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(54) **SURFACE MOUNT DIELECTRIC ANTENNAS FOR WIRELESS POWER TRANSMITTERS**

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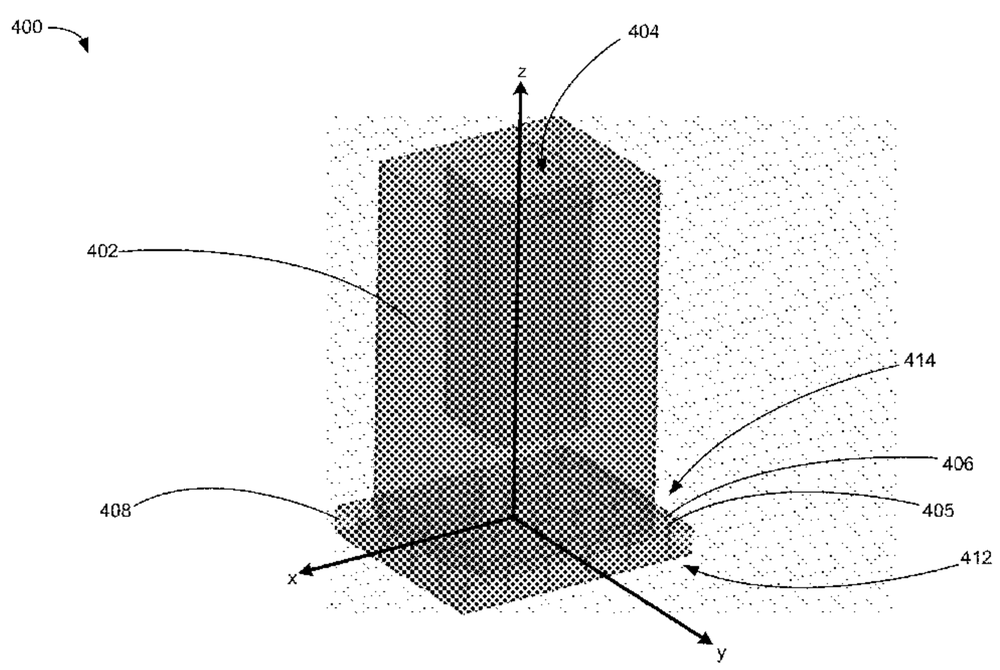
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(57) **ABSTRACT**

A wireless power transmission antenna includes a printed circuit board (PCB) with a first transmission line that conducts a first power transmission signal. A dielectric resonator that is mechanically coupled to the PCB is configured to radiate the first power transmission signal. A first feed element that is electronically coupled to the first transmission line and to the dielectric resonator is configured to receive the power transmission signal via the first transmission line and excite the dielectric resonator with the first power transmission signal.

23 Claims, 8 Drawing Sheets



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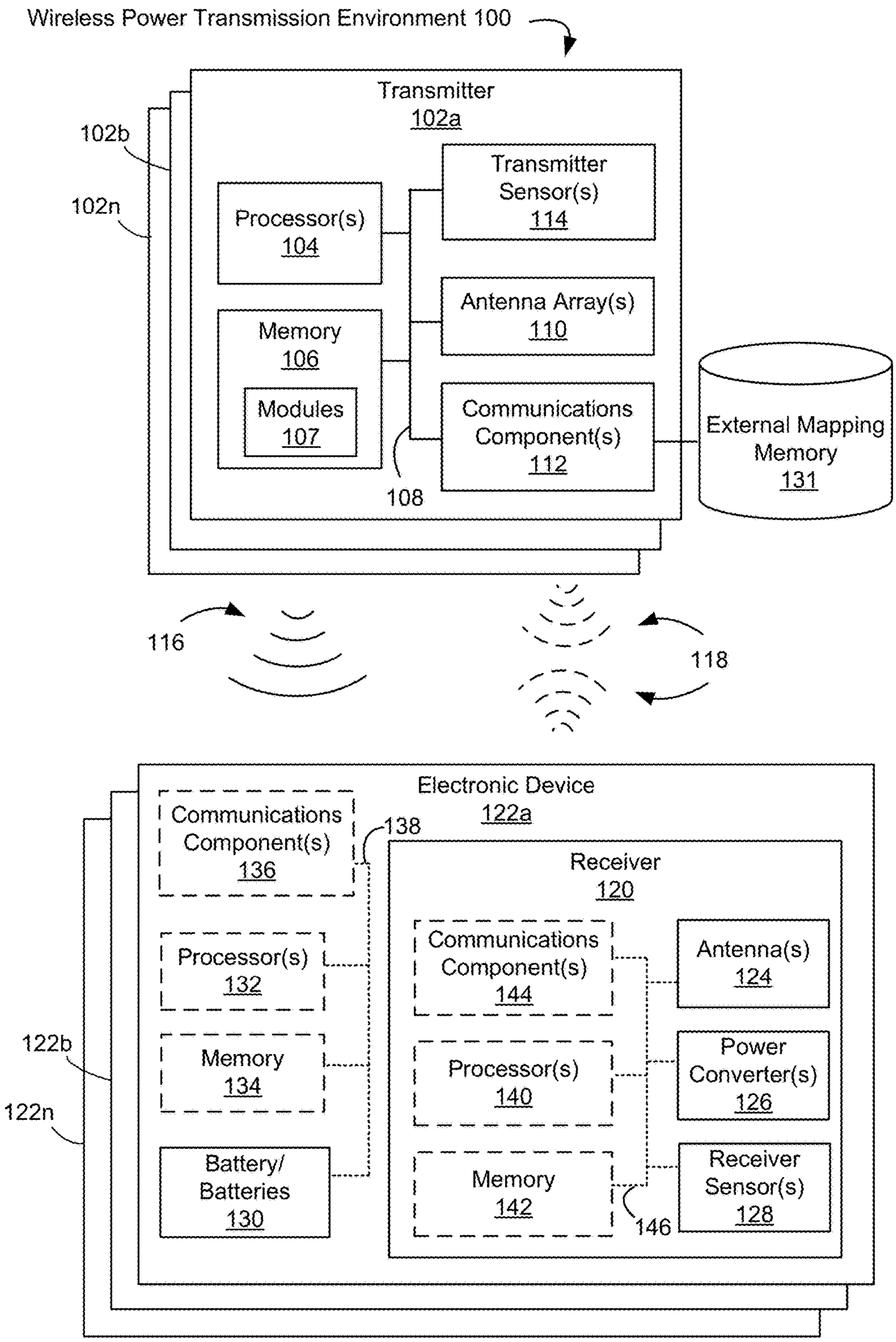

Wireless Power Transmission Environment 100
Transmitter
102a
102b
102n
Processor(s)
104
Transmitter
Sensor(s)
114
Antenna Array(s)
110
Memory
106
Modules
107
Communications
Component(s)
112
External Mapping
Memory
131
108
116
118
Electronic Device
122a
Communications
Component(s)
136
138
Receiver
120
Processor(s)
132
Communications
Component(s)
144
Antenna(s)
124
122b
Memory
134
Processor(s)
140
Power
Converter(s)
126
122n
Battery/
Batteries
130
Memory
142
Receiver
Sensor(s)
128
146

Figure 1

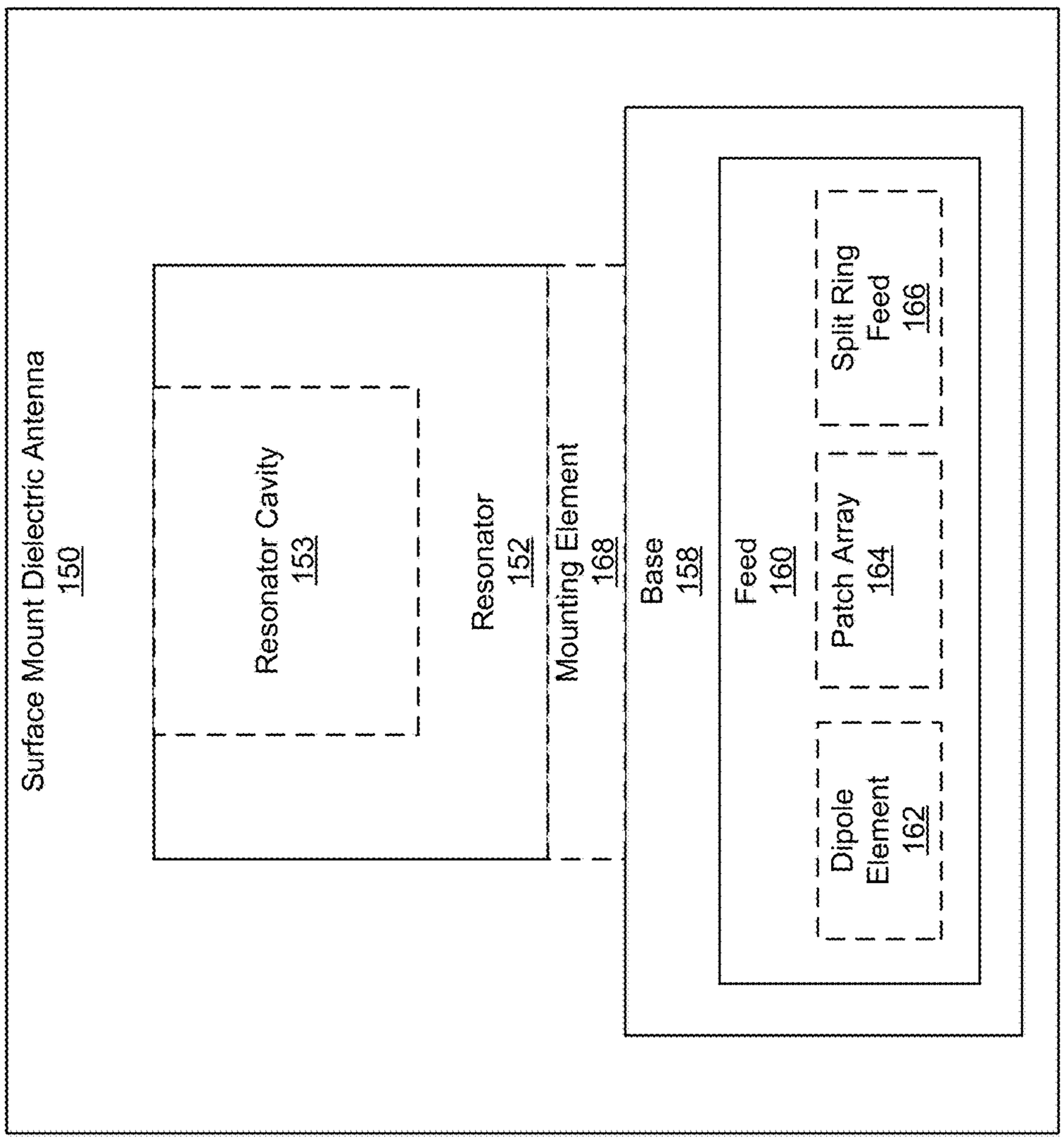

Surface Mount Dielectric Antenna
150
Resonator Cavity
153
Resonator
152
Mounting Element
168
Base
158
Feed
160
Dipole Element
162
Patch Array
164
Split Ring Feed
166

Figure 2

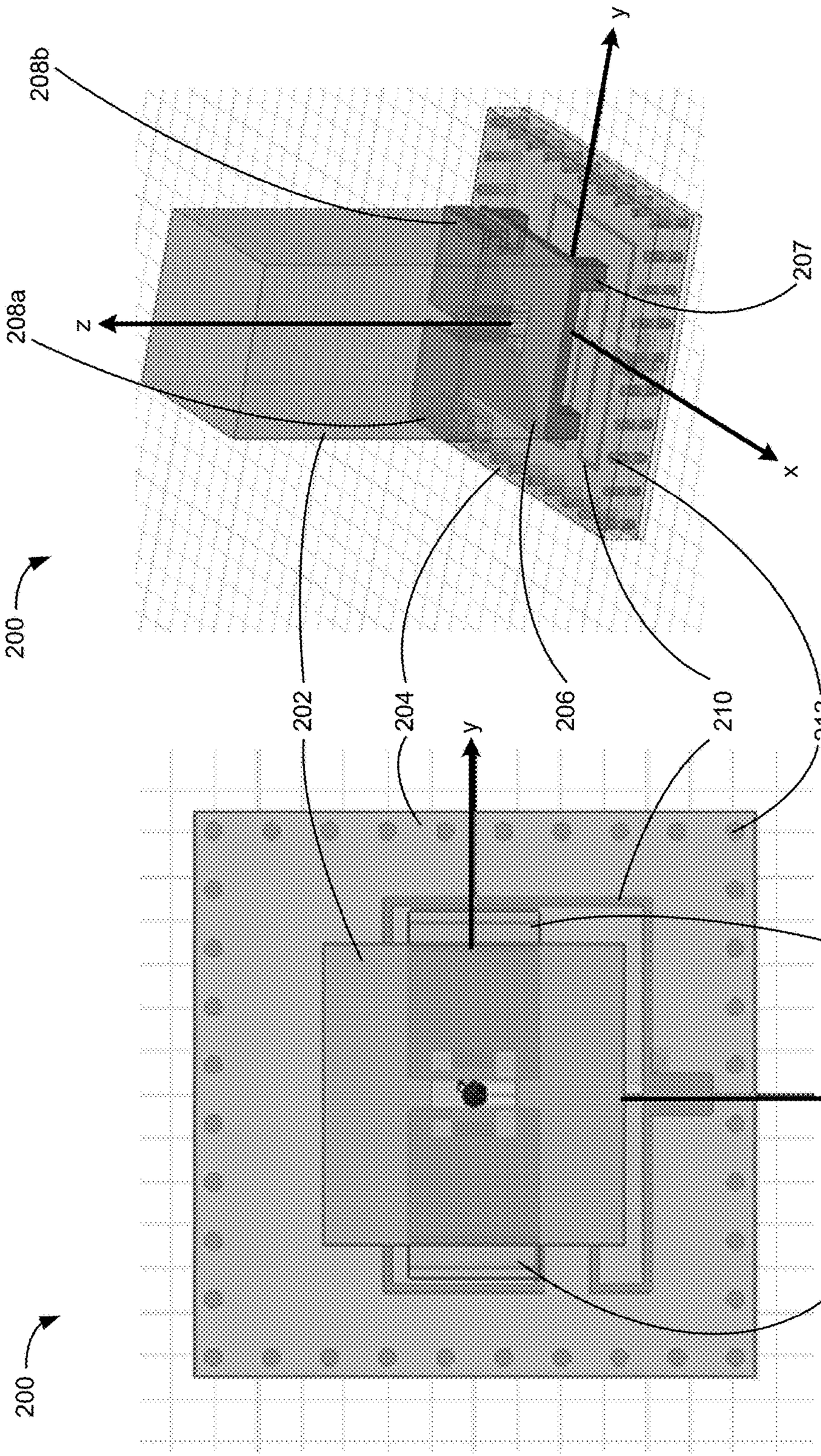


Figure 3A

Figure 3B

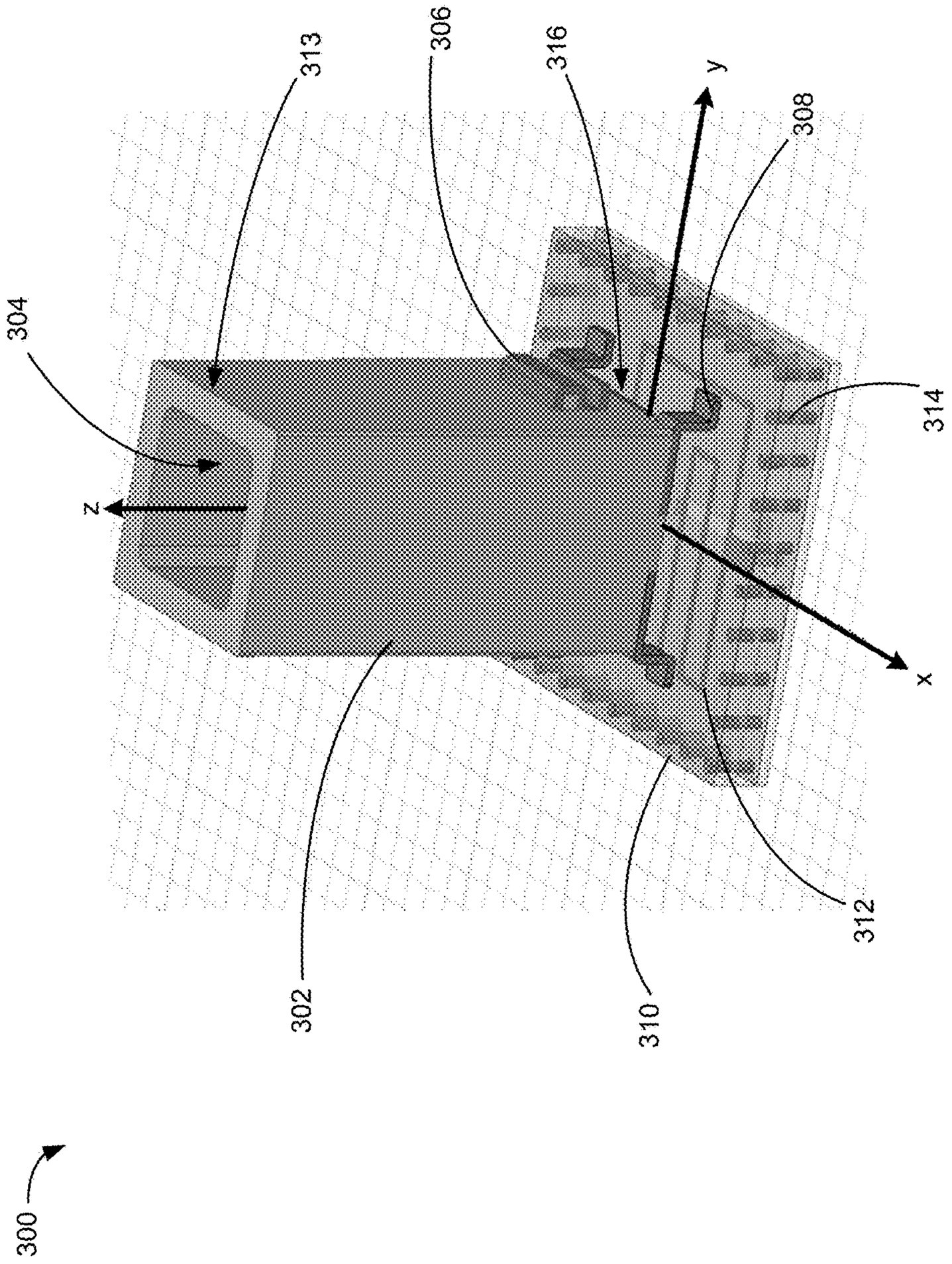


Figure 4

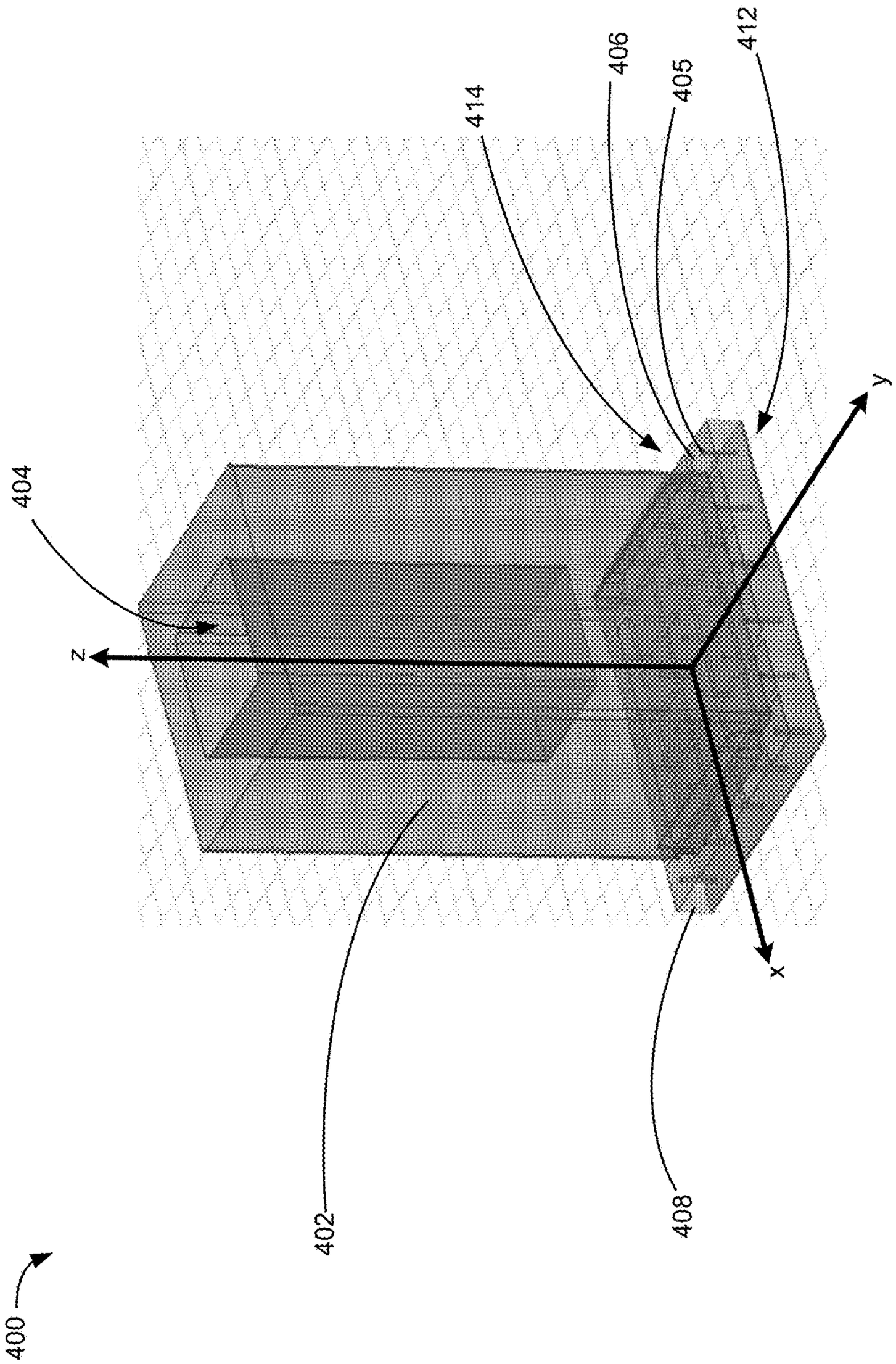


Figure 5

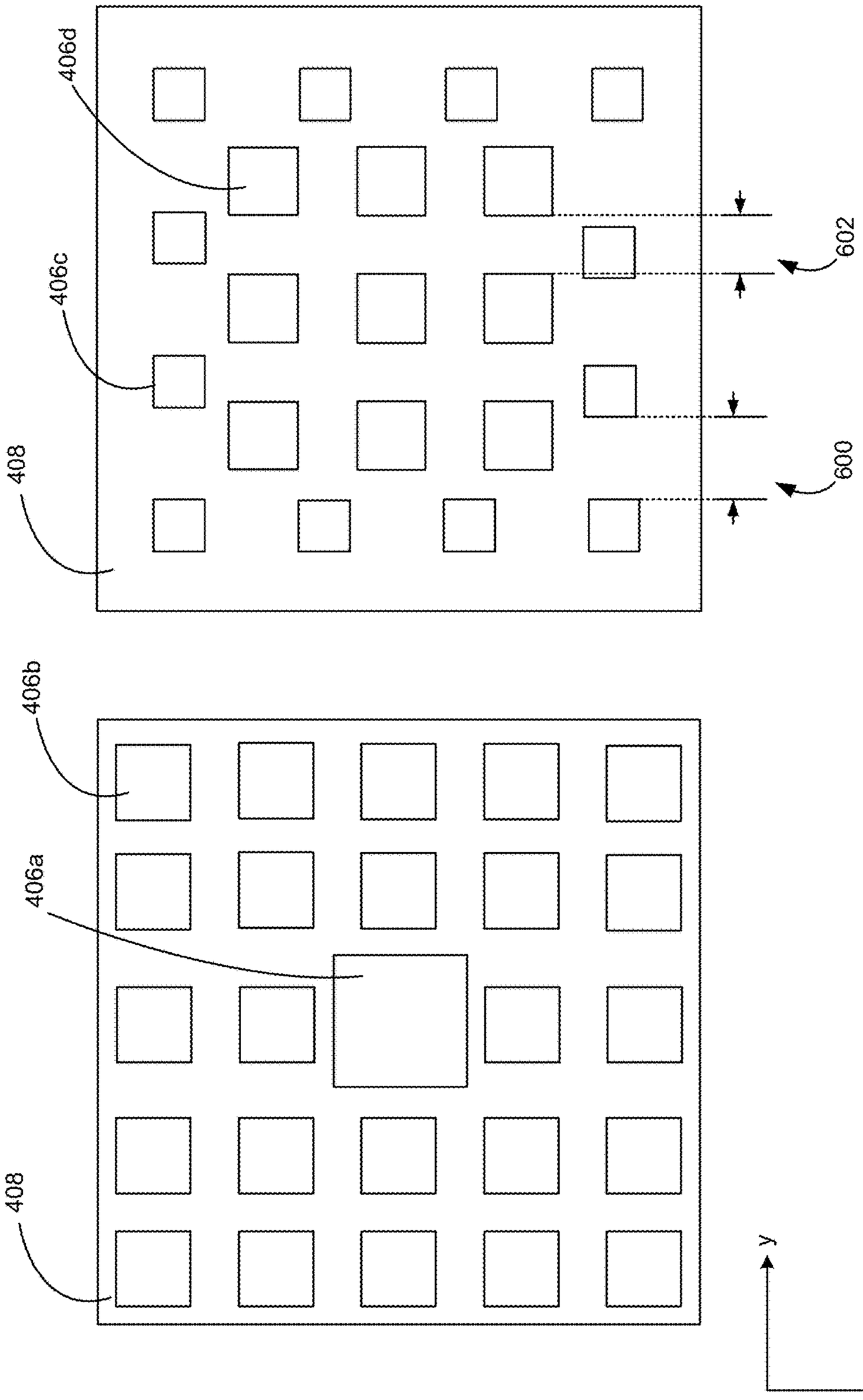


Figure 6B

Figure 6A

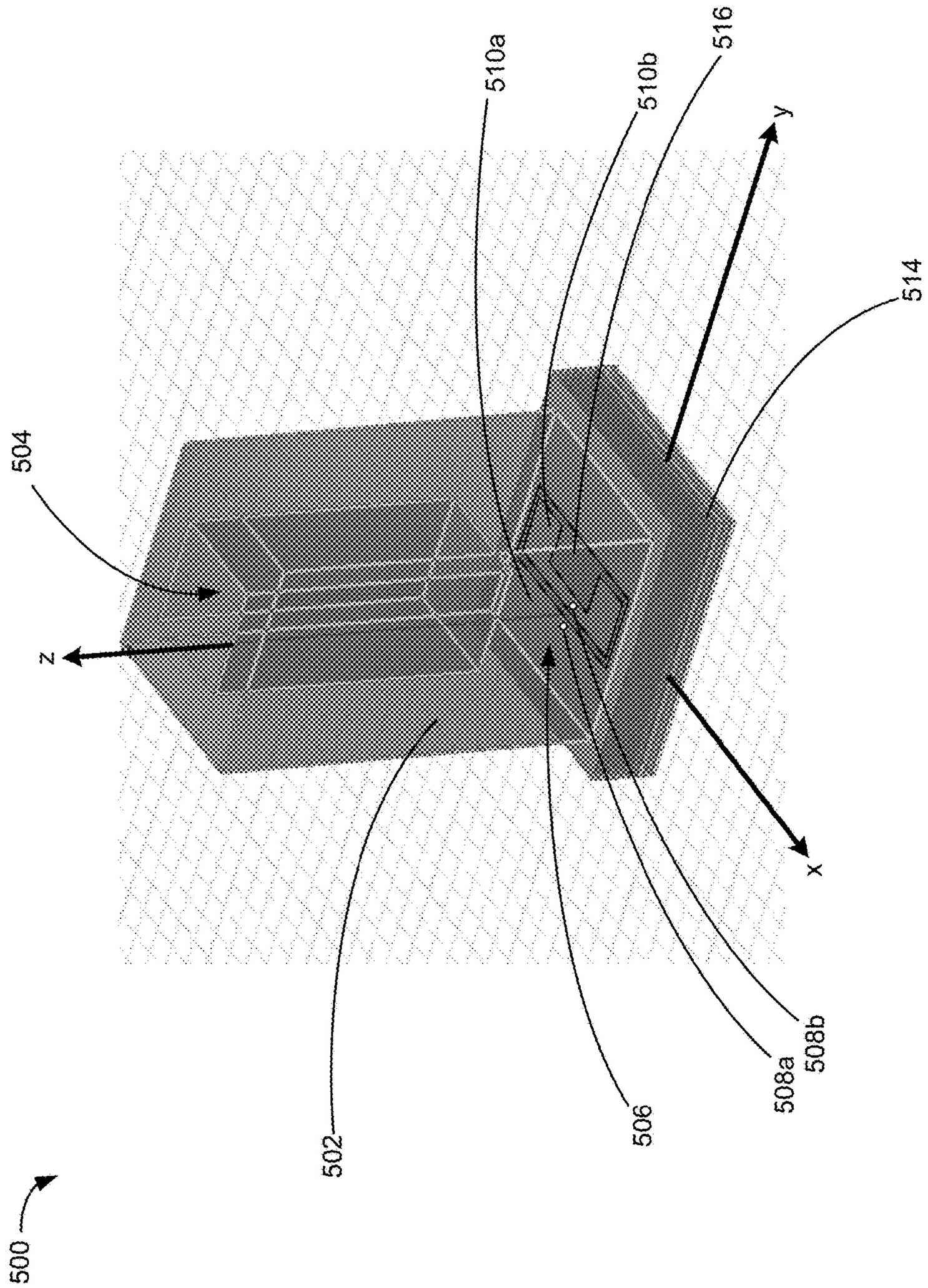


Figure 7

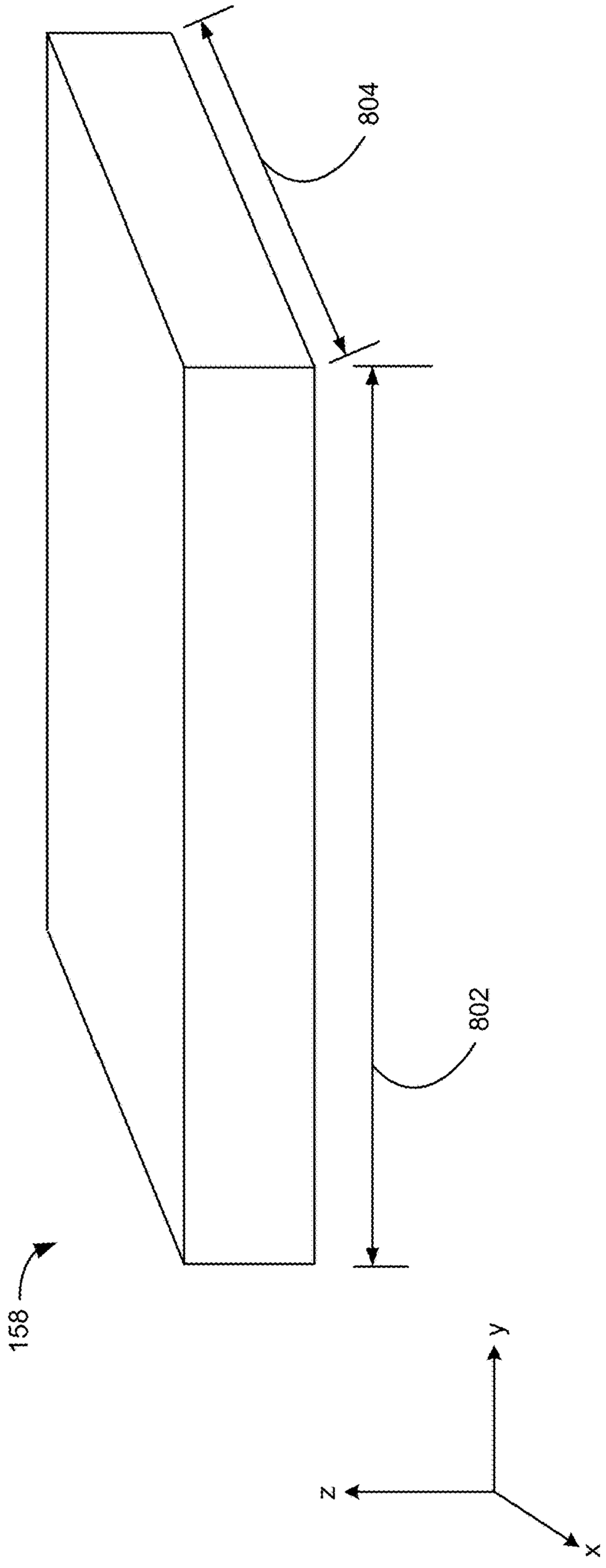


Figure 8

SURFACE MOUNT DIELECTRIC ANTENNAS FOR WIRELESS POWER TRANSMITTERS

TECHNICAL FIELD

The disclosed embodiments relate generally to wireless power transmission systems, and in particular, to surface mount dielectric antennas for wirelessly transmitting and/or receiving power.

BACKGROUND

Portable electronic devices, such as laptop computers, mobile phones, tablets, and other electronic devices, require frequent charging of a power-storing component (e.g., a battery) to operate. Many electronic devices require charging one or more times per day. Often, charging an electronic device requires manually connecting an electronic device to an outlet or other power source using a wired charging cable. In some cases, the power-storing component is removed from an electronic device and inserted into charging equipment. Accordingly, charging is time consuming, burdensome, and inefficient because users must carry around multiple charging cables and/or other charging devices, and frequently must locate appropriate power sources to charge their electronic devices. Additionally, conventional charging techniques potentially deprive a user of the ability to use the device while it is charging, and/or require the user to remain next to a wall outlet or other power source to which their electronic device or other charging equipment is connected.

Existing antennas used for transmission of power waves have large cross-sectional areas for transmission of power waves at a frequency of 900 MHz. Due to these large cross-sectional areas, integrating existing antennas with consumer electronic devices results in noticeable and undesired changes to an aesthetic appearance of the consumer electronic devices, thereby reducing the likelihood that consumers will be willing to install such devices in their homes, office spaces, and other areas. Further, due to the large antenna size of existing antennas and preferred smaller sizes for consumer electronic devices, the number of antennas that can be included in an array of antennas in a consumer device is limited, which in turn limits the beamforming and power distribution properties of an antenna array formed from existing antennas.

SUMMARY

There is a need for improved antenna designs that help to address the shortcomings of conventional charging systems described above. In particular, there is a need for antennas (e.g., surface mount dielectric antennas) that have a form factor that is suitable for integration with consumer devices. The antennas described herein address these shortcomings and have a form factor that allows large-scale arrays of antennas (e.g., arrays incorporating 30, 50, or 100 antenna elements) to be used with consumer devices. For example, in some embodiments the antennas discussed herein have a largest cross-sectional dimension of less than approximately two inches (e.g., 100 mm, 50 mm, 44 mm), making integration with consumer devices such as sound bars, televisions, media entertainment systems, light fixtures, portable air conditioning/heater systems, dashboard and glove compartments in automobiles, devices embedded in seat-backs (e.g., in trains, busses and airplanes), advertisement panels, and other consumer devices appropriate without impacting aesthetic appeal of these consumer devices, thereby ensuring that consumers will be more receptive to installing such transmitter devices (e.g., a sound bar with the novel antennas integrated therein) in their homes, offices, and other spaces. Large-scale arrays of the antenna elements described herein are capable of exhibiting improved beamforming and/or power distribution characteristics as compared to conventional antenna designs incorporating fewer elements (e.g., 5 antenna elements) due to the larger form factor of these conventional antenna designs.

(A1) In some embodiments, a wireless power transmission antenna includes a printed circuit board (PCB) including a first transmission line that conducts a first power transmission signal. The wireless power transmission antenna also includes a dielectric resonator that is mechanically coupled to the PCB and configured to radiate the first power transmission signal. The wireless power transmission antenna also includes a first feed element that is electronically coupled to the first transmission line and to the dielectric resonator. The first feed element is configured to receive the first power transmission signal via the first transmission line and excite the dielectric resonator with the first power transmission signal.

(A2) In some embodiments of (A1), the first feed element is a dipole element.

(A3) In some embodiments of (A2), the mechanical coupling of the dielectric resonator to the PCB includes a mounting platform that is coupled to the dielectric resonator and to the PCB; and the mounting platform isolates at least a portion of the dipole element from the PCB.

(A4) In some embodiments of (A2), at least a portion of the dipole element includes a meandering line feature that increases the effective length of the dipole element.

(A5) In some embodiments of any of (A1)-(A4), the PCB includes a plurality of vias that pass through the PCB.

(A6) In some embodiments of (A5), the plurality of vias at least partially surround the dielectric resonator.

(A7) In some embodiments of (A1), the PCB includes a plurality of patches. Each respective patch of the plurality of patches is electronically coupled to a respective via of a plurality of vias, the respective via passing through the PCB to couple the respective patch with a ground plane that is coupled to the first transmission line of the PCB. In some embodiments, the first feed element is the plurality of patches.

(A8) In some embodiments of (A7), each patch of the plurality of patches is fabricated from a metamaterial.

(A9) In some embodiments of any of (A7)-(A8), the plurality of patches are arranged in a uniformly spaced array.

(A10) In some embodiments of (A7), wherein the plurality of patches include a first patch and a second patch, wherein the first patch has a first area and the second patch has a second area that is different from the first area.

(A11) In some embodiments of (A10), the first patch is adjacent to a center of the dielectric resonator; and the second patch is adjacent to an edge of the dielectric resonator.

(A12) In some embodiments of (A11), a distance between the second patch and the edge of the dielectric resonator is configured to avoid interference between the transmission signal transmitted by the dielectric antenna and an adjacent transmission of an adjacent antenna.

(A13) In some embodiments of (A1), the PCB includes a second transmission line that conducts a second transmission line that conducts a second power transmission signal, the first feed element includes a first contact, and the antenna includes a second feed element that includes a second contact. The first contact is separated from the second

contact by a dielectric substrate material that surrounds the first contact. The second feed element is configured to (i) receive the second power transmission signal via the second transmission line and (ii) excite the dielectric resonator with the second power transmission signal.

(A14) In some embodiments of (A13), the first contact has a split ring shape.

(A15) In some embodiments of any of (A1)-(A14), the wireless power transmission antenna transmits the first transmission signal to a receiver that uses energy from the transmission signal to power or charge an electronic device coupled with the receiver.

(A16) In some embodiments of any of (A1)-(A15), a length of the wireless power transmission antenna is equal to or less than 40 mm.

(A17) In some embodiments of any of (A1)-(A16), the dielectric resonator includes a solid dielectric material.

(A18) In some embodiments of any of (A1)-(A17), the dielectric resonator includes a cavity.

(A19) In some embodiments of any of (A1)-(A18), the wireless power transmission antenna is one of a plurality of wireless power transmission antenna antennas mounted on the PCB.

(A20) In some embodiments, an electronic device has an integrated wireless power transmission antenna. The wireless power transmission antenna includes a printed circuit board (PCB) including a first transmission line that conducts a first power transmission signal. The wireless power transmission antenna also includes a dielectric resonator that is mechanically coupled to the PCB and configured to radiate the first power transmission signal. The wireless power transmission antenna also includes a first feed element that is electronically coupled to the first transmission line and to the dielectric resonator. The first feed element is configured to receive the first power transmission signal via the first transmission line and excite the dielectric resonator with the first power transmission signal.

(A21) In some embodiments of (A20), the first feed element is a dipole element.

(A22) In some embodiments of (A20) or (A21), the mechanical coupling of the dielectric resonator to the PCB includes a mounting platform that is coupled to the dielectric resonator and to the PCB; and the mounting platform isolates at least a portion of the dipole element from the PCB.

(A23) In some embodiments of (A20), the PCB includes a plurality of patches. Each respective patch of the plurality of patches is electronically coupled to a respective via of a plurality of vias, the respective via passing through the PCB to couple the respective patch with a ground plane that is coupled to the first transmission line of the PCB. In some embodiments, the first feed element is the plurality of patches.

(A24) In some embodiments of (A20), the PCB includes a second transmission line that conducts a second power transmission signal. The first feed element includes a first contact. The antenna includes a second feed element that includes a second contact, wherein the first contact is separated from the second contact by a dielectric substrate material that surrounds the first contact. The second feed element is configured to (i) receive the second power transmission signal via the second transmission line and (ii) excite the dielectric resonator with the second power transmission signal.

(A25) In some embodiments of (A24), the first contact has a split ring shape.

(A26) In some embodiments of any of (A20)-(A25), a length of the wireless power transmission antenna is equal to or less than 40 mm.

(A27) In some embodiments of any of (A20)-(A26), the dielectric resonator includes a solid dielectric material.

(A28) In some embodiments of any of (A20)-(A27), the dielectric resonator includes a cavity.

(A29) In some embodiments of any of (A20)-(A28), the wireless power transmission antenna is one of a plurality of wireless power transmission antennas included in the electronic device.

In some embodiments, a dipole feed antenna (i.e., an antenna that uses a dipole element as the feed element) for use in a wireless power transmission system includes a printed circuit board (PCB) that includes a transmission line. The transmission line receives a transmission signal for transmission by the antenna. A mounting platform is mechanically coupled to the PCB. A dielectric resonator is mechanically coupled to the mounting platform. At least one dipole element is electronically coupled to the transmission line and to the dielectric resonator. The at least one dipole element is configured to excite the dielectric resonator with a signal carried by the transmission line.

In some embodiments, a patch array feed dielectric antenna (i.e., an antenna that uses a plurality of patches of a patch array as the feed element) includes a printed circuit board (PCB) that includes a top surface and a bottom surface that is opposite the top surface. The bottom surface of the PCB is a ground plane that receives a transmission signal for transmission by the antenna. The top surface of the PCB includes a plurality of patches. A respective patch of the plurality of patches is electronically coupled to a via that passes through the PCB and electronically couples the respective patch to the ground plane. A dielectric resonator is electronically coupled to the plurality of patches. The plurality of patches excite the dielectric resonator with the transmission signal.

In some embodiments, a multi-contact antenna (i.e., an antenna that uses a split ring element which includes at least two contacts as the feed element) comprises a printed circuit board (PCB) that includes a first surface. The first surface of the PCB includes a first contact that is separated from a second contact by a dielectric substrate material. A first excitation slot is coupled to the first contact. A second excitation slot is coupled to the second contact. A first transmission signal is provided to the first contact via the first excitation slot. A second transmission signal is provided to the second contact via the second excitation slot. A dielectric resonator is electronically coupled to the first contact and the second contact. The first contact excites the dielectric resonator with the first transmission signal and the second contact excites the dielectric resonator with the second transmission signal.

Note that the various embodiments described above can be combined with any other embodiments described herein. The features and advantages described in the specification are not all inclusive and, in particular, many additional features and advantages will be apparent to one of ordinary skill in the art in view of the drawings, specification, and claims. Moreover, it should be noted that the language used in the specification has been principally selected for readability and instructional purposes, and may not have been selected to delineate or circumscribe the inventive subject matter.

BRIEF DESCRIPTION OF THE DRAWINGS

So that the present disclosure can be understood in greater detail, a more particular description may be had by reference

to the features of various embodiments, some of which are illustrated in the appended drawings. The appended drawings, however, merely illustrate pertinent features of the present disclosure and are therefore not to be considered limiting, for the description may admit to other effective features.

FIG. **1** is a block diagram of components of a wireless power transmission system, in accordance with some embodiments.

FIG. **2** is a block diagram of a surface mount antenna, in accordance with some embodiments.

FIGS. **3**A-**3**B are schematics of a surface mount dielectric antenna with a solid dielectric resonator, in accordance with some embodiments.

FIG. **4** is a schematic of a surface mount dielectric antenna with a hollow dielectric resonator, in accordance with some embodiments.

FIG. **5** is a schematic of a surface mount dielectric antenna with a patch array feed, in accordance with some embodiments.

FIGS. **6**A-**6**B are illustrative configurations of a surface mount dielectric antenna with a patch array feed, in accordance with some embodiments.

FIG. **7** is a schematic of a surface mount dielectric antenna with a split ring feed, in accordance with some embodiments.

FIG. **8** illustrates an x-axis dimension and a y-axis dimension of a surface mount dielectric antenna, in accordance with some embodiments.

In accordance with common practice, the various features illustrated in the drawings may not be drawn to scale. Accordingly, the dimensions of the various features may be arbitrarily expanded or reduced for clarity. In addition, some of the drawings may not depict all of the components of a given system, method or device. Finally, like reference numerals may be used to denote like features throughout the specification and figures.

DETAILED DESCRIPTION

Numerous details are described herein in order to provide a thorough understanding of the example embodiments illustrated in the accompanying drawings. However, some embodiments may be practiced without many of the specific details, and the scope of the claims is only limited by those features and aspects specifically recited in the claims. Furthermore, well-known processes, components, and materials have not been described in exhaustive detail so as not to unnecessarily obscure pertinent aspects of the embodiments described herein.

Various embodiments of surface mount dielectric antennas are described herein that addresses the shortcomings described above in conventional charging systems and with existing antenna designs. In some embodiments, a surface mount dielectric antenna described herein is a component of a transmitter and/or a receiver of a wireless power transmission environment **100** (e.g., as described with regard to FIG. **1**). For example, a surface mount dielectric antenna **150** (FIG. **2**) transmits power waves and/or receives transmitted power waves.

In some embodiments, one or more transmitters of a wireless power transmission environment generate power waves to form pockets of energy at target locations and adjust power wave generation based on sensed data to provide safe, reliable, and efficient wirelessly-delivered power to receivers (and devices associated therewith). In some embodiments, a controlled "pocket of energy" (e.g., a region in which available power is high due to constructive interference of power waves) and/or null spaces (e.g., a region in which available power is low or nonexistent due to destructive interference of power waves) may be formed by convergence of the power waves transmitted into a transmission field of the one or more transmitters. In some embodiments, the one or more transmitters include an array of the surface mount dielectric antennas **150** described herein (e.g., in reference to FIGS. **2**-**8**), and the array of the surface mount dielectric antennas **150** is used to transmit the power waves. For example, the surface mount dielectric antennas **150** discussed herein may be integrated with consumer devices such as sound bars, televisions, media entertainment systems, light fixtures, and other consumer devices, to produce a respective transmitter that remains aesthetically appealing, yet still capable of transmitting power waves sufficient to charge other electronic devices (e.g., cell phones, smart watches, etc.).

In some embodiments, pockets of energy form at one or more locations in a two- or three-dimensional field due to patterns of constructive interference caused by convergences of transmitted power waves. Energy from the transmitted power waves may be harvested by receivers (i.e., received and converted into usable power) at the one or more locations.

In some embodiments, adaptive pocket-forming is performed, e.g., by adjusting power wave transmission to achieve a target power level for at least some of the power waves transmitted by the one or more transmitters. For example, a system for adaptive pocket-forming includes a sensor. In some embodiments, when the sensor detects an object, such as a sensitive object (e.g., a person, an animal, equipment sensitive to the power waves, and the like) within a predetermined distance (e.g., a distance within a range of 1-5 feet) of a pocket of energy, of one or more of the power waves, or of a transmitter, then a respective transmitter of the one or more transmitters adjusts one or more characteristics of transmitted power waves. Non-limiting examples of the one or more characteristics include: frequency, amplitude, trajectory, phase, and other characteristics used by one or more antennas of the one or more transmitters to transmit the power waves. As one example, in response to receiving information indicating that transmission of power waves by a respective transmitter of the one or more transmitters should be adjusted (e.g., a sensor senses a sensitive object within a predetermined distance of a respective target location), the adaptive pocket-forming process adjusts the one or more characteristics accordingly.

In some embodiments, adjusting the one or more characteristics includes reducing a currently generated power level at a location by adjusting one or more transmitted power waves that converge at the target location. In some embodiments, reducing a currently generated power level includes transmitting a power wave that causes destructive interference with at least one other transmitted power wave. For example, a power wave is transmitted with a first phase that is shifted relative to a second phase of at least one other power wave to destructively interfere with the at least one other power wave in order to diminish or eliminate the currently generated power level at the target location.

In some embodiments, adjusting the one or more characteristics includes increasing a power level for some of the transmitted power waves to ensure that the receiver receives adequate energy sufficient to quickly charge a power-storing component of an electronic device that is associated with the receiver.

In some embodiments, an object is "tagged" (e.g., an identifier of the object is stored in memory in association with a flag) to indicate that the detected object is a sensitive object. In response to detection of a particular object within a predetermined distance of a target location, a determination is made as to whether the particular object is a sensitive object. In some embodiments, this determination includes performing a lookup in the memory to check whether the particular object has been previously tagged and is therefore known as a sensitive object. In response to determining that the particular object is a sensitive object, the one or more characteristics used to transmit the power waves are adjusted accordingly.

In some embodiments, sensing a sensitive object includes using a series of sensor readings from one or more sensors to determine motion of an object within a transmission field of the one or more transmitters. In some embodiments, sensor output from one or more sensors is used to detect motion of the object approaching within a predetermined distance of a pocket of energy or of power waves used to form the pocket of energy. In response to a determination that a sensitive object is approaching (e.g., moving toward and/or within a predefined distance of a pocket of energy), the currently generated power level at the location of the pocket of energy is reduced. In some embodiments, the one or more sensors include sensors that are internal to the one or more transmitters and/or the receiver. In some embodiments, the one or more sensors include sensors that are external to the one or more transmitters and the receiver. In some embodiments, the one or more sensors include thermal imaging, optical, radar, and other types of sensors capable of detecting objects within a transmission field.

Although some embodiments herein include the use of RF-based wave transmission technologies as a primary example, it should be appreciated that the wireless charging techniques that might be employed are not be limited to RF-based technologies and transmission techniques. Rather, it should be appreciated that additional or alternative wireless charging techniques may be utilized, including any suitable technology and technique for wirelessly transmitting energy so that a receiver is capable of converting the transmitted energy to electrical power. Such technologies or techniques may transmit various forms of wirelessly transmitted energy including the following non-limiting examples: ultrasound, microwave, laser light, infrared, or other forms of electromagnetic energy.

FIG. **1** is a block diagram of components of wireless power transmission environment **100**, in accordance with some embodiments. Wireless power transmission environment **100** includes, for example, transmitters **102** (e.g., transmitters **102***a*, **102***b* . . . **102***n*) and one or more receivers **120**. In some embodiments, each respective wireless power transmission environment **100** includes a number of receivers **120**, each of which is associated with a respective electronic device **122** (e.g., electronic devices **122***a*, **122***b* . . . **122***n*).

An example transmitter **102** (e.g., transmitter **102***a*) includes, for example, one or more processor(s) **104**, a memory **106**, one or more antenna arrays **110** (e.g., including antenna elements structured as described below in reference to FIGS. **2-8**), one or more communications components **112**, and/or one or more transmitter sensors **114**. In some embodiments, these components are interconnected by way of a communications bus **108**. References to these components of transmitters **102** cover embodiments in which one or more than one of each of these components (and combinations thereof) are included.

In some embodiments, memory **106** stores one or more programs (e.g., sets of instructions) and/or data structures, collectively referred to as "modules" herein. In some embodiments, memory **106**, or the non-transitory computer readable storage medium of memory **106** stores the following modules **107** (e.g., programs and/or data structures), or a subset or superset thereof:

- information received from receiver **120** (e.g., generated by receiver sensor **128** and then transmitted to the transmitter **102***a*);
- information received from transmitter sensor **114**;
- an adaptive pocket-forming module that adjusts one or more power waves **116** transmitted by one or more transmitters **102**; and/or
- a beacon transmitting module that transmits a communication signal **118** for detecting a receiver **120** (e.g., within a transmission field of the one or more transmitters **102**).

The above-identified modules (e.g., data structures and/or programs including sets of instructions) need not be implemented as separate software programs, procedures, or modules, and thus various subsets of these modules may be combined or otherwise re-arranged in various embodiments. In some embodiments, memory **106** stores a subset of the modules identified above. In some embodiments, an external mapping memory **131** that is communicatively connected to communications component **112** stores one or more modules identified above. Furthermore, the memory **106** and/or external mapping memory **131** may store additional modules not described above. In some embodiments, the modules stored in memory **106**, or a non-transitory computer readable storage medium of memory **106**, provide instructions for implementing respective operations in the methods described below. In some embodiments, some or all of these modules may be implemented with specialized hardware circuits that subsume part or all of the module functionality. One or more of the above-identified elements may be executed by one or more of processor(s) **104**. In some embodiments, one or more of the modules described with regard to memory **106** is implemented on memory **104** of a server (not shown) that is communicatively coupled to one or more transmitters **102** and/or by a memory of electronic device **122** and/or receiver **120**.

In some embodiments, a single processor **104** (e.g., processor **104** of transmitter **102***a*) executes software modules for controlling multiple transmitters **102** (e.g., transmitters **102***b* . . . **102***n*). In some embodiments, a single transmitter **102** (e.g., transmitter **102***a*) includes multiple processors **104**, such as one or more transmitter processors (configured to, e.g., control transmission of signals **116** by antenna array **110**), one or more communications component processors (configured to, e.g., control communications transmitted by communications component **112** and/or receive communications by way of communications component **112**) and/or one or more sensor processors (configured to, e.g., control operation of transmitter sensor **114** and/or receive output from transmitter sensor **114**).

Receiver **120** (e.g., a receiver of electronic device **122**) receives power signals **116** and/or communications **118** transmitted by transmitters **102**. In some embodiments, receiver **120** includes one or more antennas **124** (e.g., antenna array including multiple antenna elements), power converter **126**, receiver sensor **128** and/or other components or circuitry (e.g., processor(s) **140**, memory **142**, and/or communication component(s) **144**). In some embodiments, these components are interconnected by way of a communications bus **146**. References to these components of

receiver **120** cover embodiments in which one or more than one of each of these components (and combinations thereof) are included. Receiver **120** converts energy from received signals **116** (e.g., power waves) into electrical energy to power and/or charge electronic device **122**. For example, receiver **120** uses power converter **126** to convert captured energy from power waves **116** to alternating current (AC) electricity or direct current (DC) electricity usable to power and/or charge electronic device **122**. Non-limiting examples of power converter **126** include rectifiers, rectifying circuits, voltage conditioners, among suitable circuitry and devices.

In some embodiments, receiver **120** is a standalone device that is detachably coupled to one or more electronic devices **122**. For example, electronic device **122** has processor(s) **132** for controlling one or more functions of electronic device **122** and receiver **120** has processor(s) **140** for controlling one or more functions of receiver **120**.

In some embodiments, receiver is a component of electronic device **122**. For example, processor(s) **132** controls functions of electronic device **122** and receiver **120**.

In some embodiments, electronic device **122** includes processor(s) **132**, memory **134**, communication component(s) **136**, and/or battery/batteries **130**. In some embodiments, these components are interconnected by way of a communications bus **138**. In some embodiments, communications between electronic device **122** and receiver **120** occur via communications component(s) **136** and/or **144**. In some embodiments, communications between electronic device **122** and receiver **120** occur via a wired connection between communications bus **138** and communications bus **146**. In some embodiments, electronic device **122** and receiver **120** share a single communications bus.

In some embodiments, receiver **120** receives one or more power waves **116** directly from transmitter **102**. In some embodiments, receiver **120** harvests power waves from one or more pockets of energy created by one or more power waves **116** transmitted by transmitter **102**.

In some embodiments, after the power waves **116** are received and/or energy is harvested from a pocket of energy, circuitry (e.g., integrated circuits, amplifiers, rectifiers, and/or voltage conditioner) of the receiver **120** converts the energy of the power waves (e.g., radio frequency electromagnetic radiation) to usable power (i.e., electricity), which powers electronic device **122** and/or is stored to battery **130** of electronic device **122**. In some embodiments, a rectifying circuit of the receiver **120** translates the electrical energy from AC to DC for use by electronic device **122**. In some embodiments, a voltage conditioning circuit increases or decreases the voltage of the electrical energy as required by the electronic device **122**. In some embodiments, an electrical relay conveys electrical energy from the receiver **120** to the electronic device **122**.

In some embodiments, receiver **120** is a component of an electronic device **122**. In some embodiments, a receiver **120** is coupled (e.g., detachably coupled) to an electronic device **122**. In some embodiments, electronic device **122** is a peripheral device of receiver **120**. In some embodiments, electronic device **122** obtains power from multiple transmitters **102** and/or using multiple receivers **120**. In some embodiments, the wireless power transmission environment **100** includes a plurality of electronic devices **122**, each having at least one respective receiver **120** that is used to harvest power waves from the transmitters **102** into usable power for charging the electronic devices **122**.

In some embodiments, the one or more transmitters **102** adjust one or more characteristics (e.g., phase, gain, direction, and/or frequency) of power waves **116**. For example, a transmitter **102** (e.g., transmitter **102***a*) selects a subset of one or more antenna elements of antenna array **110** to initiate transmission of power waves **116**, cease transmission of power waves **116**, and/or adjust one or more characteristics used to transmit power waves **116**. In some implementations, the one or more transmitters **102** adjust power waves **116** such that trajectories of power waves **116** converge at a predetermined location within a transmission field (e.g., a location or region in space), resulting in controlled constructive or destructive interference patterns.

In some embodiments, respective antenna arrays **110** of the one or more transmitters **102** may include a set of one or more antennas configured to transmit the power waves **116** into respective transmission fields of the one or more transmitters **102**. Integrated circuits (not shown) of the respective transmitter **102**, such as a controller circuit and/or waveform generator, may control the behavior of the antennas. For example, based on the information received from the receiver by way of the communications signal **118**, a controller circuit may determine a set of one or more characteristics or waveform characteristics (e.g., amplitude, frequency, trajectory, phase, among other characteristics) used for transmitting the power waves **116** that would effectively provide power to the receiver **102** and electronic device **122**. The controller circuit may also identify a subset of antennas from the antenna arrays **110** that would be effective in transmitting the power waves **116**. As another example, a waveform generator circuit of the respective transmitter **102** coupled to the processor **104** may convert energy and generate the power waves **116** having the waveform characteristics identified by the controller, and then provide the power waves to the antenna arrays **110** for transmission.

In some embodiments, constructive interference of power waves occurs when two or more power waves **116** are in phase with each other and converge into a combined wave such that an amplitude of the combined wave is greater than amplitude of a single one of the power waves. For example, the positive and negative peaks of sinusoidal waveforms arriving at a location from multiple antennas "add together" to create larger positive and negative peaks. In some embodiments, a pocket of energy is formed at a location in a transmission field where constructive interference of power waves occurs.

In some embodiments, destructive interference of power waves occurs when two or more power waves are out of phase and converge into a combined wave such that the amplitude of the combined wave is less than the amplitude of a single one of the power waves. For example, the power waves "cancel each other out," thereby diminishing the amount of energy concentrated at a location in the transmission field. In some embodiments, destructive interference is used to generate a negligible amount of energy or "null" at a location within the transmission field where the power waves converge.

In some embodiments, the one or more transmitters **102** transmit power waves **116** that create two or more discrete transmission fields (e.g., overlapping and/or non-overlapping discrete transmission fields). In some embodiments, a first transmission field is managed by a first processor **104** of a first transmitter (e.g. transmitter **102***a*) and a second transmission field is managed by a second processor **104** of a second transmitter (e.g., transmitter **102***b*). In some embodiments, the two or more discrete transmission fields (e.g., overlapping and/or non-overlapping) are managed by the transmitter processors **104** as a single transmission field.

In some embodiments, communications component **112** transmits communication signals **118** by way of a wired and/or wireless communication connection to receiver **120**. In some embodiments, communications component **112** generates communications signals **118** used for triangulation of receiver **120**. In some embodiments, communication signals **118** are used to convey information between transmitter **102** and receiver **120** for adjusting one or more characteristics used to transmit the power waves **116**. In some embodiments, communications signals **118** include information related to status, efficiency, user data, power consumption, billing, geo-location, and other types of information.

In some embodiments, receiver **120** includes a transmitter (not shown), or is a part of a transceiver, that transmits communications signals **118** to communications component **112** of transmitter **102**.

In some embodiments, communications component **112** (e.g., communications component **112** of transmitter **102***a*) includes a communications component antenna for communicating with receiver **120** and/or other transmitters **102** (e.g., transmitters **102***b* through **102***n*). In some embodiments, these communications signals **118** represent a distinct channel of signals transmitted by transmitter **102**, independent from a channel of signals used for transmission of the power waves **116**.

In some embodiments, the receiver **120** includes a receiver-side communications component (not shown) configured to communicate various types of data with one or more of the transmitters **102**, through a respective communications signal **118** generated by the receiver-side communications component. The data may include location indicators for the receiver **102** and/or electronic device **122**, a power status of the device **122**, status information for the receiver **102**, status information for the electronic device **122**, status information about the power waves **116**, and/or status information for pockets of energy. In other words, the receiver **102** may provide data to the transmitter **102**, by way of the communications signal **118**, regarding the current operation of the system **100**, including: information identifying a present location of the receiver **102** or the device **122**, an amount of energy received by the receiver **120**, and an amount of power received and/or used by the electronic device **122**, among other possible data points containing other types of information.

In some embodiments, the data contained within communications signals **118** is used by electronic device **122**, receiver **120**, and/or transmitters **102** for determining adjustments of the one or more characteristics used by the antenna array **110** to transmit the power waves **106**. Using a communications signal **118**, the transmitter **102** communicates data that is used, e.g., to identify receivers **120** within a transmission field, identify electronic devices **122**, determine safe and effective waveform characteristics for power waves, and/or hone the placement of pockets of energy. In some embodiments, receiver **120** uses a communications signal **118** to communicate data for, e.g., alerting transmitters **102** that the receiver **120** has entered or is about to enter a transmission field, provide information about electronic device **122**, provide user information that corresponds to electronic device **122**, indicate the effectiveness of received power waves **116**, and/or provide updated characteristics or transmission parameters that the one or more transmitters **102** use to adjust transmission of the power waves **116**.

As an example, the communications component **112** of the transmitter **102** communicates (e.g., transmits and/or receives) one or more types of data (including, e.g., authentication data and/or transmission parameters) including various information such as a beacon message, a transmitter identifier, a device identifier for an electronic device **122**, a user identifier, a charge level for electronic device **122**, a location of receiver **120** in a transmission field, and/or a location of electronic device **122** in a transmission field.

In some embodiments, transmitter sensor **114** and/or receiver sensor **128** detect and/or identify conditions of electronic device **122**, receiver **120**, transmitter **102**, and/or a transmission field. In some embodiments, data generated by transmitter sensor **114** and/or receiver sensor **128** is used by transmitter **102** to determine appropriate adjustments to the one or more characteristics used to transmit the power waves **106**. Data from transmitter sensor **114** and/or receiver sensor **128** received by transmitter **102** includes, e.g., raw sensor data and/or sensor data processed by a processor **104**, such as a sensor processor. Processed sensor data includes, e.g., determinations based upon sensor data output. In some embodiments, sensor data received from sensors that are external to the receiver **120** and the transmitters **102** is also used (such as thermal imaging data, information from optical sensors, and others).

In some embodiments, receiver sensor **128** is a gyroscope that provides raw data such as orientation data (e.g., tri-axial orientation data), and processing this raw data may include determining a location of receiver **120** and/or or a location of receiver antenna **124** using the orientation data.

In some embodiments, receiver sensor **128** includes one or more infrared sensors (e.g., that output thermal imaging information), and processing this infrared sensor data includes identifying a person (e.g., indicating presence of the person and/or indicating an identification of the person) or other sensitive object based upon the thermal imaging information.

In some embodiments, receiver sensor **128** includes a gyroscope and/or an accelerometer that indicates an orientation of receiver **120** and/or electronic device **122**. As one example, transmitters **102** receive orientation information from receiver sensor **128** and the transmitters **102** (or a component thereof, such as the processor **104**) use the received orientation information to determine whether electronic device **122** is flat on a table, in motion, and/or in use (e.g., next to a user's head).

In some embodiments, receiver sensor **128** is a sensor of electronic device **122** (e.g., an electronic device **122** that is remote from receiver **102**). In some embodiments, receiver **120** and/or electronic device **122** includes a communication system for transmitting signals (e.g., sensor signals output by receiver sensor **128**) to transmitter **102**.

Non-limiting examples of transmitter sensor **114** and/or receiver sensor **128** include, e.g., infrared, pyroelectric, ultrasonic, laser, optical, Doppler, gyro, accelerometer, microwave, millimeter, RF standing-wave sensors, resonant LC sensors, capacitive sensors, and/or inductive sensors. In some embodiments, technologies for transmitter sensor **114** and/or receiver sensor **128** include binary sensors that acquire stereoscopic sensor data, such as the location of a human or other sensitive object.

In some embodiments, transmitter sensor **114** and/or receiver sensor **128** is configured for human recognition (e.g., capable of distinguishing between a person and other objects, such as furniture). Examples of sensor data output by human recognition-enabled sensors 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 some embodiments, transmitters **102** adjust one or more characteristics used to transmit the power waves **116** to ensure compliance with 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 maximum permissible exposure (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/m^2), milliwatts per square centimeter (mW/cm^2), or microwatts per square centimeter ($\mu W/cm^2$). In some embodiments, output from transmitter sensor **114** and/or receiver sensor **128** is used by transmitter **102** to detect whether a person or other sensitive object enters a power transmission region (e.g., a location within a predetermined distance of a transmitter **102**, power waves generated by transmitter **102**, and/or a pocket of energy). In some embodiments, in response to detecting that a person or other sensitive object has entered the power transmission region, the transmitter **102** adjusts one or more power waves **116** (e.g., by ceasing power wave transmission, reducing power wave transmission, and/or adjusting the one or more characteristics of the power waves). In some embodiments, in response to detecting that a person or other sensitive object has entered the power transmission region, the transmitter **102** activates an alarm (e.g., by transmitting a signal to a loudspeaker that is a component of transmitter **102** or to an alarm device that is remote from transmitter **102**). In some embodiments, in response to detecting that a person or other sensitive object has entered a power transmission region, the transmitter **102** transmits a digital message to a system log or administrative computing device.

In some embodiments, antenna array **110** includes multiple antenna elements (e.g., configurable "tiles") collectively forming an antenna array. Antenna array **110** generates power transmission signals, e.g., RF power waves, ultrasonic power waves, infrared power waves, and/or magnetic resonance power waves. In some embodiments, the antennas of an antenna array **110** (e.g., of a single transmitter, such as transmitter **102***a*, and/or of multiple transmitters, such as transmitters **102***a*, **102***b*, . . . , **102***n*) transmit two or more power waves that intersect at a defined location (e.g., a location corresponding to a detected location of a receiver **120**), thereby forming a pocket of energy (e.g., a concentration of energy) at the defined location.

In some embodiments, transmitter **102** assigns a first task to a first subset of antenna elements of antenna array **110**, a second task to a second subset of antenna elements of antenna array **110**, and so on, such that the constituent antennas of antenna array **110** perform different tasks (e.g., determining locations of previously undetected receivers **120** and/or transmitting power waves **116** to one or more receivers **120**). As one example, in an antenna array **110** with ten antennas, nine antennas transmit power waves **116** that form a pocket of energy and the tenth antenna operates in conjunction with communications component **112** to identify new receivers in the transmission field. In another example, an antenna array **110** having ten antenna elements is split into two groups of five antenna elements, each of which transmits power waves **116** to two different receivers **120** in the transmission field.

In some embodiments, a surface mount dielectric antenna **150** (e.g., antenna **200**, **300**, **400**, and/or **500** as described below) is an antenna element of antenna array **110** of transmitter **102**. In some embodiments, a surface mount dielectric antenna **150** (e.g., antenna **200**, **300**, **400**, and/or **500** as described below) is an antenna element of antenna **124** of receiver **120**.

FIG. **2** is a block diagram of a surface mount dielectric antenna **150**, in accordance with some embodiments. In various embodiments, a surface mount dielectric antenna includes components as described with regard to surface mount dielectric antenna **200** with a solid dielectric resonator **202** (FIGS. **3**A-**3**B), surface mount dielectric antenna **300** with a hollow dielectric resonator **302** (FIG. **4**), a surface mount dielectric antenna with a patch array feed ("patch array feed dielectric antenna") **400** (FIG. **5**), and/or a surface mount dielectric antenna with a split ring feed ("split ring feed dielectric antenna") **500** (FIG. **7**). Surface mounting a dielectric resonator to a PCB improves device miniaturization, production speed, and lowers production costs by enabling mass assembly in less time (e.g., by soldering a dielectric resonator directly to a PCB).

In some embodiments, a surface mount dielectric antenna **150** includes a resonator **152**. For example, resonator **152** is a solid dielectric resonator, such as solid dielectric resonator **202** described with regard to FIG. **3**, or a resonator with a resonator cavity **153**, such as hollow dielectric resonator **302**, **402**, or **502** described with regard to FIGS. **4**, **5**, and **7**, respectively.

A resonator **152** as described herein is fabricated, in accordance with some embodiments, from a material that is configured to resonate for transmission and/or absorption of electromagnetic radiation. For example, resonator **152** is fabricated from silicon and/or silicon dioxide. In some embodiments, resonator **152** is fabricated from a dielectric material that has a dielectric constant between 1 and 40. In some embodiments, resonator **152** is fabricated from material capable of insulating, reflecting, and/or absorbing electrical current, or otherwise housing one or more electrical channels. In some embodiments, at least one of the magnetic permeability and electrical permittivity properties is selected based upon a predetermined power-transfer requirement and/or compliance constraint (e.g., to satisfy one or more government regulations, such as exposure limits established by FCC regulations).

In some embodiments, resonator **152** is coupled to a base **158**, such as a printed circuit board (PCB) (e.g., PCB **204**, PCB **310**, PCB **408**, and/or PCB **514**) or a portion thereof. In some embodiments, a coupling between a surface mount dielectric antenna and a PCB includes a mounting element **168** (e.g., mounting platform **206** and/or one or more legs **308**). In some embodiments, resonator **152** is mounted directly to base **158** (e.g., via solder, glue, or other surface mounting materials). In some embodiments, additional components such as one or more electronic components (e.g., capacitors, inductors, and/or integrated circuits) are mounted (e.g., surface mounted) to base **158**.

In some embodiments, base **158** includes a feed **160**. Feed **160** is, e.g., a dipole element **162** (e.g., one or more dipole elements **208**, **306**), patch array feed **164** (e.g., a plurality of patches **406**), and/or a split ring feed **166** (e.g., split ring feed

506). It will be recognized that alternative feeds (e.g., any radiating element that excites a field in a resonator **152**) may be used.

In some embodiments, feed **160** is electronically coupled to resonator **152**. In some embodiments, feed **160** transmits signals (e.g., signals generated by a processor **104** using a waveform generator or other signal source) to resonator **152**, thereby causing the dielectric resonator to resonate. For example, a surface mount dielectric antenna **150** that is a component of antenna array **110** of a transmitter **102** transmits electromagnetic waves (e.g., power waves **116**) by causing resonation of resonator **152**. In some embodiments, surface mount dielectric antenna **150** receives electromagnetic waves and feed **160** receives signals from resonator **152** (e.g., when surface mount dielectric antenna **150** is included as an antenna **124** of receiver **120**). In some embodiments, surface mount dielectric antenna **150** transmits and receives electromagnetic waves. In some embodiments, multiple resonators **152** are mounted to a single base **158**. In some embodiments, a feed **160** is electronically coupled to one or more signal sources, such as one or more outputs of processor **104**, a tuner or a coupler. In some embodiments, one or more elements of feed **160** (e.g., one or more dipole elements **162**, one or more patches **406** of patch array **164**, and/or one or more excitation slots **508** of split ring feed **166**) are electronically coupled to an integrated circuit that manages the transmission/reception of electromagnetic waves by surface mount dielectric antenna **150**. In some embodiments, one or more elements of feed **160** are coupled to one or more transmission lines (e.g., a copper trace) of base **158**.

In some embodiments, feed **160** is fabricated from a metal (e.g., copper). In some embodiments, feed **160** is fabricated from a synthetic material engineered for magnetic permeability and/or electrical permittivity properties (e.g., negative permittivity and/or negative permeability), such as a metamaterial.

In some embodiments, the configuration (e.g., dimensions, material, layout, shape and/or effective length) of the one or more dipole elements **162** is selected to produce desired impedance matching characteristics (e.g., for impedance matching with feed **160** and/or the resonator **152**) and/or bandwidth characteristics. In some embodiments, one or more dipole elements **162** are fabricated from plastic, ceramic, metal (e.g., steel, copper, copper alloy, and/or other metal), and/or a composite material. For example, one or more dipole elements **162** are fabricated from stamped metal. In some embodiments, a mounting element **160** and one or more dipole elements **162** are fabricated (e.g., molded) as a single element. In some embodiments, a mounting element **160** isolates at least a portion of the one or more dipole elements **162** from a base **158** by providing space between at least a portion of the one or more dipole elements **208** and the PCB **204**.

Various design aspects of surface mount dielectric antenna **150**, such as the dimensions of the resonator **152** (e.g., cross-sectional area and height of the resonator **152**), hollow or solid resonator design, size and shape of dipoles **162**, one or more dimensions of base **158** (e.g., the cross-sectional area height of the base **158**), size and arrangement of patches on base **158**, and/or size and arrangement of split-ring contacts on base **158** are selected (e.g., optimized using a cost function) for obtaining desired antenna characteristics. Antenna characteristics that vary based on the above design aspects include, e.g., size, weight, cost, fabrication efficiency, radiation efficiency, isolation between adjacent surface mount dielectric antennas **150** in an antenna array, impedance matching (e.g., between resonator **152** and feed **160**), and/or frequency range (for transmission and/or reception of electromagnetic waves by the antenna).

In some embodiments, an array of surface mount dielectric resonator antennas (e.g., antennas **200**, **300**, **400**, and/or **500**) are mounted onto a single base **158**. For example, an array of 16 (e.g., 4×4), 64 (e.g., 8×8) or 100 (e.g., 10×10) antennas are mounted to a base **158**. In some embodiments, an array of surface mount dielectric antennas **150** includes multiple types of antennas (e.g., patch array feed dielectric antenna **400** and a split ring feed dielectric antenna **500** are mounted on the same base **158**). In some embodiments, resonators **152** and feeds **160** are mounted in various patterns among capacitors, resistors, inductors, and/or integrated circuits on a base **158**. In some embodiments, a surface mount dielectric resonator antenna **150** is connected to one or more other antennas by way of a transmission line (e.g., transmission line **210**, **312**).

In some embodiments, a frequency at which surface mount dielectric antenna **150** transmits and/or receives electromagnetic waves varies based on a length (x-axis dimension), width (y-axis dimension) and/or height (z-axis dimension) of resonator **152**.

In some embodiments, a surface mount dielectric antenna **150** that has a resonator **152** with a height (a distance between upper edge **313** and lower edge **316**, as shown in FIG. **3**) of approximately 25.4 mm transmits and/or receives electromagnetic waves within a frequency range that includes 5.8 GHz. In some embodiments, a surface mount dielectric antenna **150** that has a resonator **152** with a height of approximately 50.8 mm transmits and/or receives electromagnetic waves within a frequency range that includes 900 MHz.

In some embodiments, a surface mount dielectric antenna **150** as described herein has dimensions of $\lambda/8$ or smaller, where λ, is a wavelength that corresponds to a frequency of electromagnetic waves transmitted by the antenna **150**. For example, a surface mount dielectric antenna **150** with x-axis and y-axis dimensions of 40 mm×40 mm transmits and/or receives electromagnetic waves within a frequency range that includes 900 MHz.

Turning now to FIGS. **3A-8**, various embodiments and features of the antenna **150** are illustrated therein and described below. The antennas **200**, **300**, **400**, and **500** are non-limiting example embodiments of the antenna **150**. As will be apparent to one of skill in the art, the various features and configurations of each of the antennas **200**, **300**, **400**, and **500** may be combined or substituted in various ways to produce a variety of additional embodiments of the antenna **150** (e.g., various configurations of the antenna **150** may include solid or at least partially hollow dielectric resonators, and may also include different types of feed elements, including a dipole element, patch array feed element, and/or split ring feed element). In some embodiments, an array of antennas **150** may include different types/configurations of individual antennas **150**. For example, an array of antennas **150** includes individual antennas **150** arranged in a linear configuration, a planar configuration, or a non-planar (e.g., cylindrical array) configuration.

FIGS. **3A-3B** illustrate a surface mount dielectric antenna **200** with a solid dielectric resonator **202**, in accordance with some embodiments. FIG. **3A** illustrates a top view of surface mount dielectric antenna **200** with a solid dielectric resonator **202** and FIG. **3B** illustrates a perspective view of surface mount dielectric antenna **200** with a solid dielectric resonator **202**.

In some embodiments, solid dielectric resonator **202** is coupled to a mounting platform **206** that is mounted on a PCB **204**. In some embodiments, mounting platform **206** includes one or more legs **207** that separate mounting platform **206** from PCB **204**. In some embodiments, mounting platform **206** is omitted and solid dielectric resonator **202** is mounted directly to PCB **204**. Mounting platform **206** may be fabricated from, e.g., plastic, ceramic, a composite material, and/or metal. In some embodiments, mounting platform **206** is fabricated (e.g., molded) as a single element.

In some embodiments, mounting platform **206** is a ground for surface mount dielectric resonator antennas **200**. In some embodiments, one or more characteristics of mounting platform **206** (e.g., a shape and/or one or more dimensions of mounting platform **206**) are selected to produce desired impedance matching characteristics and/or bandwidth characteristics. In some embodiments, mounting platform **206** isolates the one or more dipole elements **208** from PCB **204**.

In some embodiments, PCB **204** includes one or more transmission lines **210** (e.g., a copper trace). In some embodiments, a transmission line **210** transmits signals (e.g., signals received from a processor **104**) to solid dielectric resonator **202**, thereby causing solid dielectric resonator **202** to resonate. In some embodiments, a transmission line **210** conducts signals from solid dielectric resonator **202** (e.g., when a surface mount dielectric antenna **200** with a solid dielectric resonator **202** is included in an antenna **124** of receiver **120**). In some embodiments, the transmission line **210** forms a meandered line pattern on a surface of the PCB (as shown in FIGS. **3**A-**3**B).

Surface mount dielectric antenna **200** includes one or more dipole elements **208**. For example, the one or more dipole elements **208** couple transmission line **210** to solid dielectric resonator **202**. In some embodiments, the one or more dipole elements **208** are radiating feeding dipoles. In some embodiments, one or more dipoles **208** have a "meandering line" feature (e.g., the S-shape and reverse-S-shape visible in FIG. **3**B for dipole elements **208***a*, **208***b*) that increases the effective length of the dipole element. In some embodiments, one or more characteristics of a dipole element **208** (e.g., dipole element **208***a*, **208***b*), such as the effective length of the dipole elements **208**, is selected to produce desired impedance matching characteristics (e.g., for impedance matching with transmission line **210** and/or solid dielectric resonator **202**). In some embodiments, characteristics (such as a shape and/or one or more dimensions) of the one or more dipole elements **208**, mounting platform **206**, and/or solid dielectric resonator **202** are selected based on a targeted power transfer requirement (e.g., to ensure that 80% or more of transmitted energy is received by the one or more electronic devices **122**).

In some embodiments, surface mount dielectric antenna **200** includes a plurality of vias **212** located at or near the edge of PCB **204**. In some embodiments, the plurality of vias **212** partial or fully surround solid dielectric resonator **202**. In some embodiments, the plurality of vias **212** provides grounding and isolates the surface mount dielectric antenna **200** from any adjacent antennas. The number and/or density of vias **212** may vary from the illustrative example of FIGS. **3**A-**3**B. In some embodiments, multiple solid dielectric resonators **202** (or other dielectric resonators, such as hollow dielectric resonators **302**) are mounted on a single PCB **204**, and vias **212** are configured to surround each solid dielectric resonator **202** on the PCB **204**.

FIG. **4** illustrates a surface mount dielectric antenna **300** with a hollow dielectric resonator **302**, in accordance with some embodiments.

Hollow dielectric resonator **302** includes a cavity **304**. In comparison with a solid dielectric resonator **202**, a hollow dielectric resonator **302** of the same dimensions has a lower weight (e.g., while providing an acceptable receiving and/or transmitting frequency range). The reduced weight of surface mount dielectric antenna **300** due to the lower weight of hollow dielectric resonator **302** reduces the weight of a transmitter **102** and/or receiver **120** that includes one or more hollow dielectric resonator antennas **300**. The reduced weight advantageously allows for increased portability of a device that includes the hollow dielectric resonator antennas **300** in lieu of larger and/or heavier antennas. In some embodiments, in comparison with a solid dielectric resonator **202**, a hollow dielectric resonator **302** of the same dimensions has a weight that is reduced by at least 30%.

In some embodiments, cavity **304** is formed in hollow dielectric resonator **302** at the time at which hollow dielectric resonator **302** is fabricated (e.g., hollow dielectric resonator **302** is molded such that cavity **304** is present in hollow dielectric resonator **302**). In some embodiments, cavity **304** is formed in hollow dielectric resonator **302** by mechanically removing a portion of material from a solid dielectric element. In some embodiments, cavity **304** extends from an upper edge **313** of hollow dielectric resonator **302** to a lower edge **316** of hollow dielectric resonator **302**. In some embodiments, cavity **304** extends from an upper edge **313** of hollow dielectric resonator **302** to a location that is partway between lower edge **316** of hollow dielectric resonator **302** and upper edge **313** of hollow dielectric resonator **302** (see, e.g., hollow dielectric resonator **402**, FIG. **5** and hollow dielectric resonator **502**, FIG. **7**). In some embodiments, the volume of cavity **304** relative to the volume of hollow dielectric resonator **302** increases as the required gain of surface mount dielectric antenna **300** increases. In some embodiments, a cross-sectional profile of cavity **304** is, e.g., square, circular, and/or polygonal. In some embodiments, cavity **304** has a hexahedronal or cylindrical shape.

In some embodiments, hollow dielectric resonator **302** is coupled to one or more legs **308** that are coupled to (e.g., soldered to) a PCB **310**. In some embodiments, the one or more legs **308** are omitted and hollow dielectric resonator **302** is mounted directly to PCB **310**. The one or more legs **308** are fabricated from, e.g., plastic, ceramic, a composite material, and/or metal. In some embodiments, legs **308** isolate the one or more dipole elements **306** from PCB **310** by providing space between the one or more dipole elements **306** and the PCB **310**.

In some embodiments, PCB **310** includes one or more transmission lines **312** (e.g., a copper trace). In some embodiments, a transmission line **312** conducts/transmits signals (e.g., signals received from a processor **104**) to hollow dielectric resonator **302**, thereby causing hollow dielectric resonator **302** to resonate. In some embodiments, a transmission line **312** receives signals from hollow dielectric resonator **302** (e.g., when a surface mount dielectric antenna **300** with a hollow dielectric resonator **302** is included in an antenna **124** of receiver **120**). As shown in FIG. **4**, in some embodiments of the antenna **300**, the one or more transmission lines **312** form a meandered line pattern on a surface of the PCB.

In some embodiments, surface mount dielectric antenna **300** includes one or more dipole elements **306**. For example, the one or more dipole elements **306** electronically couple transmission line **312** to hollow dielectric resonator **302**. In some embodiments, dipole elements **306** include properties as described with regard to dipole elements **208** (e.g., the

dipole elements **306** have a meandering line feature, which is discussed in more detail above in reference to FIG. **3**B).

In some embodiments, surface mount dielectric antenna **300** includes a plurality of vias **314** located at or near the edge of PCB **310**. In some embodiments, the plurality of vias **314** partial or fully surround hollow dielectric resonator **302**. The plurality of vias **314** provides grounding and isolates the surface mount dielectric antenna **300** from any adjacent antennas.

FIG. **5** illustrates a patch array feed dielectric antenna **400**, in accordance with some embodiments. In some embodiments, patch array feed dielectric antenna **400** includes a hollow dielectric resonator **402** coupled to a PCB **408**. A plurality of patches **406** are coupled to upper surface **414** of PCB **408**.

Each patch **406** is electronically coupled to a via **405** that passes through PCB **408**. The combination of a patch **406** and via **405** is referred to as a "mushroom antenna element." Lower surface **412** of PCB **408** includes a ground plane **412**. In some embodiments, each patch **406** receives a signal carried by via **405**.

In some embodiments, each patch of the plurality of patches **406** are fabricated from a metal (e.g., copper). In some embodiments, each patch of the plurality of patches **406** is fabricated from a metamaterial.

In some embodiments, the array of patches **406** is a uniformly spaced array of patches **406** (e.g., the size of each patch **406** is the same and/or the spacing between adjacent patches **406** in the plurality of patches **406** is the same). In some embodiments, at least one patch **406** has a rectangular (e.g., square) shape. In some embodiments, the patches **406** of the array of patches **406** are arranged in a non-uniform or random pattern. FIGS. **6**A-**6**B show alternative configurations of patches **406** on PCB **408**. In some embodiments, patch array feed dielectric antenna **400** includes a slot antenna (e.g., on ground plane **412**).

In some embodiments, the plurality of patches **406** control a field and/or aperture of electromagnetic transmissions by patch array feed dielectric antenna **400**, e.g., to meet power transmission requirements. In some embodiments, adjustments to the size and/or spacing of patches **406** on PCB **408** cause adjustments to filter, radiation efficiency, and/or isolation characteristics of patch array feed dielectric antenna **400**. For example, a range of frequencies at which patch array feed dielectric antenna **400** is able to transmit and/or receive electromagnetic waves is related to characteristics of the patch array such as the size of the surface area of one or more of the patches **406**.

In some embodiments, hollow dielectric substrate **402** is mounted on (e.g., soldered to) a PCB **408** (e.g., such that hollow dielectric substrate **402** is in contact with at least a subset of the plurality of patches **406**. In some embodiments, hollow dielectric substrate **402** has any of the properties described above with regard to hollow dielectric resonator **302** as described with regard to FIG. **3**. In some embodiments, cavity **404** has any of the properties of cavity **304** as described with regard to FIG. **4**. Although the example in FIG. **5** shows patch array feed dielectric antenna **400** including a hollow dielectric resonator **402**, in some embodiments, patch array feed dielectric antenna **400** includes a solid dielectric resonator (such as that described above in reference to FIGS. **3**A-**3**B).

FIGS. **6**A-**6**B show illustrative configurations of the plurality of patches **406** of patch array feed dielectric antenna **400**, in accordance with some embodiments.

In some embodiments, a first patch **406** on PCB **408** (e.g., patch **406***a*) has a first size (e.g., cross-sectional area) that is different from a second size of a second patch **406** (e.g., patch **406***b*) on PCB **408**. For example, in FIG. **6**A first patch **406***a* that is at or near the center of PCB **408** (and/or at or near the center of hollow dielectric resonator **402**) has a larger cross-sectional area than a second patch **406***b* that is adjacent to edge of PCB **408** (and/or at or near the edge of hollow dielectric resonator **402**). This configuration of respective patches of a smaller size surrounding a patch of a larger size helps to "trap" electromagnetic radiation by preventing that radiation from expanding beyond the area of the plurality of patches **406**.

In FIG. **6**B, a set of patches (e.g., including patch **406***c* that is near an edge of PCB **408** (and/or near the edge of hollow dielectric resonator **402**) has a smaller area than a set of patches (e.g., including patch **406***d*) that is at and/or near the center of PCB **408** (and/or at or near the center of hollow dielectric resonator **402**). Increasing the distance between the patches near that edge of PCB **408**, such as patch **406***c*, and patches that are near the edge of PCB **408**, such as patch **406***d*, provides increased isolation when signals are transmitted by adjacent antennas in an antenna array (e.g., when patch array feed dielectric antenna **400** that includes patches configured as shown in FIG. **6**B transmits a signal that signal radiates outward without as much leaking to an adjacent antenna in an array of which the antenna **400** is a component).

In some embodiments, gaps between adjacent patches **406** on a PCB **408** are uniformly sized. In some embodiments, gaps between adjacent patches **406** on a PCB **408** are non-uniformly sized. For example, in some embodiments, a first gap size (e.g., the first gap size is illustrated as gap size **600** in FIG. **6**B) between a first set of adjacent patches **406***c* on PCB **408** is different from a second gap size (e.g., the second gap size is illustrated as at gap size **602** in FIG. **6**B) between a second set of adjacent patches **406***d* on PCB **408**.

FIG. **7** illustrates a split ring feed dielectric antenna **500**, in accordance with some embodiments. In some embodiments, a split ring feed dielectric antenna **500** includes a hollow dielectric resonator **502** (e.g., with a cavity **504**), split ring feed **506**, one or more excitation slots **508** (e.g., **508***a* and **508***b*) and/or one or more contacts **510** (e.g., **510***a* and **510***b*). In some embodiments, split ring feed dielectric antenna **500** is mounted on (e.g., soldered to) a PCB **514**.

In some embodiments, split ring feed dielectric antenna **500** includes two contacts **510***a* and **510***b*, separated by dielectric substrate **516**. In some embodiments, the dielectric substrate **516** is the surface of PCB **514**. In some embodiments, contact **510***a* and/or contact **510***b* is fabricated from a metal, such as copper. In some embodiments, In some embodiments, contact **510***a* and/or contact **510***b* is fabricated from a metamaterial. In some embodiments, the two excitation slots **508***a* and **508***b* include vias that connect the bottom of PCB **514** to the hollow dielectric resonator **502** for excitation of contacts **510***a* and **510***b*. In some embodiments, a via of first excitation slot **508***a* excites a first contact **510***a* using a first signal and a via of second excitation slot **508***b* excites a second contact **510***b* using a second signal that is distinct from the first signal (e.g., the amplitude and/or phase of the first signal differs from the amplitude and/or phase of the second signal). In some embodiments, a via of first excitation slot **508***a* excites a first contact **510***a* in a first magnetic polarity and a via of second excitation slot **508***b* excites a second contact **510***b* in a second magnetic polarity that is opposite to the first magnetic polarity.

In some embodiments, hollow dielectric substrate **502** has any of the properties described above with regard to hollow dielectric resonator **302** as described with regard to FIG. **4**.

In some embodiments, cavity **504** has any of the properties of cavity **304** as described with regard to FIG. **4**. Although in FIG. **7**, split ring feed dielectric antenna **500** is shown including a hollow dielectric resonator **502**, in some embodiments, split ring feed dielectric antenna **500** may include a solid dielectric resonator (such as that described above in reference to FIGS. **3**A-**3**B).

FIG. **8** illustrates a y-axis dimension **802** (width) and an x-axis dimension **804** (length) of base **158** of a surface mount dielectric antenna **150**, in accordance with some embodiments. In some embodiments, one or more dimensions of surface mount dielectric antenna **150** are determined based on a target bandwidth of a signal transmitted by the antenna **150**. For example, in some embodiments, y-axis dimension **802** and/or x-axis dimension **804** is/are much smaller than a wavelength λ that corresponds to a target frequency (e.g., 900 MHz) of power waves transmitted by the surface mount dielectric antenna **150**. In some embodiments, the surface mount dielectric antenna **150** has a y-axis dimension **802** of less than or equal to 50.8 mm (e.g., 40 mm). In some embodiments, the surface mount dielectric antenna **150** has an x-axis dimension **804** of less than or equal to 50.8 mm (e.g., 40 mm). In some embodiments, multiple surface mount dielectric antennas **150** are mounted on a single PCB (e.g., PCB **204**, PCB **310**, PCB **408**, and/or PCB **514**). In some embodiments, the base **158** is a portion of the single PCB that corresponds to a single antenna element (e.g., a portion delineated by vias **212** or **314**, a portion that corresponds to a cross-sectional area of dielectric resonator **202** or **302**, a portion that corresponds to the set of patches **406** coupled to a single dielectric resonator **402**, and/or a portion that corresponds to a cross-sectional area of dielectric resonator **502**).

The preceding description of the disclosed embodiments is provided to enable any person skilled in the art to make or use the embodiments described herein and variations thereof. Various modifications to these embodiments will be readily apparent to those skilled in the art, and the generic principles defined herein may be applied to other embodiments without departing from the spirit or scope of the subject matter disclosed herein. Thus, the present disclosure is not intended to be limited to the embodiments shown herein but is to be accorded the widest scope consistent with the following claims and the principles and novel features disclosed herein.

Features of the present invention can be implemented in, using, or with the assistance of a computer program product, such as a storage medium (media) or computer readable storage medium (media) having instructions stored thereon/in which can be used to program a processing system to perform any of the features presented herein. The storage medium (e.g., memory **106**, **134**, and/or **142**) can include, but is not limited to, high-speed random access memory, such as DRAM, SRAM, DDR RAM or other random access solid state memory devices, and may include non-volatile memory, such as one or more magnetic disk storage devices, optical disk storage devices, flash memory devices, or other non-volatile solid state storage devices. Memory (e.g., **106**, **134**, and/or **142**) optionally includes one or more storage devices remotely located from the CPU(s) (e.g., processor(s) **104**, **132**, and/or **140**). Memory (e.g., **106**, **134**, and/or **142**), or alternatively the non-volatile memory device(s) within the memory, comprises a non-transitory computer readable storage medium.

Stored on any one of the machine readable medium (media), features of the present invention can be incorporated in software and/or firmware for controlling the hardware of a processing system (such as the components associated with the transmitters **102** and/or receivers **120**), and for enabling a processing system to interact with other mechanisms utilizing the results of the present invention. Such software or firmware may include, but is not limited to, application code, device drivers, operating systems, and execution environments/containers.

Communication systems as referred to herein (e.g., communications components **112**, **136**, and/or **144**) optionally communicate via wired and/or wireless communication connections. Communication systems optionally communicate with networks, such as the Internet, also referred to as the World Wide Web (WWW), an intranet and/or a wireless network, such as a cellular telephone network, a wireless local area network (LAN) and/or a metropolitan area network (MAN), and other devices by wireless communication. Wireless communication connections optionally use any of a plurality of communications standards, protocols and technologies, including but not limited to radio-frequency (RF), radio-frequency identification (RFID), infrared, radar, sound, Global System for Mobile Communications (GSM), Enhanced Data GSM Environment (EDGE), high-speed downlink packet access (HSDPA), high-speed uplink packet access (HSUPA), Evolution, Data-Only (EV-DO), HSPA, HSPA+, Dual-Cell HSPA (DC-HSPDA), long term evolution (LTE), near field communication (NFC), ZigBee, wideband code division multiple access (W-CDMA), code division multiple access (CDMA), time division multiple access (TDMA), Bluetooth, Wireless Fidelity (Wi-Fi) (e.g., IEEE 102.11a, IEEE 102.11ac, IEEE 102.11ax, IEEE 102.11b, IEEE 102.11g and/or IEEE 102.11n), voice over Internet Protocol (VoIP), Wi-MAX, a protocol for e-mail (e.g., Internet message access protocol (IMAP) and/or post office protocol (POP)), instant messaging (e.g., extensible messaging and presence protocol (XMPP), Session Initiation Protocol for Instant Messaging and Presence Leveraging Extensions (SIMPLE), Instant Messaging and Presence Service (IMPS)), and/or Short Message Service (SMS), or any other suitable communication protocol, including communication protocols not yet developed as of the filing date of this document.

It will be understood that, although the terms "first," "second," etc. may be used herein to describe various elements, these elements should not be limited by these terms. These terms are only used to distinguish one element from another.

The terminology used herein is for the purpose of describing particular embodiments only and is not intended to be limiting of the claims. As used in the description of the embodiments and the appended claims, the singular forms "a," "an" and "the" are intended to include the plural forms as well, unless the context clearly indicates otherwise. It will also be understood that the term "and/or" as used herein refers to and encompasses any and all possible combinations of one or more of the associated listed items. It will be further understood that the terms "comprises" and/or "comprising," when used in this specification, specify the presence of stated features, integers, steps, operations, elements, and/or components, but do not preclude the presence or addition of one or more other features, integers, steps, operations, elements, components, and/or groups thereof.

As used herein, the term "if" may be construed to mean "when" or "upon" or "in response to determining" or "in accordance with a determination" or "in response to detecting," that a stated condition precedent is true, depending on the context. Similarly, the phrase "if it is determined [that a stated condition precedent is true]" or "if [a stated condition

precedent is true]" or "when [a stated condition precedent is true]" may be construed to mean "upon determining" or "in response to determining" or "in accordance with a determination" or "upon detecting" or "in response to detecting" that the stated condition precedent is true, depending on the context.

The foregoing description, for purpose of explanation, has been described with reference to specific embodiments. However, the illustrative discussions above are not intended to be exhaustive or to limit the claims to the precise forms disclosed. Many modifications and variations are possible in view of the above teachings. The embodiments were chosen and described in order to best explain principles of operation and practical applications, to thereby enable others skilled in the art.

What is claimed is:

1. A wireless power transmission antenna comprising:
a printed circuit board (PCB) including a first transmission line that conducts a first power transmission signal;
a dielectric resonator that is:
mechanically coupled to the PCB, and
configured to radiate the first power transmission signal;
a first feed element that is:
electronically coupled to the first transmission line and to the dielectric resonator, and
configured to (i) receive the power transmission signal via the first transmission line and (ii) excite the dielectric resonator with the first power transmission signal; and
a plurality of patches, wherein:
each respective patch of the plurality of patches is electronically coupled to a respective via of a plurality of vias, the respective via passing through the PCB to couple the respective patch with a ground plane that is coupled to the first transmission line of the PCB; and
the first feed element is the plurality of patches.

2. The wireless power transmission antenna of claim **1**, wherein each patch of the plurality of patches is fabricated from a metamaterial.

3. The wireless power transmission antenna of claim **1**, wherein the plurality of patches are arranged in a uniformly spaced array.

4. The wireless power transmission antenna of claim **1**, wherein the plurality of patches include a first patch and a second patch, wherein the first patch has a first area and the second patch has a second area that is different from the first area.

5. The wireless power transmission antenna of claim **4**, wherein:
the first patch is adjacent to a center of the dielectric resonator; and
the second patch is adjacent to an edge of the dielectric resonator.

6. The wireless power transmission antenna of claim **5**, wherein:
a distance between the second patch and the edge of the dielectric resonator is configured to avoid interference between the transmission signal transmitted by the dielectric antenna and an adjacent transmission of an adjacent antenna.

7. The wireless power transmission antenna of claim **1**, wherein the wireless power transmission antenna transmits the first transmission signal to a receiver that uses energy from the transmission signal to power or charge an electronic device coupled with the receiver.

8. The wireless power transmission antenna of claim **1**, wherein a length of the wireless power transmission antenna is equal to or less than 40 mm.

9. The wireless power transmission antenna of claim **1**, wherein the dielectric resonator includes a solid dielectric material.

10. The wireless power transmission antenna of claim **1**, wherein the dielectric resonator includes a cavity.

11. The wireless power transmission antenna of claim **1**, wherein the wireless power transmission antenna is one of a plurality of wireless power transmission antennas mounted on the PCB.

12. A wireless power transmission antenna comprising:
a printed circuit board (PCB) including a first transmission line that conducts a first power transmission signal;
a dielectric resonator that is:
mechanically coupled to the PCB, and
configured to radiate the first power transmission signal;
a first feed element that is:
electronically coupled to the first transmission line and to the dielectric resonator, and
configured to (i) receive the power transmission signal via the first transmission line and (ii) excite the dielectric resonator with the first power transmission signal;
the first feed element includes a first contact;
a second transmission line that conducts a second power transmission signal;
the antenna includes a second feed element that includes a second contact, wherein the first contact is separated from the second contact by a dielectric substrate material that surrounds the first contact; and
the second feed element is configured to (i) receive the second power transmission signal via the second transmission line and (ii) excite the dielectric resonator with the second power transmission signal.

13. The wireless power transmission antenna of claim **12**, wherein the first feed element is a dipole element.

14. The wireless power transmission antenna of claim **13**, wherein:
the mechanical coupling of the dielectric resonator to the PCB includes a mounting platform that is coupled to the dielectric resonator and to the PCB; and
the mounting platform isolates at least a portion of the dipole element from the PCB.

15. The wireless power transmission antenna of claim **13**, wherein at least a portion of the dipole element includes a meandering line feature that increases the effective length of the dipole element.

16. The wireless power transmission antenna of claim **13**, wherein the PCB includes a plurality of vias that pass through the PCB.

17. The wireless power transmission antenna of claim **16**, wherein the plurality of vias at least partially surround the dielectric resonator.

18. The wireless power transmission antenna of claim **12**, wherein the first contact has a split ring shape.

19. The wireless power transmission antenna of claim **12**, wherein the wireless power transmission antenna transmits the first transmission signal to a receiver that uses energy from the transmission signal to power or charge an electronic device coupled with the receiver.

20. The wireless power transmission antenna of claim **12**, wherein a length of the wireless power transmission antenna is equal to or less than 40 mm.

21. The wireless power transmission antenna of claim **12**, wherein the dielectric resonator includes a solid dielectric material.

22. The wireless power transmission antenna of claim **12**, wherein the dielectric resonator includes a cavity.

23. The wireless power transmission antenna of claim **12**, wherein the wireless power transmission antenna is one of a plurality of wireless power transmission antennas mounted on the PCB.

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