiers, voltage conditioner) of the receiver **103** may then convert the energy of the power waves **135** (e.g., radio frequency electromagnetic radiation) to electrical energy

(i.e., electricity), which may be stored into a battery (not shown) or used by an electronic device **121**. In some cases, for example, a rectifier of the receiver **103** may translate the electrical energy from AC to DC form, usable by the electronic device **121**. Other types of conditioning may be applied as well, in addition or as an alternative to conversion from AC to DC. For example, a voltage conditioning circuit may increase or decrease the voltage of the electrical energy as required by the electronic device **121**. An electrical relay may then convey the electrical energy from the receiver **103** to the electronic device **121**.

A receiver **103** or an electronic device **121** may comprise a receiver-side communications component (not shown), which may communicate various types of data with the transmitter **101** in real-time or near real-time, through a communications signal generated by the receiver's communications component. The data may include mapping data, such as heat-map data, and device status data, such as status information for the receiver **103**, status information for the electronic device **121**, status information for the power waves **135**, and/or status information for the pockets of energy **137**. In other words, the receiver **103** may provide information to the transmitter **101** regarding the present location data of the device **121**, the amount of charge received by the receiver **103**, the amount of charge used by the electronic device **121**, and certain user account information, among other types of information.

As mentioned, in some implementations, the receiver **103** may be integrated into the electronic device **103**, such that for all practical purposes, the receiver **103** and electronic device **121** would be understood to be a single unit or product, whereas in some embodiments, the receiver **103** may be coupled to the electronic device **121** after production. It should be appreciated that the receiver **103** may be configured to use the communications component of the electronic device **121** and/or comprise a communications component of its own. As an example, the receiver **103** might be an attachable but distinct unit or product that may be connected to an electronic device **121**, to provide wireless-power charging benefits to the electronic device **121**. In this example, the receiver **103** may comprise its own communications component to communicate data with transmitters **101**. Additionally or alternatively, in some embodiments, the receiver **103** may utilize or otherwise operate with the communications component of the electronic device **121**. For example, the receiver **103** may be integrated into a laptop computer **121** during manufacturing of the laptop **121** or at some later time. In this example, the receiver **103** may use the laptop's communication component (e.g., Bluetooth®-based communications component) to communicate data with transmitters **101**.

C. Electronic Devices & Tagging Information for Devices and Objects

An electronic device **121** coupled to a receiver **103** may be any electrical device **121** that requires continuous electrical energy or that requires power from a battery. The receiver **103** may be permanently integrated into the electronic device **121**, or the receiver **103** may be detachably coupled to the electronic device **121**, which, in some cases, may result in a single integrated product or unit. As an example, the electronic device **121** may be placed into a protective sleeve comprising embedded receivers **103** that are detachably coupled to the device's **121** power supply input. Non-limiting examples of electronic devices **121** may include laptops, mobile phones, smartphones, tablets, music players, toys, batteries, flashlights, lamps, electronic watches, cameras, gaming consoles, appliances, GPS devices, and wearable devices or so-called "wearables" (e.g., fitness bracelets, pedometers, smart watch), among other types of electrical devices **121**.

Electronic devices **121** may comprise embedded or associated proximity sensors, accelerometers, compasses, gyroscopes and/or ambient light sensors, which may act as a secondary data source for transmitter **101** to supplement sensor data, heat-map data, and/or mapping data, as generated by the sensors **113** physically associated with transmitter **101**.

In some cases, neither an electronic device **121** nor an associated receiver **103**, are associated with a communications component capable of communicating with a transmitter **101**. For example, the electronic device **121** might be a smaller household electrical device **121**, such as a clock or smoke alarms, which might not include a communications component that transmits communications signals to the transmitter **101**, and therefore the electrical device **121** and the receiver **103** attached to the electrical device **121** would not be able to exchange the data needed to guide the transmitter's **101** production of power waves **135**.

To enable the transmitter **101** to locate and identify such an electrical device **121**, a user may communicate to the transmitter **101** "tagging" data, which may be recorded into an internal or external mapping memory **117**. For example, the user may provide tagging information via a user device (e.g., laptop **121**, smartphone, administrative computer or server) that is in communication with the transmitter **101** or external mapping memory **117**. The user device may execute an administrative software application that permits the user, via a graphical user interface (GUI), to generate tagging information. The tagging information may then be stored as mapping data (e.g., sensor data, heat-map data) into one or more mapping memories **117** of the system **100** for retrieval by one or more processors (e.g., transmitter processor, sensor processor, user device processor) of the system **100**. Exemplary tagging information includes location data for an electrical device **121**, level of power usage of electrical device **121**, duration of power usage of electrical device **121**, power transfer schedule of electrical device **121**, and authentication credentials of the electrical device **121**.

Additionally or alternatively, tagging information for electrical devices **121** may be automatically identified and generated by sensors **113** and/or communications components when scanning the transmission field to identify electrical devices **121** and/or sensitive objects **141**. As an example, scanning with sensors **113** may dynamically maintain an internal mapping memory of a transmitter **101**, which may update tagging information provided manually to the mapping memory **117** by a user device. In an embodiment, the transmission field of wireless power system **100** is scanned periodically to detect sensor **113** responses indicating updated tagging information for electrical devices **121** and/or sensitive objects **141**, using one or more of pyroelectric sensors, ultrasound sensors, millimeter sensors, and power sensors. In operation, after one or more sensors **113** or communications components **111** identifies the electrical device **101** and then outputs the sensor data to the transmitter processor, the transmitter processor may compare the captured sensor data with tagging information stored in the mapping memory **117** of the system **100**. Based on this comparison, the transmitter processor may determine whether the transmitter **101** should transmit power waves **135** to electrical device **121**, or whether the transmitter processor should avoid transmitting power waves **135** to the electrical device **121**.

In some embodiments, a system **100** may comprise an administrative device **123** that may function as an interface for an administrator to set configuration settings or provide operational instructions to various components of the system **100**. The administrative device **123** may be any device comprising a communications component capable of wired or wireless communication with components of the system **100** and a microprocessor configured to transmit certain types of data to components of the system **100**. Non-limiting examples of an administrative device **123** may include a guidance device (e.g., radio guidance device, infrared guidance device, laser guidance device), a computing device, a smartphone, a tablet, or other device capable of providing instructional and operational data to components of the system **100**.

In some embodiments, the administrative device **123** may be a guidance device that may comprise a processor configured to execute various routines for "tagging" an electronic device **121**, based upon the type of technology employed. As mentioned herein, tagging receivers **103** and other objects **141** within a transmission field may indicate to components of the system **100** that those components should or should not execute certain routines. As an example, the administrative device **123** may be a laser guidance device that transmits tagging data to a transmitter communication component **111**, sensor **113**, mapping memory **117**, or other device of the system **100** that is configured to receive and process the laser guidance-based tagging data. In this example, the tagging data may be generated whenever a user interacts with an interface input, such as a push button or graphical user interface (GUI), and a laser "tags" the desired object. In some cases, the resulting tagging data is immediately transmitted to the transmitter **101** or other device for storage into mapping data. In some cases, a sensor **101** having laser-sensitive technology may identify and detect the laser-based tag. Although additional and alternative means of tagging objects and devices are described herein, one having ordinary skill in the art would appreciate that there are any number of guidance technologies that may be employed to "tag" an object and generate or detect tagging data.

In some embodiments, the administrative device **123** executes a software application associated with the wireless charging system **100**, where the software application comprises software modules for generating and transmitting tagging data to components of the system **100**. The tagging data generated by the software application may contain information useful for identifying objects or the locations of objects. That is, the tagging data may be used to instruct a sensor **113** that, when a particular sensory signature (e.g., infrared) is detected, the sensor **113** should generate certain sensor data, which would eventually inform how the transmitters **101** would generate and transmit the power waves **135**.

In some implementations, the administrative device **123** may be a server computer or other workstation computer that is coupled to the transmitter processors. In such implementations, an administrator may provide tagging data directly to an external mapping memory **117**, which may be stored until need by the transmitters **101**. Although FIG. **1** shows the administrative device **123** as being a distinct device from the electronic device **121** being charged by the transmitters **101** and receivers **103**, it should be appreciated that they may be the same devices and may function similarly. In other words, the electronic device **121** may function as an administrative device **123**; and/or the administrative device **123** may receive wireless charging services through associated receivers **103**, embedded or coupled to the administrative device **123**.

II. Determining Receiver Locations & Heat-Map Data

Transmitters of the wireless charging system may determine the location of receivers in a transmission field covered by the transmitters. Transmitters may be associated with a mapping memory allowing the transmitters to track the motion of receivers, as the receivers move through a transmission field.

A. Exemplary Methods for Heat-Mapping

FIG. **2** shows an exemplary method **200** for one or more transmitters (TXs) of a wireless charging system to locate receivers within a transmission field, so that the transmitters may transmit power waves to the receiver devices. The method **200** describes actions executed by components of a single transmitter, though it should be appreciated that at least some the actions may be executed by additional or alternative components of the wireless power transmission system, such as other transmitters, microprocessors, computing devices, or other device capable of receiving and issuing instructions associated with transmitters. Moreover, it should be appreciated that the actions of the exemplary method **200** may be executed by any number of transmitters or microprocessors, simultaneously, or at individualized intervals that are particular to each device.

In a first step **201**, a transmitter (TX) may continuously transmit power waves and a communication signal into a transmission field of the transmitter. The power waves may be any type of wave having any set of characteristics that may provide power to devices located at a given location within the transmission field. Non-limiting examples of power waves may include ultrasonic waves, microwaves, infrared waves, and radio-frequency waves. The power waves may be transmitted with a certain set of physical characteristics (e.g., frequency, phase, energy level, amplitude, distance, direction) that result in the power waves providing elevated energy levels at the given location in the transmission field. In this step **201**, the transmitter may transmit so-called exploratory power waves, which are power waves having a power level comparatively lower than the power level ordinarily used to for power waves providing power to a receiver. Exploratory power waves may be used to identify receivers, and/or used to determine the appropriate characteristics for the power waves that will ultimately provide power to the receivers in the transmission field.

The communication signal may be any type of wave used by electrical devices to communicate data through associated protocols. Non-limiting examples may include Bluetooth®, NFC, Wi-Fi, ZigBee®, and the like. The communications signal may be used to communicate parameters used by the transmitter to properly formulate power waves. In this first step **201**, a communications signal may contain data describing the characteristics of the low-level power waves being transmitted. This data may indicate, for example, the direction and energy level of the power waves transmitted with the communication signal. In some implementations, the power wave characteristics, as indicated by the data of the communication signal, may be used by receivers and transmitters as parameters for a number of determinations. These parameters may then be updated and exchanged over the communications signal to update the characteristics of the power waves being generated and transmitted.

In a next step **203**, one or more antennas of a receiver may receive the power waves and the communication signal from the transmitter. The power waves may have waveform

characteristics that give the power waves low-levels of power. The communication signal may contain data indicating the characteristics of the power waves. When the transmitter formulates and/or transmits the power waves in a certain direction or to a certain location within the transmission field, a communications component of the transmitter may generate and transmit data, within the communications signal, describing the power waves. For example, the communications signal may indicate information about the power wave formation, such as the amplitude, frequency, energy level, the trajectory of the power waves, and/or the desired location to which the power waves were transmitted.

In a next step **205**, the receiver may respond to the transmitter with an indication of its location (e.g., an explicit communication of location information or a communication indicating receipt of an exploratory low power wave transmission in a segment or sub-segment, and/or confirmation that the power level of said exploratory wave exceeds a particular threshold) within the transmission field, using the data in the communications signal as input parameters. The receiver may comprise a processor configured to generate a message for responding to the transmitter with the indication of its location. The receiver may be integrated into (e.g., within a smart phone) or coupled to (e.g., a smart phone backpack) an electronic device comprising a processor that is configured to generate messages indicating the receiver's location when receiving a low power wave transmission. In an alternative embodiment, a receiver can determine its own location based upon characteristics of the received power waves as indicated by the received communication signal.

In some implementations, after the power waves are received by the receiver, the receiver must derive its location based upon the waveform characteristics of the power waves, as indicated by the communications signal. For example, the receiver processor may determine the receiver's location using data indicating a target area (i.e., where the power waves were transmitted to in the transmission field), the amount of low-level of the power waves, and the particular trajectory at which the power waves were transmitted. In this example, the receiver may determine its location within the transmission field of the transmitter, by determining the receiver's location in relation to the target area based on the amount of power actually received, and then determining where the target area is in relation to the transmitter based on the trajectory of the power waves. It should be appreciated that the above means of determining the receiver's location is merely exemplary; any number of additional or alternative calculations, inputs, parameters, and other information, may be communicated between the receiver and transmitter, and used by the receiver to determine its location within a transmission field.

In a next step **207**, after determining the receiver's location within the transmission field, the receiver may respond to the transmitter with updated transmission parameters to be utilized by the transmitter for formulating the power waves. The transmitter may generate and transmit the power waves having certain waveform characteristics that are determined by the transmitter according to a set of parameters, which are predetermined or provided from receivers via the communications signal data. In this step **207**, the receiver is providing the parameters to the transmitter after the receiver determines where it is located in relation to the transmitter. In some cases, the receiver may also provide updated parameters for the transmitter to use for generating and transmitting the power waves.

For example, the receiver may determine the effectiveness of the power waves, where the effectiveness may be determined as a ratio ("effectiveness ratio") of the amount of power being transmitted in the power waves versus the amount of power actually received by the receiver. In this example, the effectiveness may be transmitted to the transmitter using a communications signal (e.g., Bluetooth®, Wi-Fi, NFC, ZigBee®), which the transmitter may use as a parameter for determining how to generate and transmit the power waves. The receiver may also transmit updated parameter data indicating its location, as determined in a previous step **205**. As another example, after the receiver determines the effectiveness ratio of the power waves and determines its location within the transmission field, the receiver may pre-process some or all of the communication signal data, so that the receiver transmits this data to transmitter and the transmitter to employ in determine where to place pockets of energy. The receiver may then determine and transmit other useful data that the transmitter may use as updated parameters for determining the waveform characteristics of the power waves. For example, data may include a battery level of the electronic device and/or a desired battery level of the electronic device.

In an optional next step **209**, the transmitter may refine transmission parameters based on receiver feedback data to identify a more granular location of the transmitter. Based upon an initial identification scan, like in prior step **207**, the transmitter may seek updated or more refined information regarding a transmission field or a particular receiver. In some instances, this data may be stored into a mapping memory as heat-map data for the particular receiver, or may be used to update a record for a receiver, as stored in the mapping memory.

In some instances, the data feedback produced by the receiver may indicate that location coordinates for a receiver have changed. In other words, the updated or changed data parameters used for identifying the receiver and for generating power waves for the transmitter may be revised based upon the updated location or based upon the movement of the receiver, as determined by the transmitter or receiver.

In a next step **211**, the transmitter may calibrate the antennas, of the antenna array transmitting the power waves to the receiver, based on the feedback communication signal data received from the receiver.

B. Tracking Algorithms & Updating Heat-Map

FIG. **3** shows components of a wireless charging system **300** for tracking and updating mapping data for a transmission field **307** of the exemplary system **300**, where the exemplary system **300** executes an exemplary method, similar to that shown in FIG. **2**. The exemplary system **300** comprises a transmitter **301** and receiver device **309**.

A transmitter **301** may comprise a communications component **305** that may transmit a communications signal to segments **311** of the transmission field **307** at a given interval. In addition to the communications signal, the transmitter **301** may transmit to the various segments **311**, a low-level power wave, i.e., a power wave having a comparatively lower amount of energy that is detectable by receivers but may not contain enough energy to provide wireless power. The communications signal may contain data that indicates to which segment **311** the low-level power was transmitted. This indication may be in the form of information identifying the various characteristics of the low-level power wave (e.g., distance, height, azimuth, elevation, power level).

Although the exemplary embodiment recites the use of a sequential scanning of segments within a transmission field, it is intended that other scanning methods or location identification methods can be used. For example, a receiver

may determine its location and identify this location in a transmission of a communication signal to a transmitter. In one configuration, the segments can be replaced by the use of X, Y, Z coordinates or polar coordinates (e.g., azimuth, elevation, distance). In another alternative embodiment, the receiver can respond to the transmitter with an indication of its location without having received a low-level power wave and having only received a communication signal from the transmitter.

In the exemplary embodiment, the transmitter **301** may transmit communications signals and low-level power waves in sequential manner, across the segments **311**. A receiver **309** in an occupied segment **2**B may eventually receive a communications signal and a low-level power wave, and respond that the receiver **309** gathered the energy from the low-level power wave or that the receiver received the low-level power wave at or above a particular threshold power level.

The transmitter **301** may need more information to determine the location of the receiver **309** with finer detail. In some cases, the transmitter **301** may scan the transmission field **307** more efficiently by scanning larger segments **311** of the transmission field **307**. However, in such cases, the segments **311** may be too large to transmit power waves. For each instance where the transmitter **301** receives a response from a receiver **309** indicating that the receiver **309** is found at a particular occupied segment **2**B, the transmitter may then scan sub-segments **2**B**1-4** of the occupied segment **2**B; where scanning the sub-segments **2**B**1-4** may include transmitting communications signals to each respective sub-segment **2**B**1-4** to determine with finer resolution, the location of the receiver **309**. As an example, the transmitter **301** may seek resolution, where a transmitter **307** may transmit a communications signals horizontally, along an X-axis at, e.g., thirty-degree increments. When the transmitter **301** receives an indication from the receiver **309** that the receiver **309** is found at a second segment along the X-axis, the transmitter **307** may then transmit communication signals at one-degree increments within the second segment. The receiver **309** may then indicate that it is located in a second sub-segment along the X-axis. This process may repeat along a Y-axis and a Z-axis, to determine a relative height or elevation for the receiver **309** and a relative distance to the receiver **309**.

When a predetermined threshold for granularity is satisfied (i.e., the location of the receiver is determined within a sufficient area), and thus a satisfactorily small-enough pocket of energy may be defined around the receiver, the antennas of the transmitter **301** may transmit one or more power waves to the location of the receiver **309**, where the location is defined by, e.g., three coordinates found within a small-enough three-dimensional space. In some embodiments, the transmitter **301** may direct a subset of antennas of a transmitter array **303** to work alongside the communications component of the transmitter **301** to continue scanning the transmission field **307** for additional receivers **309**, while another subset of antennas of the antenna array continues to transmit the power waves to the location of the receiver **309**. As an example, the transmitter **301** may have 95% of the antenna array **303**; focus on transmitting power waves to occupied locations, while the remaining 5% continue to transmit low-level power waves in conjunction with the communication component scanning the transmission field **307**.

A transmitter **301** may detect when the receiver **309** moves when the transmitter **301** receives updated feedback data, via the communications signal, from the receiver **309**. The transmitter **301** may shut off power waves altogether if the receiver **309** moves too quickly to determine the new location of the receiver **309**, or if the receiver **309** stops transmitting feedback data. Ordinarily, the feedback data provided by the receiver **309** indicates the relative amount of power received from the power waves, which may be used to identify and hone the transmitter's **301** and/or the receiver's **309** understanding of where the receiver **309** is located in the transmission field **307**. Similarly, the transmitter **301** may implement tracking algorithms to determine whether the receiver **309** is in motion (i.e., determine displacement). In some implementations, the transmitter **301** may use this data to estimate the relative speed the receiver **309** is moving, and how to readjust the power waves accordingly. In some cases, the transmitter **301** can update the power waves such that the power waves converge at a new location where the receiver **309** is estimated to be; and in some cases, the transmitter **301** may update the power waves to transmit to an anticipated new location, in advance of the receiver's **309** arrival at the estimate new location. For example, the transmitter may determine that the antennas may transmit in new places along an X-axis in five-degree increments, as opposed to one-degree increments, as the transmitter **301** determines an increase in the rate of displacement of the receiver **309** over time.

In some instances, in order for the transmitter **301** to figure out which characteristics of the power waves to apply (e.g., phase) to the antennas of the antenna array **303**, when searching granular location, the transmitter **301** may determine a distance to a location, such as the distance to a segment **311** on the Z-axis, from every antenna element. In such embodiments, the transmitter **301** may pre-calculate the distance for every point to a receiver **309** or other point of interest. That is, the transmitter **301** anticipates the distance from every transmitter antenna, so that the transmitter **301** may identify the phase and gain of the power waves. This may be done using, e.g., predetermined data or a table, or in real-time based on the receiver's coordinates (X, Y, Z). The transmitter **301** may then determine a delay in the phase of the respective power waves, because the transmitter **301** now knows a relatively precise distance to the receiver **309**. In some cases, this pre-calculated distance may be transmitted by the communications component **305** in conjunction with the low-level power waves.

FIG. **4** shows an exemplary wireless power system **400** that employs heat-mapping, for identifying receivers **409** inside the service area (i.e., transmission field) of the wireless power system **400**. The transmitter **401** may comprise a communications component **405** and an antenna array **403**. In this example, the transmitter **401** may be situated at an elevated location within a room, from which the transmitter **401** may execute one or more mapping routines, such as heat-mapping routines to identify the receivers **409**.

During heat-mapping routines, the communications component **405** may continuously transmit a communications signal to each sequential segment falling along an X-axis, a Y-axis, and a Z-axis. In addition, in some cases, the antenna array **403** may transmit a power wave having a relatively low power level (i.e., low-level power wave) into each sequential segment, in conjunction with the communications signal. The communication signal may indicate the parameters used to transmit the low-level power signal (e.g., intended coordinates, power level). In some cases, the receiver **409** may use the data of the communications signal to respond to the transmitter **401** with values for the parameters identified in the communication signal to allow the transmitter **401** to identify the receiver's location in the

transmission field. And in some cases, the receiver **409** may respond to the communications signal, through a communications channel using a communications protocol and/or technology that is distinct from the power waves, by transmitting a responsive communications signal containing feedback data that the transmitter **401** may use to hone the locational coordinates of the receiver **409**, or to otherwise generate or cease power waves. The communications component **405** may progress through each sequential segment in any order. For example, the communications component **405** may transmit a communications signal to segments of coarse intervals within a given plane, attempting to identify receivers **409** on that plane. The communications component **405** may then progress to the next coarse interval segment on the plane, but may rescan a particular segment at relatively more granular sub-segments when a receiver **409** is identified in the coarser segment scan.

In some embodiments, data records may be stored into a mapping memory. The data records may contain data pertaining to attributes of the transmission field. For example, data records of the mapping memory may store data associated with receivers **409**, objects identified in the transmission field, and certain locations as defined by a set of coordinates. The mapping memory may be a database that contains the data received from a transmitter **301** and/or receivers **409**. The sophistication of the data may vary, from a few bits of binary data indicating whether a receiver **409** received a power wave, to data record pertaining to each attribute of a transmission field. In the current example shown in FIG. **4**, the mapping memory stores a number of data points for a number of attributes (e.g., receivers **409**, furniture, walls), as such, the mapping memory may store data that may be used to logically generate the heat-map as shown in FIG. **4**.

C. Additional or Alternative Methods Associated with Heat Mapping

FIG. **5** shows an exemplary method **500** for transmitting power wirelessly, from a transmitter to any number of receiver devices, to power the receiver devices according to an exemplary embodiment.

In a first step **501**, a transmitter (TX) establishes a connection or otherwise associates with a receiver (RX). That is, in some embodiments, transmitters and receivers may communicate control data over a communications signal, using a wireless communication protocol capable of transmitting information between two processors of electrical devices (e.g., Bluetooth®, BLE, Wi-Fi, NFC, ZigBee®). For example, in embodiments implement Bluetooth® or Bluetooth® variants, the transmitter may scan for receiver's broadcasting beacon signals, sometimes called "advertisement signals," or a receiver may transmit an advertisement signal to the transmitter. The advertisement signal may announce the receiver's presence to the transmitter, and may trigger an association between the transmitter and the receiver. As described later, in some embodiments, the advertisement signal may communicate information that may be used by various devices (e.g., transmitters, client devices, sever computers, other receivers) to execute and manage pocket-forming procedures. Information contained within the advertisement signal may include a device identifier (e.g., MAC address, IP address, UUID), the voltage of electrical energy received, client device power consumption, and other types of data related to power waves. The transmitter may use the advertisement signal transmitted to identify the receiver and, in some cases, locate the receiver in a two-dimensional space or in a three-dimensional space. Once the transmitter identifies the receiver, the transmitter may establish the connection associated in the transmitter with the receiver, allowing the transmitter and receiver to communicate communication signals over a second channel.

As an example, when a receiver comprising a Bluetooth® processor is powered-up, or is brought within a detection range of the transmitter, the Bluetooth processor may begin advertising the receiver according to Bluetooth® standards. The transmitter may recognize the advertisement and begin establishing connection for communicating control signals and power transmission signals. In some embodiments, the advertisement signal may contain unique identifiers so that the transmitter may distinguish that advertisement and ultimately that receiver from all the other Bluetooth® devices nearby within range.

In a next step **503**, when the transmitter detects the advertisement signal, the transmitter may automatically establish a communication connection with that receiver, the establishment of which may allow the transmitter and receiver to communicate via communications signals. The transmitter may then command the receiver to begin transmitting real-time sample data or control data. The transmitter may also begin transmitting power transmission signals from antennas of the transmitter's antenna array.

In a next step **505**, the receiver may then measure the voltage, among other metrics related to effectiveness of the power transmission signals, based on the electrical energy received by the receiver's antennas. The receiver may generate control data containing the measured information, and then transmit control signals containing the control data to the transmitter. For example, the receiver may sample the voltage measurements of received electrical energy, for example, at a rate of one-hundred times per second. The receiver may transmit the voltage sample measurement back to the transmitter, one-hundred times a second, in the form of control signals.

In some embodiments, the transmitter may execute one or more software modules monitoring the metrics, such as voltage measurements, received via the communications signal from the receiver. Algorithms may vary production and transmission of power transmission signals by the transmitter's antennas, to maximize the effectiveness of the pockets of energy around the receiver. For example, the transmitter may adjust the phase at which the transmitter's antenna transmits the power transmission signals, until that power received by the receiver indicates that an effective pocket of energy is established around the receiver. When an optimal configuration for the antennas is identified, memory of the transmitter may store the configurations to keep the transmitter broadcasting at that highest level.

In a next step **509**, algorithms of the transmitter may determine when it is necessary to adjust the power transmission signals and may also vary the configuration of the transmit antennas, in response to determining such adjustments are necessary. For example, the transmitter may determine the power received at a receiver is less than maximal, based on the data received from the receiver. The transmitter may then automatically adjust the phase of the power transmission signals, but may also simultaneously continue to receive and monitor the voltage being reported back from receiver.

In a next step **511**, after a determined period of time for communicating with a particular receiver, the transmitter may scan and/or automatically detect advertisements from other receivers that may be in range of the transmitter. The transmitter may establish another communications signal connection with the second receiver, which in some cases may be established in response to the second receiver or the

transmitter receiving an advertisement or beacon signal from the second receiver or the transmitter, respectively.

In a next step **513**, after establishing a second communication connection with the second receiver, the transmitter may proceed to adjust one or more antennas in the transmitter's antenna array for transmitting power waves from the transmitter to the second receiver and the first receiver at the same time or in an alternating manner. In some embodiments, the transmitter may identify a subset of antennas to service the second receiver, thereby parsing the array into subsets of arrays that are associated with a receiver. In some embodiments, the entire antenna array may service a first receiver for a given period of time, and then the entire array may service the second receiver for that period of time.

The transmitter may prioritize transmissions to more than one receiver. For example, the prioritization may be based upon a distance between the receiver and the transmitter, to determine whether the receiver is capable of receiving a sufficient amount of power due to its distance from the transmitter. This distance may be obtained from a communication signal between the transmitter and receiver. In another example, the prioritization may be based upon a power level (i.e., battery level) of a device associated with a receiver and the need of that device to charge its battery (e.g., battery with a low charge may be prioritized over a battery that is almost fully charged). The power level of a device may be obtained from the receiver in a communication signal to the transmitter. Accordingly, the transmitter can allocate a first subset of antennas and a second subset of antennas based upon this prioritization.

Manual or automated processes performed by the transmitter may select a subset of arrays to service the second receiver. In this example, the transmitter's array may be split in half, forming two subsets. As a result, half of the antennas may be configured to transmit power transmission signals to the first receiver, and half of the antennas may be configured for the second receiver. In the current step **513**, the transmitter may apply similar techniques discussed above to configure or optimize the subset of antennas for the second receiver. While selecting a subset of an array for transmitting power transmission signals, the transmitter and second receiver may be communicating control data. As a result, by the time that the transmitter alternates back to communicating with the first receiver and/or scan for new receivers, the transmitter has already received a sufficient amount of sample data to adjust the phases of the waves transmitted by second subset of the transmitter's antenna array, to transmit power waves to the second receiver effectively.

In a next step **515**, after adjusting the second subset to transmit power transmission signals to the second receiver, the transmitter may alternate back to communicating control data with the first receiver, or scanning for additional receivers. The transmitter may reconfigure the antennas of the first subset, and then alternate between the first and second receivers at a predetermined interval.

In a next step **517**, the transmitter may continue to alternate between receivers and scanning for new receivers, at a predetermined interval. As each new receiver is detected, the transmitter may establish a connection and begin transmitting power transmission signals, accordingly.

In one exemplary embodiment, the receiver may be electrically connected to a device like a smart phone. The transmitter's processor would scan for any Bluetooth devices. The receiver may begin advertising data indicating that it is, e.g., a Bluetooth-enabled device, through the communications component of the receiver, such as a Bluetooth® chip. Inside the advertisement, there may be unique identifiers so that the transmitter, upon receiving the response to the advertisement, could distinguish that receiver's advertisement, and ultimately that receiver, from all other receivers within the transmission range. When the transmitter detects that advertisement and notices it is a receiver, then the transmitter may immediately form a communication connection with that receiver and command that receiver to begin sending real time sample data.

The receiver would then measure the voltage at its receiving antennas, send that voltage sample measurement back to the transmitter (e.g., up to, or exceeding, 100 times a second). The transmitter may start to vary the configuration of the transmit antennas by adjusting the phase. As the transmitter adjusts the phase, the transmitter monitors the voltage being sent back from the receiver. In some implementations, the higher the voltage, the more energy may be in the pocket. The antenna phases may be altered until the voltage is at the highest level and there is a maximum pocket of energy around the receiver. The transmitter may keep the antennas at the particular phase so the voltage is at the highest level.

The transmitter may vary each individual antenna, one at a time. For example, if there are 32 antennas in the transmitter, and each antenna has 8 phases, the transmitter may begin with the first antenna and would step the first antenna through all 8 phases. The receiver may then send back the power level for each of the 8 phases of the first antenna. The transmitter may then store the highest phase for the first antenna. The transmitter may repeat this process for the second antenna, and step it through 8 phases. The receiver may again send back the power levels from each phase, and the transmitter may store the highest level. Next, the transmitter may repeat the process for the third antenna and continue to repeat the process until all 32 antennas have stepped through the 8 phases. At the end of the process, the transmitter may transmit the maximum voltage in the most efficient manner to the receiver.

In another exemplary embodiment, the transmitter may detect a second receiver's advertisement and form a communication connection with the second receiver. When the transmitter forms the communication with the second receiver, the transmitter may aim the original 32 antennas towards the second receiver and repeat the phase process for each of the 32 antennas aimed at the second receiver. Once the process is completed, the second receiver may get as much power as possible from the transmitter. The transmitter may communicate with the second receiver for a second, and then alternate back to the first receiver for a predetermined period of time (e.g., a second), and the transmitter may continue to alternate back and forth between the first receiver and the second receiver at the predetermined time intervals.

In yet another implementation, the transmitter may detect a second receiver's advertisement and form a communication connection with the second receiver. First, the transmitter may communicate with the first receiver and re-assign half of the exemplary **32** the antennas aimed at the first receiver, dedicating only 16 towards the first receiver. The transmitter may then assign the second half of the antennas to the second receiver, dedicating 16 antennas to the second receiver. The transmitter may adjust the phases for the second half of the antennas. Once the 16 antennas have gone through each of the 8 phases, the second receiver may be obtaining the maximum voltage in the most efficient manner to the receiver.

D. Mobile App for Receiver

In some instances, a receiver may be embedded into an electrical device, or may be controlled by a software application associated with the wireless power system. These instances arise where, e.g., the receiver and the electrical device are the same product, or the receiver has the capability to receive power waves, but may not comprise an operable communications component. In such instances, the software application, such as a smartphone application, may be used to identify or "tag" the receiver on behalf of a transmitter.

A tag may be any means of conveying to the transmitter that the transmitter is responsible for transmitting power waves to the receiver of the electrical device, regardless of whether the typical data exchange takes place. For example, in one embodiment, an administrator may use a smartphone, executing a software application of the system, to inform the transmitters to transmit power waves to a wall clock comprising receiver antennas, but lacking a communications component. Using the smartphone application, the user may place the smartphone nearby the wall clock and then select an interface input to transmit the transmission field coordinates of the wall clock to the transmitter and/or a mapping memory. As a result, the transmitter will continue to transmit power waves to the receiver, based upon the now "tagged" location provided by the smartphone application.

In some instances, the smartphone application may generate an interface indicating for the user a suggested location for receiving power waves in a pocket of energy. That is, the smartphone application may query a memory map to identify where the transmitters and/or receivers have determined to form pockets of energy and avoid identified sensitive objects. The mapping memory data may provide the smartphone application with coordinates data that the smartphone application may be preconfigured to understand and interpret to identify the locations of pockets of energy. In some embodiments, however, the smartphone may execute one or more of the algorithms performed by the receiver devices, as disclosed herein, to identify the most efficient location to place the receiver. The smartphone app may dynamically determine where within a transmission field the receiver may receive a maximally efficient amount of power from power waves or pockets of energy, as transmitted into a transmission field by one or more transmitters. The smartphone application may determine from any number of power pockets in a transmission field, which power pocket is most effective, or even the closest, and then generate an interface with an indicator, such as an arrow, directing the user to the pocket of energy.

III. Transmitter Sensors & Identifying Sensitive Objects

Some modes of operation may be sensitive to the regulatory requirements pertaining to living beings and sensitive objects. Living beings may include human beings, and other living beings such as domesticated animals. Sensitive objects include certain equipment and other valuable objects that are sensitive to electromagnetic energy in power waves. In another mode of operation, sensors may detect inanimate objects that have been tagged to avoid wireless power transmission, such as obstacles to power transmission, in trajectories of power waves. Under these circumstances, data sensors may cause transmitters to reduce or terminate power waves, or to redirect power waves (e.g., to avoid obstacles) or other responses described above.

In addition, the system for forming pockets of energy includes safety measures to address circumstances in which entities (such as objects) within the transmission field may interfere with reliable detection of humans or other living beings or sensitive objects in proximity to pockets of energy. In one embodiment, sensors detects inanimate objects or other entities (called objects in the following discussion) that have been tagged to be excluded from receipt of wireless power transmission in trajectories of power waves. Under these circumstances, sensors may cause transmitters to reduce or terminate power waves, to redirect power waves away from the tagged object, and/or other safety measures such as activating alarm. Tagged inanimate objects may include for example obstacles that interfere with sensor reception, and objects that may be occupied by infants or young children such as cribs.

To enable transmitter to detect and confirm objects that the user wishes to exclude from receipt of wireless power, the user may communicate to transmitter tagging information to be recorded in a mapping memory of transmitter. For example, the user may provide tagging information via a user device in communication with the controller of transmitter, via a graphical user interface (GUI) of the user device. Exemplary tagging information includes location data for an electrical device, which may include one-dimensional coordinates of a region in space containing the object, two-dimensional (2D) coordinates of a region in space containing the object, or three-dimensional (3D) coordinates of a region in space containing the object.

Additionally, tagging information for objects to be excluded from receipt of wireless power may be provided by scanning the transmission field of a wireless power system with sensors to detect such objects. Scanning with sensors dynamically maintains the mapping memory of transmitter, for example to update tagging information previously provided to the mapping memory via a user device as described above. In an embodiment, the transmission field of wireless power system is scanned periodically to detect sensor responses indicating updated tagging information for objects to be excluded from receipt of wireless power, using one or more of pyro-electric sensors, ultrasound sensors, millimeter sensors, and power sensors, or other sensor technologies.

Sensors may detect various conditions, such as the presence of sensitive objects or tagged objects, within a two or three-dimensional space (i.e., transmission field) serviced by a wireless charging system. Acting in conjunction with one or more transmitters of a wireless charging system, sensors and transmitters may execute various methods for providing safe, reliable, and efficient wireless power, by dynamically producing, adjusting, and/or terminating power waves generated by the transmitters. As detailed further herein, when determining the appropriate waveform characteristics for power waves, a transmitter may calculate the power levels of those power waves converging to form a pocket of energy at a predetermined location within a transmission field. These power levels measurements may include, for example, the power density (W/m2) and/or the electric field level (V/m), though one having ordinary skill in the art would appreciate that other measurements are possible as well.

A. Sensors Identifying Devices & Adjusting Power Waves

FIG. **6** shows execution steps of an exemplary method **600** of wireless power transmission using sensor data to automatically identify and adjust certain operating conditions of wireless a power transmission system.

At a first step **601**, a transmitter calculates power waves for a predetermined location within a transmission field, which may be a two or three-dimensional space receiving

wireless power services from the transmitters of the wireless power system. The transmitter may calculate power waves for the predetermined location during the start-up of operation of the transmitter, or may calculate power waves for the predetermined location during ongoing wireless power transmissions of the transmitter. In some implementations, the transmitter calculates power waves for a predetermined location for forming pockets of energy at the predetermined location. As disclosed herein, in calculating power waves, the transmitter may calculate power levels of power waves that converge in a three dimensional space to form one or more first pockets of energy at a predetermined location at the predetermined location, such as power density (W/m2) and/or electric field level (V/m).

In some embodiments of this step **601**, the transmitter's calculation power waves, for a predetermined location, is included in mapping data or heat-map data, used for determining pocket-forming locations for power waves transmitted by the transmitter. The heat-map data may be stored in a mapping database maintained by transmitter, or may be maintained in a database stored externally to transmitter, such as a database stored at a server in communication with transmitter. In an embodiment, the transmitter associates the calculated power waves with location coordinates (e.g., 3D or 2D coordinates) of a transmission field at the predetermined location.

In additional or alternative embodiments of this step **601**, the transmitter transmits power waves that converge in a transmission field to form one or more first pockets of energy at the predetermined location, and power transmission signals that converge to form one or more second pockets of energy at a second location, separated from the predetermined location. In an embodiment, the power waves generate side lobes, which result in formation of, sometimes undesired, second pockets of energy. In an embodiment, the predetermined location of the one or more first pockets of energy, and the second location of the second pockets of energy, both are included in a heat-map of pocket forming locations of the transmitter. Where such side lobes result in undesired second pockets of energy, the location data for the second pockets of energy may be used to generate a null (i.e., converge power waves to produce destructive interference) at the location of the second pockets of energy.

At a next step **603**, sensors may communicate, to the transmitter, sensor data relating to conditions within the power transmission field. In an embodiment, sensors communicate sensor data relating to unsafe or prohibited operating conditions of the system (e.g., power levels for power waves transmitted at a particular location would exceed a permissible amount). In one embodiment, the sensors communicate sensor data relating to the presence of living beings or sensitive objects within the transmission field. In another embodiment, the sensors communicate sensor data relating to presence of one or more objects to be excluded from receipt of power waves. For example, there may instances where, regardless of whether a person is presently detected by a sensor at a particular location; it might be preferable to altogether avoid transmitting power waves to the particular location.

In an embodiment of step **603**, sensors acquire and communicate to the transmitter location related information concerning a living being or object. In an embodiment, one or more sensors acquire information concerning the distance from the one or more sensors of a detected living being or object. In another embodiment, one or more sensors acquire information indicating a motion of the living being or object based upon a series at different times of the data indicating the presence of the living being or object. In another embodiment of step **603**, sensors acquire and communicate location-related information, and at least one non-location attribute, of a living being or object. In an embodiment, at least one non-location attribute of the living being or object includes one or more of pyro-electric sensor responses, optical sensor responses, ultrasound sensor responses, and millimeter sensor responses.

At step **605**, a transmitter determines whether to adjust power waves for the predetermined location based on the sensor data acquired and communicated at a previous step **603**. In an embodiment, a transmitter compares location data for a living being or object identified by the sensors in a previous step **603** with one dimensional, two dimensional, or three-dimensional coordinates of the predetermined location. In an embodiment, the transmitter compares the power levels (e.g., power density (W/m2), electric field level (V/m)) of the power waves converging at or set to converge at the predetermined location, as calculated at a previous step **601**, against one or more maximum permissible power levels for safe operation.

In another embodiment of step **605**, the transmitter compares object detection data that relates to one or more objects, and may be stored as mapping data or sensor data, against tagging information that indicates an object is to be excluded from receipt of power waves. In an embodiment, tagging information indicating an object is to be excluded from receipt of power waves was previously communicated to the transmitter by a user device, such as a workstation computer or smartphone executing a software application associated with the wireless power charging system. In another embodiment, tagging information relating to an object to be excluded from receipt of power waves was provided to transmitter by one or more sensors while scanning the transmission field for objects, e.g., sensitive objects and/or receivers. In a further embodiment, one or more sensors obtain measurements of the sensors' sensitivity at various regions within the transmission field, and communicate the sensitivity measurements to the transmitter. Regions in the transmission field where the sensors have low sensor sensitivity measurements are tagged to be excluded from receipt of power waves, by a sensor processor or transmitter processor.

At a next step **607**, after determining power levels for transmitting power waves, the transmitter calibrates antennas and transmits power waves based on the determinations made during a previous step **605**. In circumstances where the determination does not detect an unsafe or prohibited condition, then power waves transmitted in step **607** may have the waveform characteristics (e.g., power levels) that were initially calculated at a previous step **605**. On the other hand, in circumstances where the determination detects an unsafe or prohibited condition, the power waves transmitted in step **607** may be terminated from transmitting or they may have updated waveform characteristics, adjusted as needed from the power waves calculated at step **601**. In various embodiments, the unsafe or prohibited condition may be information relating to the location of a living being or a sensitive object indicating that the living being or sensitive object is proximate (e.g., touching, adjacent, nearby) to a predetermined location (e.g., location for a pocket of energy), or may be object detection data that corresponds to tagging information relating to an object to be excluded from receipt of power waves.

In an embodiment of step **607**, the transmitter reduces the power level of the power waves at the predetermined location when the determination at step **605** identifies an

unsafe or prohibited condition. In another embodiment, the transmitter terminates transmission of the power waves to the predetermined location when the determination at step **605** identifies an unsafe or prohibited condition. In a further embodiment, the transmitter adjusts the characteristics of the power waves to diminish the amount of energy provided by the power waves at the predetermined location, when the determination at step **605** identifies an unsafe or prohibited condition. In another embodiment, when the determination at step **605** identifies an unsafe or prohibited condition at a particular location in the transmission field, the transmitter may adjust the characteristics of the power waves, or adjusts the antenna array of the transmitter, to redirect the power waves around the particular location. Additionally or alternatively, the transmitter may activate an alarm when the transmitter identifies an unsafe or prohibited condition at step **605**, based upon the sensor data received from the sensors associated with the transmitter.

The initially-calculated or adjusted power waves transmitted in the current step **607** may be RF waves the converge into constructive interference patters, which may eventually form pockets of energy, which may be intercepted or otherwise received by antennas of a receiver. The receiver may rectify the RF waves to then convert the rectified RF waves into a constant DC voltage, which may be used to charge or power an electronic device.

B. Adaptively Adjusting Power Waves in Ongoing Power Charging

FIG. **7** shows steps of an exemplary method **700** for wireless power transmission that protects living beings and other sensitive objects during ongoing transmission of power waves by transmitters of a wireless power system. Transmitters of a wireless power system may comprise sensors that detect whether a living being or sensitive object is in proximity to one or more pockets of energy, power waves, and/or a transmitter. In these circumstances, the sensor data generated by the sensors may cause the transmitter to reduce or terminate power levels of power waves, among a number of additional or alternative actions.

At a first step **701**, a transmitter transmits power waves to a predetermined location. As mentioned, the power waves transmitted at this step **701** may converge into a three-dimensional constructive interference pattern, eventually forming one or more pockets of energy at the predetermined location. The predetermined location may be included in mapping data, such as sensor data or heat-map data, used for determining where in a transmission field to transmit power waves. In some implementations, the mapping data containing the predetermined location may be stored in a mapping memory that is internal or external to the transmitter. In some implementations, the mapping data may be generated in real-time or near real-time by a transmitter processor or a sensor processor. In addition, in some implementations, the mapping data containing the predetermined location may be provided from a user device, through a software application associated with the wireless charging system.

In some embodiments of step **701**, the transmitter transmits power waves that converge in the transmission field to form a pocket of energy at the predetermined location, and also power waves that converge to form a second pocket of energy at a second location in the transmission field, which is separate from the predetermined location for the first pocket of energy. That is, in some instances, power waves may result in the generation of side lobes of power waves, which causes the formation of one or more second pockets of energy, in addition to the first pocket of energy generated at the predetermined location. In some implementations, the predetermined location for the first pocket of energy and the second location having the second pocket of energy, are both included in mapping data (e.g., sensor data, heat-map data), tracking the locations of pocket-forming for the transmitter. Although waveform generation and transmission techniques may be employed to avoid or reduce formation of side lobes, various embodiments of wireless power transmission disclosed herein, such as the exemplary method **700**, may intelligently protect living beings and sensitive objects when these and other types of second pockets of energy are present in a transmission field.

At a next step **703**, one or more sensors acquire raw sensor data indicating presence of a living being or sensitive object, and then communicate raw or processed sensor data to the transmitter. In an embodiment, sensors may acquire and communicate location-related information concerning the living being or sensitive object. In an embodiment, one or more sensors acquire and communicate to the transmitter location-related information, and at least one non-location attribute, of the living being or sensitive object. In an embodiment, at least one non-location attribute of the living being or sensitive object includes one or more of pyro-electric sensor responses, optical sensor responses, ultrasound sensor responses, and millimeter sensor responses.

In an embodiment, a first sensor is located at a first position on the transmitter, and a second sensor is located at a second position on the transmitter separated from the first position. The first and second sensors acquire stereoscopic data indicating presence of a living being or sensitive object.

In an embodiment, a first sensor provides a first type of data indicating the presence of the living being or the sensitive object, and a second sensor provides a second type of data indicating the presence of the living being or the sensitive object. Use of mixed sensor types generally improves target discrimination. In an embodiment, at least one of the first types of data and the second type of data indicates location in three-dimensional space of the living being or the sensitive object.

In an embodiment, one or more sensors acquire and communicate to the transmitter human recognition sensor data, including one or more of body temperature data, infrared range-finder data, motion data, activity recognition data, silhouette data, gesture data, heart rate data, portable devices data, and wearable devices data. Additionally or alternatively, the one or more sensors that acquire sensor data indicating presence of a living being or sensitive object may comprise one or more of a passive sensor, an active sensor, and a smart sensor. The sensors may include one or more of an infrared sensor, a pyro-electric sensor, an ultrasonic sensor, a laser sensor, an optical sensor, and Doppler sensor, an accelerometer, a microwave sensor, a millimeter sensor, a resonant LC sensor, and an RF standing wave sensor.

At a next step **705**, the transmitter obtains sensor data from the sensor or mapping memory, comprising location-related information corresponding to a living being or sensitive object, as indicated by the raw or processed sensor data generated by the sensor indicating the presence of the living being or sensitive object. As an example, one or more sensors may acquire raw sensor data identifying the presence of a living being or sensitive object, process the raw sensor data, and then generate sensor data containing information indicating the distance of the living being or sensitive object from one or more sensors or transmitters.

In another embodiment, a first sensor is located at a first position on the transmitter, and a second sensor is located at a second position on the transmitter separated from the first position. In step **705**, the transmitter obtains stereoscopic location data relating to a living being or sensitive object based on the data acquired by the first and second sensors located at separated positions on the transmitter. In an embodiment, in step **705**, the transmitter combines distance information with other information, such as stereoscopic sensor data, in order to determine the proximity of the living being or sensitive object to a predetermined location for the power waves, or other location within the transmission field where transmission of power waves should be avoided.

In a further embodiment, one or more sensors may acquire raw sensor data or generate processed sensor data containing information indicating the displacement or motion of a living being or sensitive object in a transmission field, based upon a series at different times of the data indicating the presence of the living being or sensitive object. In step **705**, the transmitter uses this motion information to sense movement of the living being or sensitive object relative to the predetermined location.

In some embodiments, in step **705**, one or more sensors, the transmitter, or both, may filter sensor data indicating the presence of a living being or sensitive object, to eliminate or minimize false positives (i.e. false indications of the presence of a living being or sensitive object). This filter may query, alter, and/or remove the information relating to a location of the living being or the sensitive object, as required. As an example, a sensor processor of a pyroelectric sensor may apply filtering techniques to the pyroelectric sensor data associated with an extraneous heat source detected within the transmission field of a transmitter. In this example, the filtering may exclude data points corresponding to the extraneous heat source from the sensor data indicating a living being or sensitive object.

At a next step **707**, a transmitter determines whether to adjust the characteristics of the power waves, based upon the location data associated with a living being or sensitive object identified in mapping data or sensor data. The transmitter compares the location data for the living being or sensitive object, obtained at a previous step **705**, against planar coordinates (e.g., one-dimensional coordinates, two-dimensional coordinates, three-dimensional coordinates, polar coordinates) associated with the predetermined location, where the coordinates for the predetermined location may be stored in a mapping memory of the transmitter or the wireless charging system. In an embodiment, the transmitter compares the power levels generated by the power waves at the predetermined location (e.g., power densities (W/m2) and/or electric field levels (V/m)), which may be power levels that were calculated at a previous step **701**, against one or more maximum permissible power level for the living being or sensitive object.

In some implementations, in step **707**, the transmitter may apply safety techniques to the determination of whether to adjust the power waves, using the location data in the sensor data associated with the living being or sensitive object. One safety technique is to include a margin of error (e.g., a margin of 10%-20%) beyond the regulatory limits or other limits on maximum permissible power level or on EMF exposure, to ensure living beings or sensitive objects are not exposed to power levels at or near the limits. A second safety technique involves multistage determinations of whether, and how, to adjust characteristics of the power waves. For example, at a first stage, the location data generated by the sensor may indicate movement of a living being or sensitive object, toward the location of a pocket of energy, resulting in a determination to reduce power level of power waves (i.e., anticipating that living being or sensitive object enter the pocket of energy). At a second stage, the location data may indicate the arrival of the living being or sensitive object at the location of the pocket of energy, resulting in a determination to terminate power waves.

At a next step **709**, the transmitter may execute one or more actions, if the transmitter determines at a previous step **707** to adjust power waves based on the location data in the sensor data associated with the living being or sensitive object. In some cases, the transmitter reduces the power level of the power waves at the predetermined location, when the transmitter determines at a previous step **707** to adjust the power waves. In some cases, the transmitter terminates transmission of the power waves to the predetermined location, when the transmitter determines at a previous step **707** to adjust or terminate the power waves. In some cases, the transmitter diminishes the amount of energy of the power waves at the predetermined location, when the transmitter determines at a previous step **707** to adjust the power waves. In some embodiments, the transmitter redirects the transmission of the power waves around the living being or sensitive object, when the transmitter determines at a previous step **707** to adjust the power waves. Additionally or alternatively, the transmitter may activate an alarm of the transmitter or wireless charging system, when the transmitter determines at previous step **707** to adjust the power waves.

C. Tagging Objects to Avoid

FIG. **8** illustrates a method of wireless power transmission in which sensors acquire object detection data by detecting one or more objects, which may be inanimate objects such as obstacles to power transmission, during ongoing transmission of power waves by a transmitter. A transmitter compares the object detection data with identifying information relating to an entity to be excluded from receipt of power waves, and based on this comparison, determines whether to adjust transmission of the power waves.

At step **801**, transmitter transmits power waves to a predetermined location. In an embodiment, the power waves transmitted at this step converge in a three dimensional pattern to form one or more pockets of energy at the predetermined location.

At step **803**, at least one sensor acquires and communicates to the transmitter object detection data indicating presence of one or more objects. In an embodiment, the object detection data includes location related information for the one or more objects. In an embodiment, the object detection data comprises location related information for the one or more objects, and at least one non-location attribute for the one or more objects. In an embodiment, at least one sensor includes one or more of a passive sensor, an active sensor, and a smart sensor. In an embodiment, at least one sensor includes one or more of an infrared sensor, a pyroelectric sensor, an ultrasonic sensor, a laser sensor, an optical sensor, an Doppler sensor, an accelerometer, a microwave sensor, a millimeter sensor, a resonant LC sensor, and an RF standing wave sensor.

At step **805**, the transmitter determines whether to adjust the transmission of the power waves by comparing the object detection data with identifying information relating to an entity to be excluded from receipt of the power waves. In an embodiment, identifying information for the object to be excluded from receipt of power waves was previously

communicated by a user to the transmitter for storage in a database of the transmitter. The identifying information may include information concerning the location of the object to be excluded from receipt of power waves, and may include non-location information concerning the object to be excluded from receipt of power waves. The user may provide the identifying information using a graphical user interface (GUI) (such as a standard web browser) on a computer device in communication with the transmitter. The computer device may be for example a desktop computer, a laptop computer, a tablet, a PDA, a smartphone and/or another type of processor-controlled device that may receive, process, and/or transmit digital data. The computer device may be configured to download the graphical user interface from an application store to communicate with the transmitter.

In another embodiment, the identifying information for the object to be excluded from receipt of power waves is provided to the transmitter by at least one sensor via scanning a transmission field for the wireless power transmission to detect the identifying information.

In an embodiment, identifying information for the entity to be excluded from receipt of power waves comprises one-dimensional coordinates of a region in space containing the entity, or two-dimensional coordinates of the region in space containing the entity, or three-dimensional coordinates of the region in space containing the entity.

In an embodiment, the object detection data comprises location related information for the one or more objects and at least one non-location attribute of the one or more objects. In an embodiment, at least one non-location attribute includes one or more of pyro-electric sensor responses, optical sensor responses, ultrasound sensor responses, millimeter sensor responses of the designated device, and power sensor responses of the one or more objects.

In an embodiment, at least one sensor obtains sensitivity measurements of the sensor at various regions in space, and communicates these sensitivity measurements to the transmitter. A region in space with a low sensitivity measurement of the sensor is tagged by transmitter to be excluded from receipt of power waves. This dynamic scanning method avoids transmission of power waves to regions in space in which a sensor is blocked from detecting, or may be otherwise unable to detect, unsafe or prohibited conditions of wireless power transmission system.

In an embodiment, the object detection data includes location related information for the one or more objects, and the identifying information includes coordinates of the entity to be excluded from receipt of the power waves. In determining whether to adjust the transmission of the power waves, the transmitter determines whether the location related information indicates that the one or more objects are proximate to the coordinates of the entity to be excluded from receipt of the power waves.

At step **807**, the transmitter reduces power level, terminates transmission of power waves, or redirects the power waves if the transmitter determines at step **805** to adjust the transmission of the power waves. In an embodiment, the transmitter reduces the power level of the power waves at the predetermined location when the transmitter determines at step **805** to adjust the power waves. In another embodiment, the transmitter terminates transmission of the power waves to the predetermined location when the transmitter determines at step **805** to adjust the power waves. In a further embodiment, the transmitter diminishes energy of the power waves at the predetermined location when the transmitter determines at step **805** to adjust the power waves. In another embodiment, the transmitter redirects the power waves when the transmitter determines at step **805** to adjust the power waves. In addition, the transmitter may activate an alarm when the transmitter determines at step **805** to adjust the power waves.

D. Identifying Receivers with Sensors

As previously mentioned, in some implementations, sensors may be configured to identify receivers in a transmission field that should receive power waves from a transmitter. In such implementations, the transmitter may gather mapping data for receivers in the transmission field as an alternative or as a supplement to the communications component typically used by the transmitter to identify receivers. As an example, this alternative or additional solution of identifying receivers may be implemented by a transmitter when the receiver and/or the transmitter do not have access to a communications component.

FIG. **9** illustrates a method of wireless power transmission that powers or charges electrical devices selected (e.g., by a user) to receive power from the wireless power system. For example, the method of FIG. **9** can transmit wireless power to electrical devices, such as alarm clocks or smoke alarms, which do not include a communications component that transmits communications signals to the transmitter in order to exchange data in real-time or near real-time. In this method, sensors detect electrical devices and communicate apparatus detection data to the transmitter. The transmitter determines whether the apparatus detection data corresponds to a designated device selected to receive power from the transmitter with reference to a database of the transmitter including identifying information for one or more such designated devices. Based on this determination, transmitter may transmit power waves that converge to form one or more pockets of energy at the locations of any detected electrical devices corresponding to the designated devices selected to receive wireless power transmission.

At step **901**, at least one sensor acquires apparatus detection data indicating the presence of an electrical apparatus. In an embodiment, the apparatus detection data includes information on the location of the electrical apparatus. In another embodiment, the apparatus detection data includes information on the location of the electrical apparatus, and at least one non-location attribute for the electrical apparatus. In an embodiment, at least one sensor includes one or more of pyro-electric sensors, optical sensors, ultrasound sensors, millimeter sensors, and power sensors, among other sensor technologies.

At step **903**, the transmitter determines whether the apparatus detection data acquired at step **901** corresponds to a designated device selected to receive power from the transmitter. In an embodiment, identifying information for one or more designated device selected to receive power from the transmitter was previously communicated by a user to the transmitter for storage in a database of the transmitter. The identifying information may include information concerning the location of the one or more designated device, and may include non-location information concerning the designated device. The user may provide the identifying information using a graphical user interface (GUI) (such as a standard web browser) on a computer device in communication with the transmitter. The computer device may be for example a desktop computer, a laptop computer, a tablet, a PDA, a smartphone and/or another type of processor-controlled device that may receive, process, and/or transmit digital data. The computer device may be configured to download

the graphical user interface from an application store to communicate with the transmitter.

In an embodiment, the apparatus detection data includes information on the location of the electrical apparatus, and the transmitters compares this information with previously stored one-dimensional coordinates of a region in space containing the designated device, two-dimensional coordinates of the region in space containing the designated device, or three-dimensional coordinates of the region in space containing the designated device. In an example, the transmitter compares apparatus detection data indicating the location of the electrical apparatus (e.g., wall clock) at coordinates within a transmission field, against previously stored data records in a database coupled to the transmitter, where the data records contain data for designated devices selected to receive power from the transmitter. Based on correspondence between the location of the electrical apparatus and the previously stored transmission field coordinates, the transmitter determines that the electrical apparatus corresponds to the wall clock, and thus the wall clock should receive power waves from the transmitter at the particular coordinates.

In an embodiment, the apparatus detection data includes information on the location of the electrical apparatus, and at least one non-location attribute of the electrical apparatus. In an embodiment, the at least one non-location attribute includes one or more of pyro-electric sensor responses, optical sensor responses, ultrasound sensor responses, millimeter sensor responses of the designated device, and power sensor responses of the designated device. In an example of a non-location attribute, the apparatus detection data includes an identifier, such an RFID tag, and the transmitter compares this identifier with a unique identifier of the designed device previously stored in the transmitter. Based on correspondence between the identifier of the apparatus detection data and the previously stored unique identifier of the designed device, the transmitter determines that the electrical apparatus corresponds to the designated device. The transmitter may make a determination to transmit power to the electrical apparatus in this example, even though the electrical apparatus may have moved to a different location than a location of the designated device previously stored in the transmitter database.

In an embodiment, the apparatus detection data includes information on the location of the electrical apparatus, and in addition to carrying out the determination step **903**, the transmitter stores mapping information corresponding to the location of the electrical apparatus, for future reference. In an embodiment, the apparatus detection data includes information on the location of the electrical apparatus, and in addition to carrying out the determination step **903**, the transmitter updates previously stored mapping information corresponding to the location of the electrical apparatus.

In an embodiment of step **903**, in determining whether the apparatus detection data corresponds to a designated device, the transmitter further determines identification and attribute information for the designated device, the identification and attribute information including one or more of level of power usage of the designated device, duration of power usage of the designated device, power schedule of the designated device, and authentication credentials of the designated device.

At step **905**, the transmitter transmits power waves for receiving by the electrical apparatus if the apparatus detection data corresponds to a designated device selected to receive power from the transmitter. In an embodiment in which the transmitter determines identification and attribute information for the designated device, that identification and attribute information may control whether, or when, the transmitter transmits power waves for receiving by the electrical apparatus. Examples of identification and attribute information include power usage of the designed device, duration of power usage of the designated device, power schedule of the designated device, and authentication credentials of the designated device.

At step **907**, in the event the electrical apparatus is connected to a receiver, the receiver intercepts and converts the power waves to charge or power the electrical apparatus. In an embodiment in which the power waves are RF waves that form one or more pockets of energy in the form of constructive interference patterns of the RF waves, and then the receiver gathers the energy from the resulting pocket of energy. Here, the receiver rectifies the energy from the RF waves that produce the pocket of energy, and converts the rectified RF waves into a constant DC voltage that can charge or power the electrical apparatus.

E. Exemplary Embodiment

In the following exemplary embodiment of a sensor subsystem of a wireless power transmitter ("transmitter"), the transmitter may comprise two types of sensors: a primary sensor and a secondary sensor. The primary sensor may implement any sensor technology capable of capturing and generating sensor data regarding temperature or heat information for objects (e.g., living beings) located within a transmission field, which may include infrared or thermal sensors. The secondary sensor may operate with a sensor technology whose purpose is to measure objects at some distance and/or in proximity to the transmitter using an alternative sensor technology, such as an ultrasonic sensor. It should be appreciated that, in some embodiments, references to "primary" and "secondary" sensors does not always indicate a level of priority of the information produced by these sensors.

Continuing with this example, the primary thermal sensor and the secondary distance sensor may report analog data (i.e., raw sensor data) directly to application-specific integrated circuits (ASICs) associated with the respective sensor. The operations of the ASICs may be controlled by a sensor processor, which may be a microcontroller or processor configured to control the ASICs. As an example, after receiving the raw sensor data, each ASIC may then digitize, process, and communicate the processed sensor data to the respective processor. The ASIC and/or sensor processor may be integrated into the sensor assembly or be separated from the sensors by some physical or mechanical distance. In some embodiments, the ASIC and/or sensor processor may communicate data and commands using Serial-Peripheral-Interface (SPI) and/or an I2C serial digital communications interfaces. And in some embodiments, the sensor processor and/or primary and secondary sensor assembly may be integrated into a single printed circuit board ("sensor PCB"), or may be separated, depending upon specific mechanical requirements, and different system application needs. In this example, a sensor comprises a single PCB having the sensor processors and ASICs.

In operation, a sensor processor will communicate processed sensor data with one or more transmitters. For example, the processor may transmit the sensor data to a main transmitter's Command-and-Control-Unit (CCU), using SPI. In some implementations, the sensor PCB-to-CCU communication is performed only as often as required

to optimize safe and effective operation of the system, but while maintaining optimal resource (e.g., power, memory, processing) efficiency.

i. Exemplary Calibration Operation

At a first time sample (e.g., time=0 (T0)), the system is powered up or initialized for the first time or after memory is purged. A self-test is performed determine whether the components are operational at a low level of power. A secondary test is performed, which checks for network connectivity and (assuming an internet connection is found) software updates. Assuming all systems are operational and firmware is up-to-date, the sensor PCB will perform a self-calibration that will complete in less than 2 seconds. The sensor PCB will be fully functional and can complete calibration, even without network connectivity. Network connectivity will not be a precursor for safe and effective operation.

In some implementations, self-calibration may commence upon startup and subsequently, when several criteria are simultaneously met. As an example, for a primary sensor operating on thermal-based technology, the sensor will determine whether no thermal objects of interest (TOoI) are present in the field of view and that no power receivers are present in the field of transmission; and the presence of power receivers is detected through the CCU. For secondary sensors in this exemplary embodiment, the startup criteria requires the transmitter to be stationary, with no TOoI present nor movement detected within the transmission field, for a minimum amount of time necessary to perform self-calibration.

Next, primary sensor self-calibration processes and gain control is started when nothing in the transmission field is detected that could be determined to be a TOoI. In other words, the sensors must not detect any object with a thermal and/or shape profile matching likely presence of a living being, including (but not limited to) humans of any age and pets free to roam the transmission field. The primary sensor may then perform self-calibration processes, according to the technology implemented.

In an exemplary method of the primary sensor's self-calibration, the primary sensor shall self-calibrate by use of an isothermal shutter, which, in operation, momentarily covers the lens or input to a thermal camera array of the sensor. An independent, previously calibrated temperature sensor (e.g., NTC or PTC thermistor, 2 or 4-contact RTD, a thermocouple or other accurate temperature-sensing device) is integrated with the primary sensor assembly and is as close to isothermal with the lens or input shutter device as possible. While the isothermal shutter inhibits the primary sensor input, the external temperature-sensing device and the entire pixel array of the thermal camera is read. The analog sensor value for each thermal pixel is analyzed and assigned to (calibrated to) the temperature reading of the external (shutter-isothermal) temperature sensing device. This analog to digital, thermal-auto-calibration may be a function of the primary sensor ASIC, and may require or not require an external input or interaction from the sensor processor/controller. When the shutter is opened again (the primary sensor is unblocked), the readings from each pixel in the large array of thermal pixels in the primary sensor will be assigned an accurate, absolute temperature reading. These values will be analyzed in all subsequent thermal array collections (thermal frames) by the sensor processor to determine the position of any TOoI within the transmission field or nearby room/space.

The secondary sensor's calibration may occur simultaneous or within 1 second of primary sensor calibration, provided no scene movement or TOoI is detected by the primary sensor. The operation of ultrasonic distance and other proximity sensors is to transmit a small number of quick transmit pulses into the room or space, and receive reflections back from all objects in the room. The transmit pattern will typically occur for less than 1/1000 of a second (<1 ms), and the reflections may be sensed for tens of milliseconds, allowing for depth range as well as sensing and bounding of the area of interest (which includes the area of wireless power transmission). The reflections gathered by each secondary sensor, under these conditions (i.e., no TOoI and no movement detected) will form the reference frame, or the background reflection pattern against which future secondary sensor reception frames will be measured.

ii. Normal Operation:

After the primary sensor is calibrated, objects like a thermal objects of interest (TOoI) can be sensed and identified by the sensor processor. When a TOoI is sensed, a pair of ultrasonic or proximity sensors will send standard transmit pulses out and receive reflection patterns back. The reflection patterns give the distance and angle to the TOoI, based upon mathematical (e.g., trigonometric) sensor analysis and processing. The mathematics and reflection processing will be used to detect and track the living bodies (e.g., humans, animals) within the field of power transmission; and in some embodiments, primary sensor operation and detection may be done completely without the CCU.

In some cases, when the CCU detects the presence of a power receiver, the CCU may request for the coordinates of living bodies (TOoI) in X, Y, Z or X, Y, and directional angle from the transmitter, which the sensor PCB will report back almost immediately. From the knowledge of the location of any receivers and/or the locations of any living bodies (e.g., an end user) in the room, the power waves used to generate a pocket of energy may be controlled, not just in space, but in power output as well, because the CCU shall have the power to modulate, scale, and control the power waves transmitted to a pocket of energy around a receiver. Advantageously, this system enables optimal power transmission, simultaneous with maximum compliance and safety, with zero active interaction or thought from the end user.

A receiver may receive maximum power for a pocket of energy when the system detects that a living object is outside of a periphery of that pocket of energy in the transmission field. If the pocket of energy is very close to the living body, then the power transmission will be automatically throttled, by adjusting the power waves, to be within FCC compliance and safety specifications.

If there is a receiver receiving wireless power, but no TOoI (i.e., living bodies) are detected in the transmission field, and any obstruction quickly moves across the field of view (potentially very close to the transmitter), then the sensor and sensor processor shall sense and respond fast enough to send an interrupt signal to the CCU of the transmitter, which will immediately and temporarily disable power transmission until such time as the area of the receiver is free of the obstruction and the power transmission can be resumed. For example, a transmitter can have a sensor that detects that a TOoI is in close proximity to the transmitter, whereby the transmitter disables power transmission until the TOoI is no longer in a transmission path between the transmitter and a receiver. In another example, the transmitter can have a sensor that detects that a TOoI is in close proximity to the transmitter, whereby the transmitter disables power transmission until the TOoI is no longer in proximity to the transmitter.

IV. Generating Power Waves & Forming Pockets of Energy

In a wireless charging system, transmitters are devices that comprise, or are otherwise associated with, various components and circuits responsible for, e.g., generating and transmitting power waves, forming pockets of energy at locations in a transmission field, monitoring the conditions of the transmission field, and generating null spaces where needed. A transmitter may generate and transmit power waves for pocket-forming and/or null steering based on the one or more parameters. The parameters may be determined by a transmitter processor, sensor processor, or other processor providing instructions to the transmitter, based on data received from the one or more receivers, sensors internal to the transmitter, and/or sensors external to the transmitter. With regard to the sensors of the system, it should be appreciated that an internal sensor may be an integral component of the transmitter, or receiver. It should also be appreciated that an external sensor may be a sensor that is placed within the working area of a transmitter, and may be in wired or wireless communication with one or more transmitters of the system.

Transmitters may wirelessly transmit power waves having certain physical waveform characteristics, which are particular to the particular waveform technology implemented. The power waves may be transmitted to receivers within a transmission field of the transmitters in form of any physical media capable of propagating through space and being converted into useable electrical energy for charging the one or more electronic devices. The examples of the physical media may include radio frequency (RF) waves, infrared, acoustics, electromagnetic fields, and ultrasound. The power transmission signals may include any radio signal, having any frequency or wavelength. It should be appreciated by those skilled in the art that the wireless charging techniques are not limited to RF wave transmission techniques, but may include alternative or additional techniques for transmitting energy to the one or more receivers.

A. Components of a System Generating and Using Power Waves

FIG. **10** illustrates generation of pocket of energy to power one or more electronic devices in a wireless power transmission system, according to an exemplary embodiment.

The wireless power transmission system **1000** comprises a transmitter **1002** that transmits the one or more power transmission waveforms **1004** from the antenna array **1006** to power the one or more electronic devices such as a mobile phone **1008** and a laptop **1010**. Non-limiting examples of one or more electronic devices may include laptops, mobile phones, smartphones, tablets, music players, toys, batteries, flashlights, lamps, electronic watches, cameras, gaming consoles, appliances, and GPS devices among other types of electrical devices.

The examples of the power waves may include microwaves, radio waves, and ultrasound waves. The power waves **1004** are controlled through the microprocessor of the transmitter **1002** to form the pocket of energy **1012** in locations where the pocket of energy **1012** is intended. In the illustrative embodiment, the pocket of energy **1012** is intended in the locations of the one or more electronic devices **1008** and **1010**. The transmitter **1002** is further configured to transmit the power waves **1002** that may converge in three-dimensional space to create the one or more null spaces in the one or more locations where transmitted power waves cancel each other out substantially.

The microprocessor of the transmitter **1002** is further configured to, based on one or more parameters, select the power transmission waveform, select the output frequency of the power transmission waveforms, the shape of the one or more antenna arrays **1006**, and the spacing of the one or more antennas in at least one antenna array **1006** to form the pocket of energy at the targeted location to power the one or more electronic devices **1008**, **1010**. The microprocessor of the transmitter **1002** is further configured to, based on the one or more parameters, select the output frequency of the power waves, the shape of the one or more antenna arrays **1006**, and the spacing of the one or more antennas in at least one antenna array **1006** to form the one or more null spaces at the one or more locations within the transmission field of the transmitter **1002**. The pockets of energy are formed where the power waves **1002** accumulate to form a three-dimensional field of energy, around which one or more corresponding transmission null in a particular physical location may be generated by the transmitter **1002**.

The antennas of the antenna array **1006** of the transmitter **1002** that transmit the power waves may operate in a single array, a pair array, a quad array, or any other arrangement that may be selected in accordance with the one or more parameters by the microprocessor of the transmitter **1002**. In the illustrative embodiment, the antennas of the antenna array **1006** of the transmitter **1002** are operable as the single array.

The receiver may communicate with the transmitter **1002** in order to indicate its position with respect to the transmitter **1002**. The communications component may enable receiver to communicate with the transmitter **1002** by transmitting communication signals over a wireless protocol. The wireless protocol can be selected from a group consisting of Bluetooth®, BLE, Wi-Fi, NFC, or the like. The communications component may then be used to transfer information, such as an identifier for the one or more electronic devices **1008**, **1010**, as well as battery level information of the one or more electronic devices **1008**, **1010**, geographic location data of the one or more electronic devices **1008**, **1010**, or other information that may be of use for the transmitter **1002** in determining when to send power to receiver, as well as the location to deliver power waves **1002** creating the pockets of energy **1012**. The receiver may then utilize power waves **1002** emitted by the transmitter **1002** to establish the pocket of energy **1012**, for charging or powering the one or more electronic devices **1008**, **1010**. The receiver may comprise circuitry for converting the power waves **1002** into electrical energy that may be provided to the one or more electronic devices **1008**, **1010**. In other embodiments of the present disclosure, there can be multiple transmitters and/or multiple antenna arrays for powering various electronic equipment for example, may include smartphones, tablets, music players, toys, and other items.

In some embodiments, the one or more electronic devices **1008**, **1010** may be distinct from the receiver associated with the one or more electronic devices **1008**, **1010**. In such embodiments, the one or more electronic devices **1008**, **1010** may be connected to the receiver over a wire that conveys converted electrical energy from the receiver to the one or more electronic devices **1008**, **1010**.

After receiving the communication from the receiver by the transmitter **1002**, the transmitter **1002** identifies and locates the receiver. A path is established, through which the transmitter **1002** may know the gain and phases of the communication signals coming from the receiver. In addition to the communication signals from the receiver, the transmitter **1002** receives information/data from the one or

more internal sensors, the one or more external sensors, and heat mapping data about the location of the receiver and the location of the one or more objects such as human beings and animals. Based on the all the information and data received from the internal and external sensors, the heating mapping data, and the communication signals from the receiver, the microprocessor of the transmitter **1002** analyzes the information and data, and then determines the one or more parameters that will act as the inputs in determining the selections require to produce the pocket of energy **1012** at the targeted locations. After the determination of the one or more parameters, the transmitter **1002** then selects the type of power transmission wave **1002** to be transmitted, and the output frequency of power transmission wave **1002**, to generate the pockets of energy **1012** at the targeted locations within the transmission field of the transmitter **1002**. In another embodiment, in addition to selecting the type of power transmission wave **1002**, and determining the output frequency of power transmission wave **1002**, the transmitter **1002**, may also select a subset of antennas from a fixed physical shape of the one or more antenna arrays **1006** that corresponds to a desired spacing of antennas, which will be used to generate the pockets of energy **1012** at the targeted locations within the transmission field of the transmitter **1002**. After the selection of the output frequency of power waves **1002**, shape of one or more antenna arrays **1006**, and spacing of one or more antennas in each of the one or more antenna array **1006**, the antennas of the transmitter **1002** may start to transmit the power waves **1002** that may converge in three-dimensional space. These power waves **1002** may also be produced by using an external power source and a local oscillator chip using a piezoelectric material. The power waves **1002** are constantly controlled by the microprocessor of the transmitter **1002**, which may also include a proprietary chip for adjusting phase and/or relative magnitudes of power waves **1002**. The phase, gain, amplitude, frequency, and other waveform features of the power waves **1002** are determined based on the one or more parameters, and may serve as one of the inputs for the antennas to form the pocket of energy **1012**.

FIG. **11** illustrates generation of pocket of energy in a wireless power transmission system, according to an exemplary embodiment.

As illustrated in the FIG. **11**, the transmitter **1102** generates the power waves **1104** that form the pocket of energy **1106** at the receiver. As discussed earlier, the microprocessor of the transmitter **1106** will determine the one or more parameters based on all the information and data received from the internal and external sensors, the heating mapping data, and the communication signals from the receiver. The one or more parameters will then be used as the input by the microprocessor of the transmitter **1102** to select the power waves **1104** from a list of one or more waveforms and then generate the power waves **1104** by the waveform generator at the desired output frequency. The phase, gain, amplitude, frequency, and other waveform features of the power waves **1104** are also determined based on the one or more parameters by the microprocessor of the transmitter **1102**. The one or more parameters will also be used as the input by the microprocessor of the transmitter **1102** to select a subset of antenna arrays from the total number of the antenna arrays, and the subset of antennas from total number of antennas in the selected subset of the antenna arrays for transmitting the power waves **1104** to form the pocket of energy **1106**.

Based on the one or more parameters, the microprocessor of the transmitter **1102** will select the antenna array, select the shape of the selected antenna array, select the antennas to be used in the selected antenna array, select the waveform to be generated by the waveform generator for transmission by the selected antennas of the selected antenna array, and lastly the output frequency of the selected waveform to be transmitted by the selected antennas of the selected antenna arrays. The microprocessor of the transmitter **1102** may further select the transmission timing of the selected waveform from the selected antennas of the selected antenna array based on the one or more parameters. In one embodiment, the microprocessor of the transmitter **1102**, continuously receives the new information and data from the internal and external sensors, the heating mapping data, and the communication signals from the receiver; and based on the newly received information and data, the microprocessor of the transmitter **1102** may generate a new set of the one or more parameters. The new set of the one or more parameters are then utilized by the microprocessor of the transmitter **1102** to manipulate the frequency of the transmitted power waves **1104**, as well as selection of new set of antenna array and antennas for the transmission of new power waves **1104**. For example, as shown in FIGS. **3** and **4**, the transmitter **1102** can continuously scan segments of the transmission field to identify a new location of the receiver, and as shown in FIG. **13**, the transmitter **1102** can adjust direction of an antenna power wave transmission, a selection of antennas in the antenna array (e.g., shape of the antenna array, spacing of antennas), and output frequency based on the new parameters.

In FIG. **11**, a safe zone **1108** may be an area proximate to the transmitter **1102** that is within such proximity to the antenna array that the power waves **1104** cannot be "canceled-out" using null steering, and thus the radiated energy of the power waves **1104** cannot be nullified by the transmitter **1102**. In some implementations, the energy generated by the power waves **1104** from the transmitter **1102** is not suitable for objects such as human beings and animals. As such, the safe zone **1108** represents a location within the transmission field where the transmitter **1102** automatically drops the amount of energy produced or halts transmission of power waves **1104** altogether, particularly if a sensor identifies a human being or sensitive object within the safe zone.

FIG. **12** illustrates a graphical representation of formation of pocket of energy in a wireless power transmission system, according to an exemplary embodiment. As illustrated in the FIG. **12**, a graphical representation between the distance and decibel milliwatts (dBm) is shown. The pocket of energy is formed at 36 dBm and 5 feet. The transmitter antennas transmit the power transmission signals such that the power transmission signals converge in this three-dimensional space around the receiver, which is located at the 5 feet distance. The resulting field around the receiver forms the pocket of energy at 36 dBm from which the receiver may harvest electrical energy. As illustrated, the amount of energy contained in the power waves quickly diminishes beyond the intended location for the pocket of energy, in order to avoid creating unwanted energy in other areas nearby the location of the pocket of energy. In the present figure, the pocket of energy is intended to be generated at a distance of five feet, and therefore the power transmission signals diminish at any distance beyond five feet. FIG. **12** shows two curves of how power waves die down using antenna arrays of equally spaced antennas, versus antenna arrays that may have unequal antenna spacing and may be placed in a non-planar antenna array. In the case of unequal

antenna spacing and non-planar antennas, the power level quickly diminishes beyond the intended location of the pocket of energy.

FIG. **13** illustrates a method of formation of pocket of energy for one or more devices in a wireless power transmission system, according to an exemplary embodiment.

In a first step **1302**, a transmitter (TX) receives sensor data collected and produced from one or more sensors. In some cases, the transmitter establishes a connection with a receiver (RX), according to the wireless protocol used for communications between a communications component of the transmitter and a communications component of the receiver. That is, a communications component of the transmitter and a communications component of the receiver may communicate data with one another using a wireless communication protocol (e.g., Bluetooth®, Wi-Fi, NFC, ZigBee) capable of transmitting information between processors of electrical devices, such as a transmitter processor and a receiver processor. For example, the transmitter may scan for a receiver's broadcasting signals or vice-versa, or a receiver may transmit a signal to the transmitter. The signal may announce the receiver's presence to the transmitter, or the transmitter's presence to the receiver, and may trigger an association between the transmitter and the receiver. Once the transmitter identifies the receiver, the transmitter may establish the connection associated in the transmitter with the receiver, allowing the transmitter and receiver to communicate signals. The transmitter may then command that the receiver begins transmitting data. The receiver measures the voltage among other metrics and may transmit the voltage sample measurement back to the transmitter. The transmitter further receives the information and data from the one or more internal sensors, the one or more external sensors, and the heat mapping data related to the location of the receiver, the information about the one or more electronic devices, and the one or more objects.

In a next step **1304**, the transmitter may determine the one or more parameters. In one embodiment, the microprocessor of the transmitter may execute one or more software modules in order to analyze the received data and information, and based on the analysis identify the one or more parameters. The one or more parameters act as an input to the microprocessor to make the necessary selections to form the pocket of energy at one or more targeted locations.

In a next step **1306**, the transmitter may execute one or more software modules based on the one or more parameters to select a waveform to be generated by the waveform generator, select the output frequency of the waveform, a subset of antennas from a fixed physical shape of the one or more antenna arrays that correspond to a desired spacing of antennas to form the pocket of energy at the targeted location of the one or more receivers.

In one embodiment, the transmitter algorithms based on the one or more parameters may vary production and transmission of power transmission signals by the transmitter's antennas to optimize the pockets of energy around the receiver. For example, the transmitter may adjust the phase at which the transmitter's antenna transmits the power transmission signals, until that power received by the receiver indicates an effectively established pocket of energy around the receiver. When an optimal configuration for the antennas is identified, memory of the transmitter may store the configurations to keep the transmitter broadcasting at that highest level.

In one embodiment, the algorithms of the transmitter based on the one or more parameters may determine when it is necessary to adjust the power transmission signals and may also vary the configuration of the transmit antennas. For example, the transmitter may determine the power received at a receiver is less than maximal, based on the one or more parameters. The transmitter may then adjust the phase of the power transmission signals, but may also simultaneously continues to generate the new one or more parameters based on the information and data being reported back from receiver and the sensor devices.

In one embodiment, when the transmitter receives the information and data from the receiver and sensor devices regarding a presence of a new receiver, the transmitter will generate new one or more parameters, and based on the new one or more parameters, the transmitter may adjust one or more antennas in the transmitter's antenna array. In some embodiments, the transmitter may identify a subset of antennas to service the new receiver, thereby parsing the array into subsets of arrays. In some embodiments, the entire antenna array may service the original receiver for a given period of time, and then the entire array may service the new receiver. The automated processes are performed by the transmitter to select a subset of arrays to service the new receiver. In one example, the transmitter's array may be split in half, forming two subsets. As a result, half of the antennas may be configured to transmit power transmission signals to the original receiver, and half of the antennas may be configured for the new receiver.

In the next step **1308**, the transmitter will generate the pocket of energy for the one or more receivers. The one or more receivers may be electrically connected to the electronic device like a smart phone. The transmitter may continue to alternate between receivers and scanning for new receivers at a predetermined interval and thereby generating the new one or more parameters. As each new receiver is detected, the new one or more parameters are generated, and based on the new one or more parameters, the transmitter may establish a connection and begin transmitting power transmission signals, accordingly.

B. Waveforms for Power Waves & Manipulating Waveforms

FIGS. **14**A and **14**B illustrates a waveform to form a pocket of energy in a wireless power transmission system, according to an exemplary embodiment. The waveforms or the power waves **1402**, **1404** are produced by the transmitter **1406** and transmitted by the one or more antennas of the transmitter **1406** directed to the receiver **1408** to form the pocket of energy at the desired location.

The transmitter **1406** receives a communication signal. In one embodiment, the transmitter **1406** may receive the communication signal from a sensor device. The sensor device may comprise one or more internal sensors and/or one or more external sensors. The one or more internal sensors are integral components of the transmitter **1406**. The one or more external sensors are located outside the transmitter **1406**. The one or more external sensors may be formed as an integral component of the receiver **1408**. In another example, the one or more external sensors may be located in an operating area of the wireless communication system of the present disclosure. In yet another example, one or more external sensors may be fixed on the one or more electrical devices to be charged. In another embodiment, the transmitter **1406** may receive the communication signal directly from the receiver **1408**. The microprocessor of the transmitter **1406** processes the communication signal or the information sent by the receiver **1408** through a communications component for determining optimum times and locations for forming the pocket of energy. The communications component and the sensor device may be used to

transfer information such as an identifier for the device or user, battery level, location or other such information. Other communications components may be possible which may include radar, infrared cameras or sound devices for sonic triangulation for determining the device's position and the or more objects position. The transmitter **1406** may further generate a transmission signal based on the received communication signal. The transmitter **1406** generates the transmission signal according to an operational mode determined by the microprocessor. The operation mode reflects the transmission frequency determined by the microprocessor of the transmitter **1406**. In one embodiment, a user manually sets the operational mode using a user interface associated with the microprocessor of the transmitter **1406**. In another embodiment, the operational mode is automatically set by the microprocessor of the transmitter **1406**, based on received information in the communication signal.

Once transmitter **1406** identifies and locates receiver **1408** based on the information/data contained in the communication signal, a path is established. The transmitter **1406** may start to transmit power waves that converge in a three dimensional space, by using the one or more antennas of at least one antenna array of the one or more antenna arrays.

In an embodiment, the operation mode (operating frequency) of the transmitter **1406** is determined based on the communication signal received by the transmitter **1406** from the sensor device or the communication component. The microprocessor of the transmitter **1406** then evaluates the communication signal, and based on the results of the communication signal, the transmitter **1406** initiates the generation of the waveforms (of one or more types) to be transmitted by the one or more antennas of each of the one or more antenna arrays. In one example, if the information/data received by the sensor device or the communication component comprises data indicating a first location of the receiver **1408** (e.g., close to the transmitter **1406**), then a low power waveform generator may be used. In the continuous wave mode, the waveforms can have durations as long as milliseconds. In another example, if the information/data received by the sensor device or the communication component comprises data indicating a second location of the receiver **1408** (e.g., far from the transmitter **1406**), then high power pulses may be required to transmit more energy to the receiver, so the transmitter uses a high power path (a pulsed waveform generator). Each of these waveforms is typically stored in a database to be used as a suite of possible transmitted waveforms as conditions require. In other words, based on information contained in the communication signal received from the sensor device or the communication component, the transmitter **1406** then generates the desired type of waveforms for transmission by the one or more antennas and further selects the operating frequency and amplitude of the generated waveforms. As discussed above, the transmitter **1406**, using a waveform generator, or any arbitrary waveform generator circuit, may produce both pulse and continuous waveforms. In another embodiment, these RF waves may also be produced by using an external power source and a local oscillator chip using a piezoelectric material. The RF waves may be controlled by an RFIC circuit, which may include a proprietary chip for adjusting phase and/or relative magnitudes of RF signals that may serve as inputs for one or more antennas to form pocket forming. The pocket forming may take advantage of interference to change the directionality of the one or more antennas where one form of the interference generates the pocket of energy and another form of the interference generates the null space. The receiver **1408** may then utilize the pocket of energy produced by pocket forming for charging or powering the electronic devices and therefore effectively providing wireless power transmission.

The transmitter **1406** comprises waveform generation components for generating waveforms that are utilized in one embodiment of the present disclosure. The transmitter **1406** includes a housing. The housing can be made of any material that may allow for signal or wave transmission and/or reception. The housing may include the one or more microprocessors, and the power source. In an embodiment, several transmitters may be managed by a single base station and a single microprocessor. Such capability may allow the location of transmitters in a variety of strategic positions, such as ceiling, walls, or the like.

The housing of the transmitter **1406** comprises the one or more antennas arrays. Each of the one or more antenna arrays comprises the one or more antennas. The one or more antennas may include antenna types for operating in frequency bands, such as roughly 900 MHz to about 100 GHz or other such frequency band, such as about 1 GHz, 5.8 GHz, 24 GHz, 60 GHz, and 72 GHz. In one embodiment, the antenna may be directional and include flat antennas, patch antennas, dipole antennas, and any other antenna for wireless power transmission. The antenna types may include, for example, patch antennas with heights from about ⅛ inch to about 6 inches and widths from about ⅛ inch to about 6 inches. The shape and orientation of antenna may vary in dependency of the desired features of the transmitter **1406**; the orientation may be flat in X-axis, Y-axis, and Z-axis, as well as various orientation types and combinations in three-dimensional arrangements. The antenna materials may include any material that may allow RF signal transmission with high efficiency and good heat dissipation. The number of antennas may vary in relation with the desired range and power transmission capability of the transmitter **1406**. In addition, the antenna may have at least one polarization or a selection of polarizations. Such polarization may include vertical polarization, horizontal polarization, circularly polarized, left hand polarized, right hand polarized, or a combination of polarizations. The selection of polarizations may vary in dependency of the transmitter **1406** characteristics. In addition, the antenna may be located in various surfaces of the transmitter **1406**. The antenna may operate in single array, pair array, quad array and any other arrangement that may be designed in accordance with the one or more parameters.

The housing of the transmitter **1406** further comprises one or more printed circuit boards (PCB), one or more RF integrated circuits (RFIC), one or more waveform generators, and one or more microprocessors.

The transmitter **1406** may include a plurality of PCB layers, which may include antennas, and/or RFICs for providing greater control over forming the pockets of energy based on the one or more parameters. PCBs may be single sided, double sided, and/or multi-layer. The multiple PCB layers may increase the range and the amount of power that could be transferred by the transmitter. The PCB layers may be connected to a single microprocessor and/or to dedicated microprocessors. In some implementations, the transmitter **1406** including a plurality of PCB layers inside it may include antenna for providing greater control over forming the pockets of energy and may increase the response for targeting receivers based on the one or more parameters. Furthermore, range of wireless power transmission may be increased by the transmitter. The multiple PCB layers may increase the range and the amount of power waves that could be transferred and/or broadcasted wirelessly by transmitter

1406 due the higher density of antenna. The PCB layers may be connected to a single microcontroller and/or to dedicated microcontroller for each antenna.

The transmitter **1406** may include a RFIC that may receive the RF waves from the microprocessor, and split the RF waves into multiple outputs, each output linked to an antenna. In one implementation, each RFIC may be connected to four antennas. In other implementations, each RFIC may be connected to multiple antennas. The RFIC may include a plurality of RF circuits that may include digital and/or analog components, such as, amplifiers, capacitors, oscillators, piezoelectric crystals or the like. The RFIC control features of the antenna, such as gain and/or phase for pocket forming. In other implementations of the transmitter **1406**, the phase and the amplitude of the transmitted power waves from each antenna may be regulated by the corresponding RFIC in order to generate the desired pocket of energy and null steering based on the one or more parameters. The RFIC and the antenna may operate in any arrangement that may be designed in accordance with the desired application. For example, the transmitter **1406** may include the antenna and the RFIC in a flat arrangement. A subset of and/or any number of antennas may be connected to a single RFIC based on the one or more parameters.

The microprocessor comprises an ARM processor and/or DSP. The ARM may comprise one or more microprocessors based on a reduced instruction set computing (RISC). The DSP may be a signal processing chip configured to provide a mathematical manipulation of an communications signal, to modify or improve the communications signal in some way, where the communications signal can be characterized by the representation of discrete time, discrete frequency, and/or other discrete domain signals by a sequence of numbers or symbols and the processing of these signals. The DSP may measure, filter, and/or compress continuous real-world analog signals. The first step may be conversion of the signal from an analog to a digital form, by sampling and then digitizing it using an analog-to-digital converter (ADC), which may convert the analog signal into a stream of discrete digital values. The microprocessor may also run Linux and/or any other operating system. The microprocessor may also be connected to Wi-Fi in order to provide information through a network. Furthermore, the microprocessor may transmit power waves that converge to form multiple pockets of energy for multiple receivers. The transmitter may allow distance discrimination of the wireless power transmission. In addition, the microprocessor may manage and control communication protocols and signals by controlling the communication component.

The waveform generation components of the transmitter **1406** further comprises the waveform generator, the Digital to Analog (D/A) convertor, the power amplifier, and the one or more filters. The waveform generator of the transmitter **1406** is typically programmed to produce waveforms with a specified amount of noise, interference, frequency offset, and frequency drift. The waveform generator of the transmitter **1406** is configured to generate multiple versions of the waveform, one for each antenna at the transmitter based on the one or more parameters. In one implementation, the waveform generator of the transmitter **1406** produces the waveforms to be transmitted by the individual elements of the antenna array. A different wave signal is produced by the waveform generator of the transmitter **1406** for each of the one or more antennas. Each of these signals is then passed through the D/A converter and the one or more filters. The resulting analog signals are each amplified by a power amplifier and then sent to a corresponding antenna of the one or more antennas. A description of a waveform generator may be found in commonly-assigned U.S. application Ser. No. 13/891,445, entitled "Transmitters for Wireless power Transmission," filed Dec. 27, 2014 and commonly-assigned U.S. application Ser. No. 14/584,364, entitled "Enhanced Transmitter for Wireless Power Transmission," filed Dec. 29, 2014, each of which are hereby incorporated by reference herein, in their entirety.

In one example, assuming that the transmitted signals are to be in the form of cosine waveforms determined based on the one or more parameters, the waveform generator of the transmitter **1406** first produces a series of phase angles corresponding to the phase of the waveform to be transmitted. The series of phase angles produced by the waveform generator of the transmitter **1406** may or may not be common to all the antennas. In the present example, the series of phase angles produced by the waveform generator of the transmitter **1406** is common to all the antennas. The waveform phase angles may also be adjusted to steer the waveform by adding a time delay and a phase adjustment for each antenna. A series of adjusted phase angles is thus produced for each antenna. A signal is then produced for each antenna by applying a cosine function to the adjusted phase angles. This may be accomplished using a Cosine Look-up Table. Each cosine wave is then loaded and read out to the D/A converters. The waveform generator of the transmitter **1406** produces a series of phase angles corresponding to the phase of the signal to be transmitted. These phase angles are common to each antenna in the antenna array. The phase angle selection by the waveform generator of the transmitter **1406** can be implemented by a Direct Digital Synthesizer (DDS) or similar device. The waveform phase angles are then worked upon to add a time delay and a phase adjustment for each antenna. The time delay allows uniform pointing over a wide bandwidth, and the phase adjustment compensates for the time delay quantization at the center frequency. In order to steer the transmitted wave, each antenna may also need to have a particular phase angle added to the common waveform. The waveform generator of the transmitter **1406** is configured to perform all of the above-mentioned functions on the waveform based on the input of the one or more parameters.

The waveform generator of the transmitter **1406** is further configured to generate the one or more power waves having the one or more characteristics according to the one or more transmission parameters. The one or more power waves are non-continuous waves having a frequency and amplitude that may be increased and decreased based on one or more updates to the one or more transmission parameters corresponding to the one or more characteristics of the one or more power waves. In one example, the non-continuous power waveform may be a chirp waveform. The chirp waveforms are typically used since the frequency of the waveform is changing linearly or logarithmically in time and thereby sweeps the frequency band without creating concentrated energy in one particular frequency, which may not be desirable. Of course, other time dependences of the frequencies can be used, depending on the application and on which frequency domain waveform may be currently needed. In other words, the chirp waveform is a frequency modulated pulse or signal where the modulated frequency typically linearly increases from an initial frequency over a finite time equaling a pulse width, for example, from −50 MHz to +50 MHz, providing a 100 MHz bandwidth, over the pulse width, for example, 10 microseconds, and modulating an intermediate center frequency, for example, 160 MHz. This modulated waveform is typically stepped up and

may be mixed to a higher RF carrier prior to transmission by the one or more antennas of the transmitter, such as 900 MHz to 100 GHz. The chirp waveforms may be generated by various other hardware means. One of the methods to produce chirp waveforms may include a group of lumped circuit elements. For example, the group of lumped circuit elements may include a group of the circuits that generate a respective group of staggered delay signals which are summed together and which provide the chirp waveforms. Another method of producing a chirp waveform may comprise a metalized crystalline device that is subjected to the high impulse signal to produce the linear frequency modulated chirp waveform. In yet another example method of producing chirp waveform, Direct Digital Synthesis systems may be employed. The DDS methods of generating the chirp waveform typically employ programmed memories having stored sinusoidal values that are typically fed into the D/A converter, such that as the digital values are cycled into the D/A converter at an increasing rate for a certain pulse width time, the analog converter produces the chirp waveforms through that pulse width.

In another embodiment, a chirp sub pulse waveform may be generated and mixed to a desired center intermediate frequency based on the one or more parameters. A plurality of chirp sub pulses waveforms are contiguously generated and respectively mixed with intermediate frequencies of a plurality of intermediate frequencies. This contiguous mixed chirp waveform has an extended pulse width equaling the sum of the pulse widths of all of the chirp sub pulse waveforms. In the situation, where all of the chirp sub pulse waveforms have the same pulse width, the extended pulse width of the contiguous chirp pulse waveform will be equal to the number of sub pulses multiplied by the pulse width of each sub pulse.

In yet another embodiment, a relatively high frequency carrier signal may be modulated with the data to produce the waveform to drive one or more antennas based on the one or more parameters. One type of modulation is angle modulation, which involves modulating the angle of the carrier signal. The angle modulation may involve modulating the frequency of the carrier signal or modulating the phase of the carrier signal. The waveform forming process includes generating an angle modulated wave signal and progressively filtering the angle modulated wave signal in the waveform generator of the transmitter using a plurality of low pass filters to produce a modulated sinusoidal waveform to drive the one or more antennas. The technique includes programming the transmitter to tune a corner frequency of the filtering to a frequency within a range of frequencies selectable using the programming by the microprocessor of the transmitter **1406**.

In order to generate the pocket of energy, the transmitter **1406** using a waveform generator produces one or more power waves having a very low correlation with itself. In one example, a chirp wave is being used. The chirp wave has a very low correlation with itself. In one embodiment, the waveform generator of the transmitter **1406** produces a same chirp waveform for all of the one or more antennas. In another embodiment, the waveform generator of the transmitter **1406** produces a different chirp waveform for each of the one or more antennas. In yet another embodiment, the waveform generator of the transmitter **1406** produces a first chirp waveform for a first set of antennas in the one or more antennas and a second chirp waveform for a second or remaining set of antennas in the one or more antennas. In yet another embodiment, the waveform generator of the transmitter **1406** may include one or more sub waveform generators wherein a first sub waveform generator is configured to produce a first chirp waveform for a first antenna array in the one or more antenna arrays and a second sub waveform generator is configured to produce a second chirp waveform for a second antenna array in the one or more antenna arrays and so on.

The waveform generator of the transmitter **1406** described above produces the chirp waveform. The chirp waveform may be generated as a linear chirp waveform and as a non-linear chirp waveform. The nonlinear chirp waveform is selected from the group consisting of exponential, logarithmic, and arbitrarily formulated chirp waveform. The waveform generator of the transmitter **1406** produces the chirp waveform based on one or more parameters. The one or more parameters are identified by the microprocessor of the transmitter **1406** based on the information received in the communication signal from the sensor devices and/or the communication component. The output frequency of the chirp waves generated by the waveform generator of the transmitter **1406** is also determined based on the one or more parameters. Based on the one or more parameters, the waveform generator of the transmitter **1406** may produce multiple chirp waveforms for multiple antennas wherein each of the chirp waveform has a unique output frequency and amplitude. The transmitter **1406** is further configured to increase, based on the one or more parameters, the frequency and the amplitude of the transmitted chirp waves in relation to the change in time and distance. The transmitter **1406** is further configured to decrease, based on the one or more parameters, the frequency and the amplitude of the transmitted one or more power waves in relation to change in time and distance. In one example, the frequency of the chirp waveforms transmitted by the transmitter **1406** is randomly changed between 1 to 1000 times per second. The frequency may be increased at Nth second, and then the frequency may be decreased at N+2th second. In another embodiment, the frequency of the one or more power waves transmitted by the one or more antennas of the transmitter is varied based on maximum permissible exposure level (MPE) of one or more objects.

In the illustrated figures, a first waveform generator of the transmitter **1406** generate a first waveform **1402** having a frequency f**1** based on a first set of one or more parameters determined by the microprocessor of the transmitter **1406**. The microprocessor of the transmitter **1406** continually receives new data and new information from the sensor devices and the receivers, and based on the new data and the new information, the microprocessor of the transmitter **1406** may generate a second set of one or more parameters. The second set of the one or more parameters are different from the first set of the one or more parameters. Based on the second set of the one or more parameters, the microprocessor of the transmitter **1406** may provide instructions to the first waveform generator to change (increase/decrease) the frequency f**1** of the transmitted waveform. In another embodiment, based on the second set of the one or more parameters, the microprocessor of the transmitter **1406** may provide instructions to the first waveform generator to generate a new waveform **1404** having a frequency f**2**. In yet another embodiment, based on the second set of one or more parameters, the microprocessor of the transmitter **1406** may use a new waveform generator other than the first waveform generator to generate a new waveform **1404** having a frequency f**2**.

FIG. **15** illustrates a method to generate a waveform in a wireless power transmission system, according to an exemplary embodiment.

In a first step **1502**, a transmitter (TX) receives sensor data. The transmitter establishes a connection with a receiver (RX). The transmitter and receiver communicate information and data over the communications signal, using a wireless communication protocol capable of transmitting information between two processors of electrical devices, such as Bluetooth®. For example, the transmitter may scan for a receiver's broadcasting signals or visa-versa, or a receiver may transmit a signal to the transmitter. The signal may announce the receiver's presence to the transmitter, or the transmitter's presence to the receiver, and may trigger an association between the transmitter and the receiver. Once the transmitter identifies the receiver, the transmitter may establish the connection associated in the transmitter with the receiver, allowing the transmitter and receiver to communicate signals. The transmitter may then command that the receiver begins transmitting data. The receiver measures the voltage among other metrics and may transmit the voltage sample measurement back to the transmitter. The transmitter further receives the information and data from the one or more internal sensors, the one or more external sensors, and the heat mapping data related to the location of the receiver, the information about the one or more electronic devices such as battery usage, and the one or more objects.

In a next step **1504**, the transmitter may determine the one or more parameters. In one embodiment, the microprocessor of the transmitter may execute one or more software modules in order to analyze the received data and information, and based on the analysis identify the one or more parameters. The one or more parameters acts as an input to the microprocessor to make the necessary selections of the waveforms and their output frequency to form the pocket of energy at one or more targeted locations.

In the next step **1506**, the transmitter selects the waveform (e.g., radio frequency waves, ultrasound waves) to be generated by the waveform generator based on the one or more parameters. For example, based on one set of the one or more parameters the transmitter may select the chirp waves for transmission, and based on another set of the one or more parameters, the transmitter may select sine waves for transmission. The transmitter may select the chirp waves since the frequency and the amplitude of the chirp waves continually increases or decreases with increases in the time and distance, and the one or more parameters may suggest the requirement of the signals that do not have a continuous frequency over a period of time.

In the next step **1508**, the transmitter provides instructions to the waveform generator to generate the selected waveform such as chirp waves. The waveforms may also be produced by using an external power source and a local oscillator chip using a piezoelectric material. The waveforms may be controlled by the waveform generator and the transmitter circuitry, which may include a proprietary chip for adjusting frequency, phase and/or relative magnitudes of waveforms. The frequency, phase, gain, amplitude, and other waveform features of the waveforms are adjusted to form the pocket of energy at the targeted locations of the one or more electronic devices.

C. Null Steering

FIG. **16** illustrates formation of a null space in a wireless power transmission system, according to an exemplary embodiment. The transmitter **1602** comprises the one or more antennas in the antenna array. The transmitter is configured to adjust the phase and amplitude among other possible attributes of power waves being transmitted from antennas of the transmitter **1602** to the receiver **1604**. In the absence of any phase or amplitude adjustment, the power waves may be transmitted from each of the antennas of the transmitter **1602** and will arrive at different locations and have different phases. These differences are often due to the different distances from each antenna of the transmitter **1602** to receivers located at the respective locations. In order to form the pocket of energy, the power waves transmitted by the transmitter **1602** arrive at the receiver **1604** exactly in phase with one another and combine to increase the amplitude of the each wave to result in a composite wave that is stronger than each constituent power wave.

In the illustrated figure, the receiver **1604** may receive multiple power transmission signals from the transmitter **1602**. Each of the multiple power transmission signals comprising power waves from multiple antennas of the transmitter **1602**. The composite of these power transmission signals may be essentially zero, because the power waves add together to create the null space. That is, the antennas of the transmitter **1602** may transmit the exact same power transmission signal, which comprises the power waves having the same features (e.g., phase, amplitude). Because the power waves **1606**, **1608** of each power transmission signal have the same characteristics, when the power waves **1606**, **1608** of arrive at the receiver **1604**, the power waves **1606**, **1608** are offset from each other by 180 degrees. Consequently, the power waves **1606**, **1608** transmitted by the transmitter **1602** cancel or nullify one another.

In one embodiment, based on the communication signal and mapping data (e.g., heat mapping data and/or sensor data), the transmitter **1602** will generate power waves based upon an indication of a location of the receiver **1604**. The transmitter **1602** will then generate the null space behind the location of the receiver **1604**, **1604** or in other locations proximate to the receiver **1604**, or otherwise, where it would be undesirable to have a pocket of energy with power levels exceeding a particular threshold. In another embodiment, based on the mapping data (e.g., heat mapping data and/or sensor data), the transmitter **1602** will determine the location of the one or more objects such as the human beings and the animals, and then generate the null space at or near the location of the one or more objects, or where it would otherwise be undesirable to have a pocket of energy with power levels exceeding a particular threshold. The transmitter **1602** will continuously receive the data from the sensors regarding the one or more objects and the location of the one or more receivers. The transmitter **1602** on one hand is configured to generate the pocket of energy at the location of the one or more receivers, and on the other hand the transmitter **1602** will generate the one or more null spaces outside of the location of the receivers, and at or near the location of the one or more objects, or where it would otherwise be undesirable to have a pocket of energy with power levels exceeding a particular threshold. The transmitter **1602** is configured to constantly measure the distance between the location of the one or more objects and the one or more receivers. Based on the distance, the transmitter **1602** will select the power waves transmitting from the one or more antennas of the one or more antenna arrays for creating the pocket of energy or the null spaces.

In one embodiment, at least two waveforms may be generated by the generated by the waveform generator of the transmitter **1602**. The at least two waveforms generated have different frequencies. The change in phase of the frequency of one of the at least two waveforms or all waveforms of the at least two waveforms may result in formation of a unified waveform. The uniform waveform is such that it will

generate the pocket of energy at one or more targeted spots, along with one or more null spaces in certain areas.

FIG. **17** illustrates a method for forming a null space in a wireless power transmission system, according to an exemplary embodiment.

In a first step **1702**, a transmitter (TX) transmits the power waves to generate the pocket of energy at the location of the one or more targeted electronic devices. The transmitter transmit power waves that converge in three-dimensional space. The power waves are controlled through phase and/or relative amplitude adjustments to form the pocket of energy in locations where the pocket of energy is intended. The pocket of energy is formed by the two or more power waves that converge at the targeted location in three-dimensional space.

In a next step **1704**, the transmitter receives location data of objects. The one or more internal sensors and the one or more external sensors transmits the data to the transmitter regarding the presence and location of the objects within the working area of the transmitter. The one or more objects may include humans and animals.

In the next step **1706**, the transmitter measures the distance between objects and receivers. Once the location data of the objects is received, the transmitter measures the distance between the location data of the objects and the location of the one or more receivers (e.g., as identified in the process described in FIG. **2**) where the pocket of energy is directed. The transmitter is further configured to measure the distance between location data of the one or more objects from the transmitter and the power waves. Based on these measurements of various distances, the transmitter then determines whether to generate the null spaces or not, and if yes, the location of the null spaces.

In the next step **1708**, if the transmitter determines that the objects are close to the pocket of energy with a power level that exceeds a given threshold, the transmitter creates a null space at or proximate to the location of the pocket of energy, or corresponding to the location of the objects. In some circumstances, transmitter can create a null space at the location where a pocket of energy is intended to be generated, when an object is detected at the same location as the intended pocket of energy. In these circumstances, the transmitted power waves cancel each other out, resulting in no significant energy being transmitted to the location containing the object.

D. Configurations of Transmitter Antenna Array

i. Spacing of Antennas in Antenna Array

FIG. **18** illustrates arrangement of antennas in an antenna array of a wireless power transmission system, according to an exemplary embodiment.

In one implementation, the system for wireless power transmission comprises the one or more transmitters. Each of the one or more transmitters comprises one or more antenna arrays. In the illustrative embodiment, a single antenna array **1802** is shown. Each of the one or more antenna arrays comprises one or more antennas to transmit one or more power waves. In the illustrative embodiment, the single antenna array **1802** comprises a plurality of antennas **1804**. The antennas of the one or more antennas are spaced from each other such that the one or more power waves transmitted by the plurality of antennas are directed to form the pocket of energy to power the targeted electronic device.

The system for wireless power transmission further comprises a receiver configured to receive the pocket of energy generated using the one or more power waves transmitted by the one or more antennas in the one or more antenna arrays of the one or more transmitters. In an embodiment, the height of at least one antenna of the one or more antennas on the transmitter can be from about ⅛ inches to about 1 inch, and the width of the at least one antenna can be from about ⅛ inches to about 1 inch. A distance between two adjacent antennas in an antenna array can be between ⅓ to 12 Lambda. In one embodiment, the distance can be greater than 1 Lambda. The distance can be between 1 Lambda and 10 Lambda. In one embodiment, the distance can be between 4 Lambda and 10 Lambda.

The antennas of the one or more antennas in the antenna array are placed at a pre-defined distance with respect to each other such that the one or more power waves transmitted by the antennas are directed to form the pocket of energy at the receiver. Further, each of the one or more antennas are positioned at the pre-defined distance with respect to each other in a 3-dimensional space such that the one or more power waves transmitted by each of the one or more antennas do not form the pocket of energy outside the receiver. Further, each of the one or more antennas are positioned at the pre-defined distance with respect to each other in a 3-dimensional space such that the one or more power waves transmitted by each of the one or more antennas are directed to form the pocket of energy at the receiver, wherein the energy within the pocket of energy is greater than the energy present outside a periphery of the receiver because of the one or more power waves.

In one embodiment, the one or more antennas are fixed upon movable elements and the distance between the one or more antennas in each of the one or more antenna arrays is dynamically adjusted depending on location of the receiver such that the one or more power waves transmitted by the one or more antennas are directed to form the pocket of energy at the receiver. The movable elements are any mechanical actuators that are controlled by the microprocessor of the transmitter. The microprocessor of the transmitter receives the information from the one or more internal sensors, the one or more external sensors, and the heat mapping data regarding the location of the receiver or the targeted electronic device, and based on some or all of this sensor data, the microprocessor controls the movement of the mechanical actuators on which the antennas are mounted.

In one embodiment, the one or more antennas in each of the one or more antenna arrays are positioned at the pre-defined distance from each other that allows the mutual coupling between the one or more antennas, and wherein the mutual coupling is inductive or capacitive coupling between the plurality of antennas.

The one or more antennas of each of the one or more antenna arrays are configured to transmit the one or more power waves at a different time from each other because of the placement of the one or more antennas. In another embodiment, the one or more antennas of each of the one or more antenna arrays are configured to transmit the one or more power waves at a different time from each other because of a presence of timing circuit that is controlled by the microprocessor of the transmitter. The timing circuit can be used to select a different transmission time for each of the one or more antennas. In one example, the microprocessor may pre-configure the timing circuit with the timing of transmission of the one or more transmission waves from each of the one or more antennas. In another example, based on the information received from the one or more internal sensors, the one or more external sensors, and the communication signal, the transmitter may delay the transmission of few transmission waves from few antennas.

In yet another embodiment, there is provided the system for wireless power transmission. The system comprises a transmitter. The transmitter comprises the one or more antenna arrays. Each of the one or more antenna arrays comprises a plurality of antennas. The plurality of antennas transmit one or more power waves. The transmitter further comprises the microprocessor configured to activate a first set of antennas of the plurality of antennas based on the target for directing a pocket of energy using the one or more power waves. The first set of antennas is selected from the one or more antennas based on distance between antennas of the first set of antennas that corresponds to the desired spacing of the antennas to form the pocket of energy. In other words, the distance selected between antennas of the first set of antennas is such that the adjacent antennas are preferably far away from each other, and the one or more power waves transmitting from the first set of antennas forms the pocket of energy to power the targeted electronic device.

In one implementation, the transmitter comprises the antenna circuit configured to switch, each of the one or more antennas in the antenna array, on or off based on the communication signals. The communication signals may be received from the one or more internal sensors, the one or more external sensors, or the heat mapping data. In one embodiment, the antenna array is configured such that the power wave direction can be steered in a first direction by switching on a first set of antenna of the one or more antennas, and the power waves direction of the antenna array can be steered in a second direction by switching on a second set of antennas of the one or more antennas. The second set of antennas can include one or more antennas from the first set of antennas, or the second set of antennas may not include any antennas from the first set. In one embodiment, the power wave direction of the antenna array can be steered in a plurality of directions by switching on a set of antennas from the one or more antennas for each of the plurality of directions. The selections of antennas in the first set of antennas and the second set of antennas are based upon the distances between the antennas in the first set of antennas and the second set of antennas. The distances are so chosen that the power waves emerging out of the first set, second set or any set of antennas generate the efficient pocket of energy at the desired locations.

In one implementation, the spacing between the antennas that will transmit the transmission waves for generating the pocket of energy is determined based on the location of the receiver where the pocket of energy has to be created. The transmitter will determine the location of the receiver. In one example, the location of the receiver is measured using the communication signals such as Bluetooth signals transmitted by the receiver over the communication component. The location of the receiver may be used by microprocessor in order to adjust and/or select antennas from the plurality of antennas to form pockets of energy that may be used by the receiver in order to charge an electronic device.

In one embodiment, the antenna array comprises 1000 antennas. The antenna switching circuit configured to connect any number of the 1000 antennas at a given time. The switching circuit comprises a signal splitter adapted to split a signal into any number of signals. In addition, the switching circuit includes 1000 number of switches, and switching circuit adapted to control the number of switches so that a specified set of the number of 1000 antennas are switched on. The switching circuit may comprise micro electromechanical system switches. In another embodiment, the switching circuit may comprise a filter adapted to separate transmit and receive signals to/from the antenna array.

In another embodiment, the antenna array comprises Z number of the antennas, and the switching circuitry is configured to control X number of antennas at a given time. In accordance with this embodiment, the switch circuit comprises a signal splitter adapted to split a signal into X number of signals, a switching matrix comprising X number of 1×Z switches, and switch circuit adapted to control the switching matrix so that a contiguous set of the X-number of the antennas are activated. In some embodiments, the 1×Z switches comprise multiplexers.

ii. Shape of Antenna Array Configuration

FIG. **19** illustrates arrangement of a plurality of antenna arrays in a wireless power transmission system, according to an exemplary embodiment.

In an embodiment, the system for wireless power transmission is provided. The system comprises the transmitter. The transmitter comprises at least two antenna arrays. In one example, the at least two antenna arrays comprises a first antenna array **1902** and a second antenna array **1904**. It should be noted that for the simplicity of explanation only the system with the first antenna array **1902** and the second antenna array **1904** is being described, however more than two antenna arrays may be included in the system without moving out from the scope of the disclosed embodiments. Each of the first antenna array **1902** and the second antenna array **1904** comprises one or more rows and one or more columns of antennas configured to transmit one or more power waves. The transmitter further comprises the microprocessor. The microprocessor is configured to control the spacing between the first antenna array **1902** and the second antenna array **1904**. The first antenna array **1902** of the at least two arrays is spaced to be offset at the pre-defined distance behind the second antenna array **1904** of the at least two arrays in the 3-dimensional space such that the one or more power waves transmitted by the antennas of each of the first antenna array **1902** and the second antenna array **1904** are directed to form the pocket of energy to power the targeted electronic device. The first antenna array **1902** and the second antenna array **1904** are positioned at the pre-defined distance from each other depending on the location of the targeted electronic device. In other words, the pre-defined distance is selected by the transmitter based on the location of the targeted electronic device.

In an embodiment, the distance between the first antenna array **1902** and the second antenna array **1904** is dynamically adjusted depending on the location of the targeted electronic device such that the one or more power waves transmitted by antennas of the first antenna array **1902** and the second antenna array **1904** are directed to form the pocket of energy at the targeted electronic device. In an embodiment, the first antenna array **1902** and the second antenna array **1904** are flat shaped and the offset distance between the at least two antenna arrays is 4 inches.

iii. Multiple Arrays

FIG. **20** illustrates arrangement of a plurality of antenna arrays in a wireless power transmission system, according to an exemplary embodiment.

In an embodiment, the system for wireless power transmission is provided. The system comprises the transmitter. The transmitter comprises at least two antenna arrays. In one example, the at least two antenna arrays comprises a first antenna array **2002** and a second antenna array **2004**. It should be noted that for the simplicity of explanation only the system with the first antenna array **2002** and the second antenna array **2004** is being described, however more than

two antenna arrays may be included in the system without moving out from the scope of the disclosed embodiments. Each of the first antenna array **2002** and the second antenna array **2004** comprises one or more rows and one or more columns of antennas configured to transmit one or more power waves.

In one embodiment, the first antenna array **2002** and the second antenna array **2004** are both used for creation of the pocket of energy at the same time. In another embodiment, the first antenna array **2002** and the second antenna array **2004** are both used for creation of the null space at the same time. In yet another embodiment, the first antenna array **2002** and the second antenna array **2004** are both used for creation of the pocket of energy and the null space at the same time.

iv. Three-Dimensional Array Configuration

FIG. **21** illustrates an antenna array configuration in a wireless power transmission system, according to an exemplary embodiment.

In one embodiment, an antenna array **2102** having a particular array size and shape is disclosed. The antenna array **2102** described herein is a three dimensional antenna array. The shape of the three-dimensional antenna array may include, but not limited to, arbitrary shaped planar antenna arrays as well as cylindrical, conical, and spherical. The antenna array comprises the one or more antennas of a particular type, size and shape. For example, one type of antennas is a so-called patch antenna having a square shape and a size compatible with operation at a particular frequency (e.g. 10 GHz). Further, the antennas are arranged in a square configuration and having a spacing, e.g., of one wavelength (1λ). Those of ordinary skill in the art will recognize that additional or alternative shapes, spaces, and types of antennas may also be used. One skilled in the art would also appreciate that the size of one or more antennas may be selected for operation at any frequency in the RF frequency range (e.g., any frequency in the range of about 900 MHz to about 100 GHz). The types of antennas that may be used in the antenna array of the present disclosure may include, but are not limited to, notch elements, dipoles, or slots, or any other antennas well known to those of ordinary skill in the art. In addition, reference will be made herein to generation of an antenna power transmission wave having a particular shape or power transmission wave-width based on the shape of the antenna array. Those of ordinary skill in the art will appreciate that antenna power waves having other shapes and widths may also be used and may be provided using well-known techniques such as by inclusion of amplitude and phase adjustment circuits into appropriate locations in the antenna feed circuit.

In one embodiment, the three dimensional antenna arrays are used in the wireless power transmission system of the present disclosure. The three dimensional antenna array may be of two types. The two types comprise an active antenna array and a passive antenna array. The active antenna array includes active devices such as semiconductor devices to aid in transmission of the power waves. The passive antenna array does not aid in the transmission of the power waves. The phase characteristics between the antennas of the array are provided in some way in either the active or passive arrays. In one embodiment, the active antenna array will generally include controllable phase-shifters which can be used to adjust the phase of the RF waves being fed to one (or to a subset) of the antennas of the array. In another embodiment, the need for a phase-shifting power transmission wave-former may be avoided by using a non-phase-controlled signal amplitude divider in conjunction with control of the phase control elements associated with each antenna or subset of antennas. Thus, in general, the active antenna array comprises the plurality of antennas and radio frequency circuits connected to the antennas. The active antenna array is an antenna system for imparting an appropriate phase difference or the phase difference and an appropriate gain difference to a RF signal to be transmitted, of each antenna. Thus, directional power transmission wave scan can be performed or an arbitrary directional power transmission wave can be realized. The active antenna array may further have a transmit amplifier and a receive amplifier associated with each antenna or subset of antennas.

In an alternative or additional embodiment, the antenna array includes the cubical shaped surface. In order to point a power wave in a particular direction with maximum gain or a desired gain, to generate the pocket of energy, it may be preferable to select (i.e., activate) as many antennas of the plurality of the antennas as possible, or at least a pre-selected number of antennas. Because of the shape of the array not being linear, the shape will cause the phase differences between the antennas. For example, one antenna, which may be considered as the reference antenna, will produce a gain pattern or radiation pattern that has a main lobe axis in the desired power transmission wave direction. Other antennas also will have radiation patterns, which can contribute to the power transmission wave gain in the desired direction, but because of the shape of the array, phase differences caused by the contour of the antenna surface will limit the cluster size that may produce a useful antenna power transmission wave shape. In one implementation, the phase differences are caused by the location of the antennas with respect to reference antenna that has the radiation pattern in the desired direction. For example, reference antenna points its power transmission wave perpendicular to its aperture. Because of the shape of the array, other antennas do not point in the same direction, and in addition, their signal phases are not aligned with the signal from reference antenna. In most instances, the phase shift is greater for elements further away from reference element and is a function of the angle between plane and the surface of the antenna array. Because of the phase shift, there is a loss of coherence between the signal from reference antenna and all other antenna in its cluster and on the antenna array. The phase-delayed waves will have components that can add to the overall wave, but at a certain point, will also subtract or cancel from the wave. This limits the size of the cluster, and hence, the maximum gain of a cluster array.

In another embodiment, the one or more antennas comprise a first set of antennas and a second set of antennas. The first set of antennas and the second set of antennas are placed at a different angles in relation to the non-planar shaped antenna array surface of the three dimensional array. By selecting which antennas should transmit power waves, the shape of the three dimensional array can be dynamically adjusted based on the location of the receiver. In an alternative embodiment, one or more antenna arrays can have a particular configuration based upon a predetermined, predicted, or expected receiver location.

A first antenna can be positioned at a distance from a second antenna, where both antennas transmit power waves to the receiver wherein the pocket of energy is generated at receiver. It may be desirable to have a distance between the first and second antennas such that the transmitted power waves are not substantially parallel to each other. An optimal distance between the first and second antennas is based upon the distance of a receiver, a size of a room, frequency of the power waves, and an amount of power to be transmitted.

FIGS. **22**A and **22**B illustrate an antenna array configuration in a wireless power transmission system, according to an exemplary embodiment. The plurality of antennas **2202** are arranged in the antenna array **2204**. As illustrated in FIGS. **22**A and **22**B, the antenna array **2204** is a 3-dimensional antenna array. The increased spacing between the plurality of antennas **2202** in the antenna array **2204** results in the size (or pocket size) of the pocket of energy to be small as represented in FIG. **22**C. In this example, the configuration of the antenna array **2204** is 40"×40".

FIGS. **23**A and **23**B illustrate an antenna array configuration in a wireless power transmission system, according to an exemplary embodiment. The plurality of antennas **2302** are arranged in the antenna array **2304**. The antenna array **2304** is a 3-dimensional antenna array. As illustrated in FIGS. **23**A and **23**B, the addition of depth in the arrangement of the plurality of antennas **2302** in the antenna array **2304** results in the size (or pocket size) of the pocket of energy to be small as represented in FIG. **23**C. In this example, the configuration of the antenna array **2304** is 40"×40"×5".

FIGS. **24**A and **24**B illustrate an antenna array configuration in a wireless power transmission system, according to an exemplary embodiment. The plurality of antennas **2402** are arranged in the antenna array **2404**. The antenna array **2404** is a 3-dimensional antenna array. As illustrated in FIGS. **16**A and **16**B, the nonlinear spacing between the plurality of antennas **2402** in the antenna array **2404** results in the change in the distribution of energy by the one or more power waveforms around the size (pocket size) of the pocket of energy as represented in FIG. **24**C. The nonlinear spacing represented in the figures is logarithmic spacing. In this example, the configuration of the antenna array **2404** is 40"×40".

FIGS. **25**A and **25**B illustrate an antenna array configuration in a wireless power transmission system, according to an exemplary embodiment. The plurality of antennas **2502** are arranged in the antenna array **2504**. The antenna array **2504** is a 3-dimensional antenna array. As illustrated in FIGS. **25**A and **25**B, the nonlinear spacing between the antennas **2502** in the antenna array **2504**, results in the change in the distribution of energy by the one or more power waveforms around the size (pocket size) of the pocket of energy as represented in FIG. **25**C. The nonlinear spacing represented in the figures is logarithmic spacing. In this example, the configuration of the antenna array **2504** is 40"×40"×6".

FIGS. **26**A and **26**B illustrate an antenna array configuration in a wireless power transmission system, according to an exemplary embodiment. The plurality of antennas **2602** are arranged in the antenna array **2604**. The antenna array **2604** is a 3-dimensional antenna array. As illustrated in FIGS. **26**A and **26**B, the increase in the distance between the plurality of antennas **2602** in the antenna array **2604** results in the creation of multiple power waves that do not cancel each other and thus results in producing a large pocket of energy as represented in FIG. **26**C. In this example, the configuration of the antenna array **2604** is 13"×75".

FIGS. **27**A and **27**B illustrate an antenna array configuration in a wireless power transmission system, according to an exemplary embodiment. The plurality of antennas **2702** are arranged in the antenna array **2704**. The antenna array **2704** is a 3-dimensional antenna array. As illustrated in FIGS. **27**A and **27**B, the decrease in the distance between the plurality of antennas **2702** in the antenna array **2704** results in the creation of strong power waves that do not cancel each other and thus results in producing a large pocket of energy as represented in FIG. **27**C. In this example, the configuration of the antenna array **2704** is 8"×16".

FIGS. **28**A and **28**B illustrate an antenna array configuration in a wireless power transmission system, according to an exemplary embodiment. The plurality of antennas **2802** are arranged in the antenna array **2804**. The antenna array **2804** is a 3-dimensional antenna array. As illustrated in FIGS. **28**A and **28**B, the spacing/distance between the plurality of antennas **2802** in the antenna array **2804** along with the size of antenna array **2804** results in the production of the pocket of energy as represented in FIG. **28**C. In this example, the configuration of the antenna array **2804** is 45"×93".

FIGS. **29**A and **29**B illustrate an antenna array configuration in a wireless power transmission system, according to an exemplary embodiment. The plurality of antennas **2902** are arranged in the antenna array **2904**. The antenna array **2904** is a 3-dimensional antenna array. As illustrated in FIGS. **29**A and **29**B, the spacing/distance between the plurality of antennas **2902** in the antenna array **2904** along with the size of antenna array **2904** results in the production of the pocket of energy as represented in FIG. **29**C. In this example, the configuration of the antenna array **2904** is 30"×63".

FIGS. **30** and **31** illustrate an antenna array configuration in a wireless power transmission system, according to an exemplary embodiment. The transmitter comprises one or more antennas configured to transmit one or more power waves for forming the pocket of energy to power the targeted electronic device. The one or more antennas are positioned on a non-planar shaped antenna array surface of a three dimensional array selected from the group consisting of a concave shape and a convex shape. The non-planar shape may also be selected from the group consisting of a spherical concave shape, a spherical convex shape, a parabolic concave shape, and a parabolic convex shape. In one embodiment, the one or more antennas in the three-dimensional antenna array are positioned in such a way with respect to each other due to the non-planar shaped antenna array surface that the one or more power waves transmitted by the one or more antennas do not form the pocket of energy outside a periphery of a receiver, as described in FIGS. **11-16**. In another embodiment, the one or more antennas in the three-dimensional antenna array are positioned in such a way with respect to each other due to the non-planar shaped antenna array surface that the one or more power waves transmitted by the one or more antennas are directed to form the pocket of energy at a receiver which is greater than the energy present outside a periphery of a receiver.

V. Exemplary Wireless Power Transmission Method, Using Heat Mapping and Sensors

FIG. **32** illustrates a method **3200** for forming a pocket of energy in a wireless power transmission system, according to an exemplary embodiment.

At a first step **3202**, a transmitter (TX) receives data (e.g., heat-map data) indicating a location of a receiver (RX), and also establishes a connection with the receiver according to one or more protocols used to communicate via a communications signal. That is, the transmitter and the receiver may communicate various types of data, such as heat-map data, over the communications signal, using a wireless communications protocol capable of transmitting information between two processors of electrical devices (e.g., NFC, ZigBee®, Bluetooth®, Wi-Fi), where the wireless communications protocol ordinarily accomplishes some routines establishing an association between the transmitter and the

receiver. Once the transmitter identifies the receiver, the transmitter may establish the connection associated in the transmitter with the receiver, allowing the transmitter and receiver to communicate. After the association is established, then in current step **3202**, the receiver may transmit heat-map data to the transmitter, indicating a location (e.g., coordinates, segment) where the receiver may be found in the transmission field.

At a next step **3204**, the transmitter transmits power waves to generate a pocket of energy at the location of the receiver. The transmitter transmit the power waves that converge in the three-dimensional space. The power waves may be controlled through phase and/or relative amplitude adjustments to form the pocket of energy at the receiver location where the pocket of energy is intended. In one embodiment, the pocket of energy is formed by the two or more power waves that converge at the receiver location in the three-dimensional space.

At a next step **3206**, the transmitter receives location data of a living being or a sensitive object. One or more sensors acquire sensor data indicating presence of the living being or the sensitive object, and then communicate raw or processed sensor data to the transmitter. The one or more sensors may acquire and communicate location-related sensor data indicating the location of living beings or other sensitive object. In an embodiment, one or more sensors acquire and communicate to the transmitter location-related information, and at least one non-location attribute of the living being or sensitive object. In an embodiment, at least one non-location attribute of the living being or sensitive object includes one or more of pyro-electric sensor responses, optical sensor responses, ultrasound sensor responses, and millimeter sensor responses.

At a next step **3208**, the transmitter measures the distance between the living being or the sensitive object and the power waves. In one embodiment, the transmitter compares the location data for the living being or sensitive object against the location of the power waves (transmitted between the transmitter and the receiver). The transmitter also compares the location data for the living being or sensitive object against planar coordinates (e.g., one-dimensional coordinates, two-dimensional coordinates, or three-dimensional coordinates, or polar coordinates) associated with the location of the receiver whose coordinates may be stored in a mapping memory of the transmitter. The transmitter compares the power levels generated by the power waves against one or more maximum permissible power level for the living being or the sensitive object. If the transmitter determines the distance between the living being or the sensitive object and the power waves indicate not enough proximity. In other words, the power levels generated by the power waves are comparatively lower than the one or more maximum permissible power level at the location of the living being or the sensitive object, then the transmitter continues to transmit the power waves, thereby forming the pocket of energy at the location of the receiver.

If the transmitter determines the distance between the living being or the sensitive object and the power waves or the path of the power waves indicate proximity (i.e., the power levels generated by the power waves is higher than or closer to the one or more maximum permissible power level at the location of the living being or the sensitive object), then the transmitter at step **3210**, adjust the power waves based on the location of the living being or the sensitive object. In some case, the transmitter reduces the power level of the power waves at the receiver location. In some cases, the transmitter terminates transmission of the power waves to the receiver location. In some cases, the transmitter diminishes the amount of energy of the power waves at the receiver location. In some embodiments, the transmitter redirects the transmission of the power waves around the living being or the sensitive object. In some embodiments, the transmitter creates a null space at or proximate to the location of the receiver or corresponding to the location of the living being or the sensitive object. In some instances, the transmitter creates the null space at the location where the pocket of energy is being generated when the living being or the sensitive object is detected at the same location as the intended pocket of energy. In these circumstances, the transmitted power waves cancel each other out resulting in no significant energy being transmitted to the location of the living being or the sensitive object.

In one embodiment, each of the one or more antennas have a same size, and at least one antenna in the one or more antennas of the transmitter is selected from the group consisting of: a flat antenna, a patch antenna, and a dipole antenna. The one or more antennas of the transmitter are configured to operate in a frequency band ranging from about 900 MHz to about 100 GHz, including about 1 GHz, 5.8 GHz, 24 GHz, 60 GHz, and 72 GHz. The one or more antennas are configured to transmit the one or more power waves at a different time from each other depending on the placement of the one or more antennas in the at least one three dimensional antenna array.

The one or more antennas are evenly spaced within the three-dimensional antenna array. The one or more antennas are also asymmetrically located within the three-dimensional antenna array, and therefore the three-dimensional antenna array allow the transmission of the one or more power waves into any one of large range of directions. In another embodiment, the one or more antennas can be evenly spaced on the antenna array, asymmetrically located on the antenna array, or both, thereby allowing the transmission of the one or more power waves in a wide range of directions. In yet another embodiment, the one or more antennas can be unevenly spaced on the antenna array, asymmetrically located on the antenna array, or both, thereby allowing the transmission of the one or more power waves in a wide range of directions. In another embodiment, the one or more antennas in the three dimensional array are arranged in two, two-dimensional arrays.

The foregoing method descriptions and the process flow diagrams are provided merely as illustrative examples and are not intended to require or imply that the steps of the various embodiments must be performed in the order presented. As will be appreciated by one of skill in the art the steps in the foregoing embodiments may be performed in any order. Words such as "then," "next," etc. are not intended to limit the order of the steps; these words are simply used to guide the reader through the description of the methods. Although process flow diagrams may describe the operations as a sequential process, many of the operations can be performed in parallel or concurrently. In addition, the order of the operations may be re-arranged. A process may correspond to a method, a function, a procedure, a subroutine, a subprogram, etc. When a process corresponds to a function, its termination may correspond to a return of the function to the calling function or the main function.

The various illustrative logical blocks, modules, circuits, and algorithm steps described in connection with the embodiments disclosed herein may be implemented as electronic hardware, computer software, or combinations of both. To clearly illustrate this interchangeability of hardware

and software, various illustrative components, blocks, modules, circuits, and steps have been described above generally in terms of their functionality. Whether such functionality is implemented as hardware or software depends upon the particular application and design constraints imposed on the overall system. Skilled artisans may implement the described functionality in varying ways for each particular application, but such implementation decisions should not be interpreted as causing a departure from the scope of the present invention.

Embodiments implemented in computer software may be implemented in software, firmware, middleware, microcode, hardware description languages, or any combination thereof. A code segment or machine-executable instructions may represent a procedure, a function, a subprogram, a program, a routine, a subroutine, a module, a software package, a class, or any combination of instructions, data structures, or program statements. A code segment may be coupled to another code segment or a hardware circuit by passing and/or receiving information, data, arguments, parameters, or memory contents. Information, arguments, parameters, data, etc. may be passed, forwarded, or transmitted via any suitable means including memory sharing, message passing, token passing, network transmission, etc.

The actual software code or specialized control hardware used to implement these systems and methods is not limiting of the invention. Thus, the operation and behavior of the systems and methods were described without reference to the specific software code being understood that software and control hardware can be designed to implement the systems and methods based on the description herein.

When implemented in software, the functions may be stored as one or more instructions or code on a non-transitory computer-readable or processor-readable storage medium. The steps of a method or algorithm disclosed herein may be embodied in a processor-executable software module, which may reside on a computer-readable or processor-readable storage medium. A non-transitory computer-readable or processor-readable media includes both computer storage media and tangible storage media that facilitate transfer of a computer program from one place to another. A non-transitory processor-readable storage media may be any available media that may be accessed by a computer. By way of example, and not limitation, such non-transitory processor-readable media may comprise RAM, ROM, EEPROM, CD-ROM or other optical disk storage, magnetic disk storage or other magnetic storage devices, or any other tangible storage medium that may be used to store desired program code in the form of instructions or data structures and that may be accessed by a computer or processor. Disk and disc, as used herein, include compact disc (CD), laser disc, optical disc, digital versatile disc (DVD), floppy disk, and Blu-ray disc where disks usually reproduce data magnetically, while discs reproduce data optically with lasers. Combinations of the above should also be included within the scope of computer-readable media. Additionally, the operations of a method or algorithm may reside as one or any combination or set of codes and/or instructions on a non-transitory processor-readable medium and/or computer-readable medium, which may be incorporated into a computer program product.

What is claimed is:

1. A method for wireless power transmission, the method comprising:

receiving, by a transmitter, from one or more sensors, location data about a location associated with one or more objects within a transmission field of the transmitter, wherein:

the one or more sensors include a proximity sensor configured to send the location data of the one or more objects, and

the one or more objects are associated with a maximum permissible exposure (MPE) level;

transmitting, by the transmitter, one or more power waves to converge to form a pocket of energy at a location of an electronic device; and

transmitting, by the transmitter, one or more power waves to converge destructively to form a null space at the location of the one or more objects, the null space having a power density level that is below the MPE level.

2. The method of claim **1**, wherein the transmitting of the one or more power waves to converge destructively to form the null space at the location of the one or more objects is performed in accordance with a determination that a power density level at the location of the one or more objects exceeds the MPE level associated with the one or more objects.

3. The method of claim **2**, wherein the one or more sensors include at least one sensor configured to sense the power density level and send data indicating the power density level to the transmitter.

4. The method according to claim **1**, wherein the proximity sensor is externally located outside of the transmitter and electronically sends the location data to the transmitter.

5. The method according to claim **1**, wherein the one or more sensors comprise a millimeter wave sensor, and wherein the millimeter wave sensor is configured to send information that exactly identifies the location of the electronic device to the transmitter.

6. The method according to claim **1**, further comprising:

receiving, by the transmitter, a location of a receiver based on heat mapping data; and

generating, by the transmitter, the null space proximate to the location of the receiver.

7. The method according to claim **1**, further comprising,

receiving, by the transmitter, a location of a receiver from an internal or external sensor device; and

generating, by the transmitter, the null space proximate to the location of the receiver.

8. The method according to claim **1**, wherein the null space comprises a space where a pocket of energy does not form.

9. The method according to claim **1**, further comprising using, by the transmitter, generation of the null space to reduce or eliminate energy in a pocket of energy that is located in a certain direction or dimension.

10. The method according to claim **1**, wherein generation of the null space is cancelled when the one or more objects have moved outside a pre-defined distance from the transmission field.

11. The method according to claim **1**, wherein a power density level is approximately five thousand times less at the generated null space in relation to a power density level at the pocket of energy.

12. The method according to claim 1, wherein:

the transmitter includes an antenna array,

a first subset of antennas of the antenna array is used to transmit the one or more power waves that converge destructively to generate the null space, and

a second subset of antennas of the antenna array is used to transmit the one or more power waves that converge to form the pocket of energy.

13. A system for wireless power transmission, the system comprising:

one or more transmitters, each of the one or more transmitters comprising one or more antenna arrays, each of the one or more antenna arrays comprising one or more antennas, wherein the one or more antenna arrays of a respective transmitter are configured to:

transmit one or more power waves that converge to create a pocket of energy at a location of an electronic device, and

transmit one or more power waves that converge destructively to generate a null space at a location of one or more objects, the location of the one or more objects based on location data received from one or more sensors indicating that the location of one or more objects is within a transmission field of the one or more transmitters,

wherein:

the one or more sensors include a proximity sensor configured to send the location data of the one or more objects,

the one or more objects are associated with a maximum permissible exposure (MPE) level, and

the null space has a power density level that is below the MPE level.

14. The system according to claim 13, further comprising a sensor device configured to determine the location data associated with the one or more objects in a pre-defined distance from the transmitter, receiver, or one or more power waves travelling between the transmitter and the receiver.

15. The system according to claim 13, wherein the one or more antenna arrays comprise a first antenna array and a second antenna array, and wherein the first antenna array is configured to create the pocket of energy and the second antenna array is configured to create the null space.

16. The system according to claim 13, wherein the one or more antenna arrays comprise a first antenna array and a second antenna array, and wherein the first antenna array and the second antenna array are each configured to create both the pocket of energy and the null space.

17. The system according to claim 13, wherein the one or more transmitters receive a location of a receiver based on heat mapping data, and generate the null space proximate to the location of the receiver.

18. The system according to claim 13, wherein the one or more transmitters receive location of a receiver from an internal or external sensor device, and generate the null space proximate to the location of the receiver.

19. The system according to claim 13, wherein the one or more transmitters select a size and a depth of the pocket of energy based on the location data of the one or more objects received.

20. The system of claim 13, wherein the one or more antenna arrays transmit the one or more power waves to generate the null space at the location of the one or more objects in accordance with a determination that a power density level at the location of the one or more objects exceeds the MPE level associated with the one or more objects.

21. The system of claim 20, wherein the one or more sensors include at least one sensor configured to sense the power density level and send data indicating the power density level to the transmitter.

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