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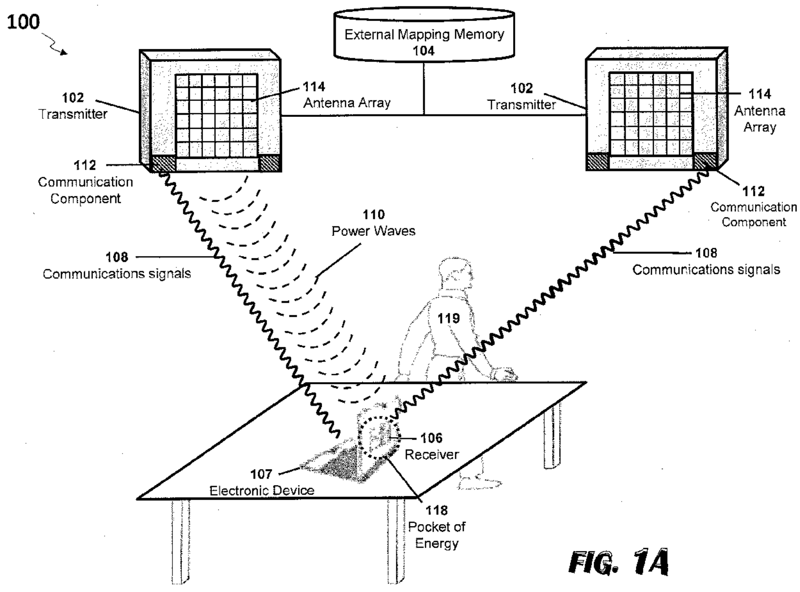

FIG. 1A

(57) Abstract: Embodiments disclosed herein may include a receiver configured to determine location data associated with one or more objects. The receiver transmits the location data associated with the one or more objects to a transmitter configured to transmit wireless power waves. The receiver then receives the wireless power waves transmitted by antennas of the transmitter having one or more characteristics, where the one or more characteristics are defined based on the location data by a processor of the transmitter.

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RADAR MOTION DETECTION USING STEPPED FREQUENCY IN WIRELESS POWER TRANSMISSION SYSTEM

TECHNICAL FIELD

[0001] This application generally relates to wireless charging systems and the hardware and software components used in such systems.

BACKGROUND

[0002] Numerous attempts have been made to wirelessly transmit energy to electronic devices, where a receiver can consume the transmission and convert it to electrical energy. However, most conventional techniques are unable to transmit energy at any meaningful distance. For example, magnetic resonance provides electric power to devices without requiring an electronic device to be wired to a power resonator. However, the electronic device is required to be proximately located to a coil of the power resonator (i.e., within a magnetic field). Other conventional solutions may not contemplate user mobility for users who are charging their mobile devices or such solutions do not allow devices to be outside of a narrow window of operability.

[0003] Wirelessly powering a remote electronic device requires a means for identifying the location of electronic devices within a transmission field of a power-transmitting device. Conventional systems typically attempt to proximately locate an electronic device, so there are no capabilities for identifying and mapping the spectrum of available devices to charge, for example, in a large coffee shop, household, office building, or other three-dimensional space in which electrical devices could potentially move around. Moreover, what is needed is a system for managing power wave production, both for directionality purposes and for power output modulation. Because many conventional systems do not contemplate a wide range of movement of the electronic devices they service, what is also needed is a means for dynamically and accurately tracking electronic devices that may be serviced by the power-transmitting devices.

[0004] Wireless power transmission may need to satisfy certain regulatory requirements. Devices transmitting wireless energy may be required to adhere to electromagnetic field (EMF) exposure protection standards for humans or other living beings. Maximum exposure limits are defined by US and European standards in terms of power density limits and electric field limits (as well as magnetic field limits). Some of these limits are established by the Federal Communications Commission (FCC) for Maximum

Permissible Exposure (MPE), and some limits are established by European regulators for radiation exposure. Limits established by the FCC for MPE are codified at 47 CFR § 1.1310. For electromagnetic field (EMF) frequencies in the microwave range, power density can be used to express an intensity of exposure. Power density is defined as power per unit area. For example, power density can be commonly expressed in terms of watts per square meter (W/m^2), milliwatts per square centimeter (mW/cm^2), or microwatts per square centimeter (II W/cm^2).

[0005] Accordingly, it is desirable to appropriately administer the systems and methods for wireless power transmission to satisfy these regulatory requirements. What is needed is a means for wireless power transmission that incorporates various safety techniques to ensure that humans or other living beings within a transmission field are not exposed to EMF energy near or above regulatory limits or other nominal limits.

SUMMARY

[0006] Disclosed herein are systems and methods intended to address the shortcomings in the art and these systems and methods may also provide additional or alternative advantages as well. Embodiments disclosed herein may generate and transmit power waves that, as result of appropriately selecting their physical waveform characteristics (e.g., frequency, amplitude, phase, gain, direction), converge at a predetermined location in a transmission field to generate a pocket of energy. Receivers associated with an electronic device being powered by the wireless charging system, may extract energy from these pockets of energy and then convert that energy into usable electric power for the electronic device associated with a receiver. The pockets of energy may manifest as a three-dimensional area of physical space within a transmission field of a transmitter device, where energy may be harvested by receivers positioned within or near a pocket of energy. A technique for identifying regions in the transmission field may be employed to determine where pockets of energy should be formed and where power waves should not be transmitted. In one example, this technique may result in determination of one or more objects in proximity to receivers by the receivers to let the transmitter know where the power waves should not be transmitted and null space shall instead be formed. In yet another example, sensors may generate sensor data that may identify the one or more objects that the power waves should avoid. This sensor data may be an additional or alternative form of data in comparison to location data associated to one or more objects

generated by the receivers, which may also be stored into a mapping memory for later reference or computation.

[0007] In some embodiments, a method of wireless power transmission includes generating, by a receiver, location data associated with one or more objects based upon one or more object detection signals reflected from the one or more objects and indicating a location of each respective object in relation to the receiver; transmitting, by the receiver, one or more communications signals including the location data to the transmitter; and receiving, by the receiver, from one or more antennas of the transmitter one or more power waves having one or more waveform characteristics, wherein the one or more waveform characteristics are based on the location data generated for each respective object.

[0008] In some embodiments, a method of wireless power transmission includes emitting, by a first antenna of a receiver, a plurality of outbound object detection signals, each respective object detection signal having a successively stepped frequency with respect to a preceding object detection signal; receiving, by a second antenna of the receiver, one or more inbound object detection signals that are reflected from one or more objects, and at least one inbound object detection signal is reflected from an object, and wherein the at least one inbound object detection signal indicates a location of the object in relation to the receiver; generating, by a processor of the receiver, location data associated with each respective object of the one or more objects based on the one or more inbound object detection signals; transmitting, by a communications component of the receiver, to a transmitter one or more communication signals containing the location data associated with each respective object of the one or more objects; and receiving, by a third antenna of the receiver, from the transmitter one or more power waves having one or more characteristics, and the one or more characteristics are based on the location data associated with each respective object of the one or more objects.

[0009] In some embodiments, a receiver in a wireless power transmission system comprises a first antenna configured to emit a plurality of outbound detection signals, each outbound detection signal having a successively stepped frequency; a second antenna configured to receive a plurality of inbound detection signals reflected from one or more objects, and one or more detection signals are reflected from an object; a processor configured to generate location data associated with a respective object of the one or more objects based on the one or more inbound detection signals reflected from the respective object, and the location data of the respective object indicates the location of the respective object in relation to the receiver; a communications component configured to transmit to the transmitter communications signals including the location data associated with each respective object of the one or more objects; and a third antenna configured to receive from the transmitter one or more power waves having one or more characteristics causing the one or more power waves to converge at a location proximate to the receiver based on the location data associated with the one or more objects.

[0010] It is to be understood that both the foregoing general description and the following detailed description are exemplary and explanatory and are intended to provide further explanation of the invention as claimed.

BRIEF DESCRIPTION OF THE DRAWINGS

[0011] The accompanying drawings constitute a part of this specification and illustrate embodiments of the invention. The present disclosure can be better understood by referring to the following figures. The components in the figures are not necessarily to scale, emphasis instead being placed upon illustrating the principles of the disclosure.

[0012] **FIG. 1A** shows components of a wireless power transmission system, according to an exemplary embodiment.

[0013] **FIG. 1B** shows components of a receiver of a wireless power transmission system, according to an exemplary embodiment.

[0014] **FIG. 2** shows a method of transmission of power waves in a wireless power transmission system, according to an exemplary embodiment.

[0015] **FIG. 3** shows a method of transmission of power waves in a wireless power transmission system, according to an exemplary embodiment.

DETAILED DESCRIPTION

[0016] Reference will now be made to the exemplary embodiments illustrated in the drawings, and specific language will be used here to describe the same. It should be understood that no limitation of the scope of the invention is intended through the descriptions of such exemplary embodiments. Alterations and further modifications of the exemplary embodiments and additional applications implementing the principles of the inventive features, which would occur to a person skilled in the relevant art and having possession of this disclosure, are to be considered within the scope of this disclosure.

[0017] **FIG. 1A** shows components of an exemplary wireless power transmission system **100**. The exemplary system **100** may include transmitters **102,** an external mapping memory **104,** a receiver **106,** and an electronic device **107** to be charged. The transmitters **102** may send various types of waves such as communication signals **108** and power waves **110,** into a transmission field, which may be a two or three-dimensional space into which the transmitters **102** may transmit the power waves **110.**

[0018] The transmitters **102** may transmit the power waves **110,** which may be captured by the receiver **106** that is configured to convert energy from the power waves **110** into electrical energy, for the electronic device **107** associated with the receiver **106**. The receiver **106** may include circuitry that may convert the captured power waves **110** into a useable source of electrical energy on behalf of the electronic device **107** associated with the receiver **106**. In some embodiments, the transmitters **102** may intelligently transmit the power waves **110** into a transmission field of the transmitters **102** by manipulating characteristics of the power waves **110** (e.g., phase, gain, direction, frequency) based on location associated to one or more objects such as humans **119** with respect to the receiver **106** and/or the transmitters **102**. In some implementations, the transmitters **102** may manipulate the characteristics of the power waves **110** so that trajectories of the power waves **110** cause the power waves **110** to converge at a predetermined location within a transmission field (e.g., a 3D location or region in space), resulting in constructive or destructive interference.

[0019] The transmitters **102** each may comprise or be associated with one or more respective transmitter processors (not shown), a respective communications component **112,** and a respective antenna array **114.**

[0020] The one or more transmitter processors may control, manage, and otherwise govern the various processes, functions, and components of the transmitters **102**. The one or more transmitter processors may be configured to process and communicate various types of data (e.g., location data associated with the receiver **106,** location data associated with the one or more objects such as humans **119).** Additionally or alternatively, a transmitter processor of the transmitters **102** may manage execution of various processes and functions of the transmitters **102**, and may manage the components of the transmitters **102**. For example, the one or more transmitter processors may determine an interval at which a beacon signal may be broadcast by a communication component **112** to identify the receiver **106** that may be present within the transmission field.

[0021] The communications component **112** may effectuate wired and/or wireless communications to and from the receiver **106** of the system **100**. In some cases, the communication component **112** may be an embedded component of the transmitter **102;** and, in some cases, the communication component **112** may be attached to the transmitter **102** through any wired or wireless communications medium. The communication component **112** may comprise electromechanical components (e.g., processor, antenna) that allow the communications component **112** to communicate various types of data with one or more receivers **106** via the communications signals **108**. In some implementations, the communications signals **108** may represent a distinct channel for hosting communications, independent from the power waves **110**. The data may be communicated using the communications signals **108**, based on predetermined wired or wireless protocols and associated hardware and software technology. The communications component **112** may operate based on any number of communication protocols, such as Bluetooth®, Wireless Fidelity (Wi-Fi), Near-Field Communications (NFC), ZigBee, and others.

[0022] The data included within the communications signals **108**, for example, may include location data associated with one or more sensitive objects, such as humans **119** received by the receiver **106**, and may be used by the one or more transmitter processors to determine how the transmitter **102** may transmit safe and effective power waves **110**. In some embodiments, the transmitter **102** may transmit safe and effective power waves **110** that generate a pocket of energy **118**, from which the receiver **106** may capture energy and convert it to useable alternating current (AC) or direct current (DC) electricity. Using the communications signal **108,** the transmitters **102** may communicate data that may be used to, *e.g.*, identify the receiver **106** within the transmission field, determine whether the electronic device **107** or users are authorized to receive wireless charging services from the system **100,** determine safe and effective waveform characteristics for the power waves **110,** and hone the placement of the pocket of energy **118,** among other possible functions. As an example, the communications component **112** of the transmitter **102** may communicate (i.e., send and receive) different types of data containing various types of information. Non-limiting examples of the information may include a beacon message, a transmitter identifier (TX ID), a device identifier (device ID) for an electronic device **107**, a user identifier (user ID), the battery level for the device **107**, the receiver **106**'s location in the transmission field, the objects **120** location in the transmission field, and other such information.

[0023] Similarly, a communications component (shown in **FIG. 1B)** of the receiver **106** may use the communications signal **108** to communicate data that may be used to, *e.g.*, alert transmitters **102** that the receiver **106** has entered, or is about to enter, the transmission field, provide the location data generated that is associated with the one or more sensitive objects such as humans **119**, provide information about the electronic device **107** being charged by the receiver **103**, indicate effectiveness of the power waves **110**, and provide updated transmission parameters that the transmitters **102** may use to adjust the power waves **110**, as well as other types of useful data.

[0024] In some embodiments, the antenna array **114** of the transmitters **102**, which may be a set of one or more antennas, is configured to transmit the power waves **110**. In some embodiments, the antenna array **114** may comprise one or more antennas, which may be configurable "tiles" comprising an antenna and zero or more integrated circuits controlling the behavior of the antenna, such as generating the power waves **110** having predetermined characteristics (e.g., amplitude, frequency, trajectory, phase). An antenna of the antenna array **114** may transmit a series of the power waves **110** having the predetermined characteristics, such that the series of the power waves **110** arrive at a given location within the transmission field, and exhibit those characteristics. Taken together, the antennas of the antenna array **114** may transmit the power waves **110** that intersect at the given location (usually where the receiver **106** is detected) and, due to their respective characteristics, form the pocket of energy **118** from which the receiver **106** may collect energy and generate usable power. It should be appreciated that, although the exemplary system **100** describes radio-frequency based power waves **110,** additional or alternative transmitting arrays or elements and/or wave-based technologies may be used (e.g., ultrasonic, infrared, magnetic resonance) to wirelessly transmit power from the transmitter **102** to the receiver **106**.

[0025] The transmitters **102** may use data corresponding to the location data of the receiver **106** and the object, such as a human **119,** in the transmission field to determine where and how the antenna array **114** should transmit the power waves **110**. The location data of the receiver **106** and the object such as human **119** may indicate for each respective transmitter **102** where the power waves **110** should be transmitted and the pockets of energy **118** should be formed, and, in some cases, where the power waves **110** should not be transmitted. The location data may be interpreted by processors associated with the respective transmitter **102**, from which the respective transmitter **102** may determine how one or more antennas of the antenna array **114** should form and transmit the power waves **110**. When determining how the power waves should be formed, the respective transmitter **102** determines waveform characteristics for each of the power waves **110** to be transmitted from each of the respective antennas of the antenna array **114**. Non-limiting examples of waveform characteristics for the power waves **110** may include: amplitude, phase, gain, frequency, and direction, among others.

[0026] In one example, to generate the pocket of energy **118** at a particular location, the respective transmitter **102** identifies a subset of one or more antennas from the antenna array **114** that sends the power waves **110** to transmit power to the predetermined location, and then the transmitter **102** generates the power waves **110** such that the power waves **110** transmitted from each antenna of the subset have comparatively different characteristics (e.g., phase, frequency, amplitude). In this example, a waveform-generating integrated circuit (not shown) of the transmitter **102** can form a phased array of delayed versions of the power waves **110,** apply different amplitudes to the delayed versions of the power waves **110**, and then transmit the power waves **110** from appropriate antennas. In another example, to generate the null space at a particular location of the object **119,** the transmitter **102** identifies a subset of antennas from the antenna array **114** and sends the power waves **110** that converge at a location of the object **119** such that their respective waveform characteristics destructively interfere with each other (i.e., waveforms cancel each other out), thereby diminishing the amount of energy concentrated at a location of the object **119**.

[0027] Although the exemplary embodiments described herein mention the use of RF-based wave transmission technologies, it should be appreciated that the wireless charging techniques that might be employed are not be limited to such RF-based technologies and techniques. Rather, it should be appreciated that there are additional or alternative wireless charging techniques, which may include any number of technologies and techniques for wirelessly transmitting energy to a receiver that is capable of converting the transmitted energy to electrical power. Non-limiting exemplary transmission techniques for energy that can be converted by a receiving device into electrical power may include: ultrasound, microwave, laser light, infrared, or other forms of electromagnetic energy.

[0028] In some embodiments, control systems of transmitters **102** adhere to electromagnetic field (EMF) exposure protection standards for human subjects. Maximum exposure limits are defined by US and European standards in terms of power density limits and electric field limits (as well as magnetic field limits). These include, for example, limits established by the Federal Communications Commission (FCC) for MPE, and limits established by European regulators for radiation exposure. Limits established by the FCC for MPE are codified at 47 CFR § 1.1310. For electromagnetic field (EMF) frequencies in the microwave range, power density can be used to express an intensity of exposure. Power density is defined as power per unit area. For example, power density can be commonly expressed in terms of watts per square meter (W/m2), milliwatts per square centimeter (μW/cm2), or microwatts per square centimeter (μW/cm2).

[0029] In some embodiments, the present systems and methods for wireless power transmission **100** incorporate various safety techniques to ensure that human occupants in or near a transmission field are not exposed to EMF energy near or above regulatory limits or other nominal limits. One safety method is to include a margin of error (e.g., about 10% to 20%) beyond the nominal limits, so that human subjects are not exposed to power levels at or near the EMF exposure limits. A second safety method can provide staged protection measures, such as reduction or termination of wireless power transmission if humans (and in some embodiments, other living beings or sensitive objects) move toward a pocket of energy with power density levels exceeding EMF exposure limits.

[0030] **FIG. 1B** shows components of the receiver **106** of the wireless power transmission system **100**, which identifies human subjects to ensure that human occupants are not exposed to power waves near or above regulatory limits or other nominal limits. **FIG. 1B** will now be described in conjunction with **FIG. 1A**. The receiver **106** may be used for powering or charging an associated electronic device, which may be the electronic device **107** coupled to or integrated with the receiver **106**. In an embodiment, the receiver **106** may include a housing. The housing can be made of any material that may allow for object detection signals, communication signals, or power waves transmission and/or reception. The housing may include antennas **120** of various types, a processor **122,** a signal generator **124,** a communications component **126,** and a memory **128.**

[0031] The antennas **120** may comprise one or more object detection antennas. Object detection antennas may emit a plurality of outbound object detection signals and then receive one or more inbound object detection signals. In some embodiments, the antennas **120** may include a set of one or more object detection antennas configured to transmit outbound object detection signals, and another, separate set of object detection antennas configured to receive inbound object detection signals. The antennas **120** may further include a set of power antennas configured to receive one or more power waves from a transmitter.

Still other antennas may be configured to receive data or communications signals and/or waves. The antennas for sending and receiving object detection signals, antennas for reception of power waves, and antennas for sending and receiving communication signals may be tuned to the same frequency or different frequencies.

[0032] The receiver **106** may include a plurality of PCB layers, which may include all the antennas **120** that transmit and receive object detection signals that are utilized for determining the location of the one or more objects, such as a human being **119**. PCBs may be single sided, double sided, and/or multi-layer. The PCB layers may be connected to the processor **122** and/or to dedicated microprocessors.

[0033] In some implementations, the receiver **106** includes a plurality of PCB layers that may include the antennas **120** for detecting reflected signals from the object, such as a human **119**. Furthermore, the range of the object detection signals may be increased by the receiver **106** by including a higher density of the antennas **120**. The PCB layers may be connected to the processor **122** and/or to dedicated microcontrollers for each antenna.

[0034] The receiver **106** may comprise a signal generator **124**, a Digital to Analog (D/A) convertor, a power amplifier, and one or more filters. The signal generator **124** of the receiver **106** may be configured to generate object detection signals of various types, such as tones waves, chirp signals, sinusoidal waves, and the like. In some implementations, where the object detection signals are tone waves, such tone waves may require minimal filtering and are not modulated. In some embodiments, object detection antennas of the antennas **120** may transmit individual tone waves at a given frequency (F1). In some embodiments, after a pre-defined time delay (T1), the object detection antennas transmit individual tone waves at a second frequency (F2). In some embodiments, the signal generator **124** continues to change the frequency of each tone wave in a pre-defined bandwidth (F1:Fn), such that each tone wave transmitted from the object detection antennas has a stepped-up frequency from the preceding tone wave. In another embodiment, each tone wave transmitted from the object detection antennas has a stepped-down frequency from the preceding tone wave. In yet another embodiment, each of the tone waves transmitted from the object detection antennas may be generated at a random frequency. These tone waves are reflected back from one or more objects. The object detection antennas may then receive reflected object detection signals from the one or more objects. The processor **122** then generates the location data of each respective object by determining a lag time between emitting the object detection signals and receiving reflected object detection signal reflected from the respective object at one or more object detection antennas of the receiver **106**. Each of the reflected object detection signals received from an object has a different phase as received at the one or more object detection antennas in relation to one another based on an angular position of the object in a spatial direction in relation to the receiver. This allows the processor **122** to determine the location data associated with the object.

[0035] The signal generator **124** may produce non-continuous object detection signals having a frequency and amplitude that may be increased or decreased randomly, incrementally, or at some predetermine interval. In one example, the non-continuous object detection signals may be chirp signals. When producing chirp signals, the frequency of the chirp signals may change linearly over time, and thereby sweeps the frequency band (Fl:Fn) without creating concentrated energy in one particular frequency, which may not be desirable. In some embodiments, the chirp signal is also a frequency modulated pulse or signal where the modulated frequency typically linearly increases from an initial frequency over a finite time equaling a pulse width, for example, from 57 GHz to 66 GHz, providing a 9 GHz bandwidth, over the pulse width, for example, 10 microseconds, and modulating an intermediate center frequency. This modulated signal may be stepped up and mixed to a higher signal carrier prior to transmission by the transmission antennas, such as 50GHz to 100GHz.

[0036] In an embodiment, the chirp signals may be generated by various other hardware means. One of the methods to produce chirp signals may include a group of lumped circuit elements. For example, the group of lumped circuit elements may include a group of the circuits that generate a respective group of staggered delay signals which are summed together and which provide the chirp signals. Another method of producing chirp signals may comprise a metalized crystalline device that is subjected to the high impulse signal to produce the linear frequency modulated chirp signal. In yet another example method of producing chirp signals, DDS systems may be employed. DDS methods of generating the chirp signal typically employ programmed memories having stored sinusoidal values that are typically fed into the D/A converter, such that as the digital values are cycled into the D/A converter at an increasing rate for a certain pulse width time, the analog converter produces the chirp signals through that pulse width.

[0037] The chirp signal may be generated as a linear chirp signal and as a non-linear chirp signal. The nonlinear chirp signal may be selected from a group consisting of exponential, logarithmic, and arbitrarily formulated chirp signal. The output frequency of the chirp signals generated by the signal generator **124** may be pre-defined and stored in the memory **128**. The output frequency of the chirp signals generated by the signal generator **124** may be defined by the processor **122**. The signal generator **124** may produce multiple chirp signals for multiple transmission antennas where each of the chirp signals has a unique output frequency and amplitude. Some of the frequencies or amplitudes may be the same. The signal generator **124** may also be configured to increase or decrease the frequency and adjust the amplitude of the transmitted chirp signals in relation to the change in time and distance. In one example, the frequency of the chirp signals transmitted by the transmission antennas may be randomly changed (increased or decreased) between 1 to 1000 times per second. The frequency may be increased at each Nth second, and then the frequency may be decreased at each N+2th second.

[0038] The receiver antennas may receive reflected object detection signals from an object of the one or more objects. In some embodiments, the processor **122** then generates the location data of the respective object by determining a lag time between emitting the object detection signals and receiving reflected object detection signal reflected from the object. The power antennas may receive power waves **110** originating from the transmitters **102**. The power antennas may receive the power waves **110** produced by and transmitted directly from the transmitters **102**, or the power antennas may harvest the power waves **110** from one or more pocket of energy **118**, which may be a three-dimensional field in space resulting from the convergence of a plurality of the power waves **110** produced by the one or more transmitters **102**. After the power waves **110** are received and/or energy is gathered from the pocket of energy **118**, circuitry (e.g., integrated circuits, amplifiers, rectifiers, voltage conditioner) of the receiver **106** may then convert the energy of the power waves **110** (e.g., radio frequency electromagnetic radiation) to electrical energy (i.e., electricity), which may be stored into a battery or used by the electronic device **107** in which the receiver **106** may be embedded. In some cases, for example, a rectifier of the receiver **106** may translate the electrical energy from AC to DC form, usable by the electronic device **107**. Other types of conditioning may be applied as well, in addition or as an alternative to conversion from AC to DC. For example, a voltage conditioning circuit may increase or decrease the voltage of the electrical energy as required by the electronic device **107**. An electrical relay may then convey the electrical energy from the receiver **106** to the electronic device **107**.

[0039] The receiver **106** may include or be associated with the processor **122** (or a microprocessor). The processor **122** may control, manage, and otherwise govern the various processes, functions, and components of the receiver **106**. In some embodiments, the processor **122** implements a system to control the operations of the receiver **106**. The processor **122** may be an integrated circuit that includes logic gates, circuitry, and interfaces that are operable to execute various processes and tasks for controlling the behavior of the receiver **106** as described herein. The processor **122** may comprise or implement a number of processor technologies known in the art; non-limiting examples of the processor include, but are not limited to, an x86 processor, an ARM processor, a Reduced Instruction Set Computing (RISC) processor, an Application-Specific Integrated Circuit (ASIC) processor, or a Complex Instruction Set Computing (CISC) processor, among others. The processor may also include a Graphics Processor (GPU) that executes the set of instructions to perform one or more processing operations associated with handling various forms of graphical data, such as data received from a visual or thermal camera, or to produce a graphical user interface (GUI) allowing a user to configure and manage operation of the receiver **106**.

[0040] The processor **106** may be configured to process and communicate various types of data (e.g., location data associated with one or more objects such as humans **119**). Additionally or alternatively, the processor **106** may manage execution of various processes and functions of the receiver **106**, and may manage the components of the receiver **106**. In one example, the processor **122** may process the object detection signals reflected by the one or more objects to identify the location of human objects when they enter a pre-defined distance from the receiver **106**, and/or enter within respective transmission fields of the transmitters **102**. In another example, the processor **122** may obtain and process sensor data of one or more objects captured by sensors (not shown), to identify human objects that may enter a pre-defined distance from of the receiver **106,** and/or may inhabit the transmission field of the transmitter **102**.

[0041] The communications component **126** of the receiver **106** may effectuate wired and/or wireless communications to and from the communications component **112** of the transmitter **102** of the wireless power transmission system in real-time or near real-time, through communications signals generated by either the communications component **126** of the receiver **106** and/or the communication component **112** of the transmitter **102**. In one embodiment, the communications component **126** may be an embedded component of the receiver **106**; and in another embodiment, the communication component **126** may be attached to the receiver **106** through any wired or wireless communications medium. In some embodiments, the communications component **126** of the receiver **106** may include electromechanical components (e.g., processor) that allow the communication component **126** of the receiver **106** to communicate various types of data (such as location data associated with the one or more objects) with one or more transmitters **102** of the wireless power transmission system **100**, and/or other components of the receiver **106**. The data may be communicated using communications signals, based on predetermined wired or wireless protocols and associated hardware and software technology. The communications component **126** of the receiver **106** may operate based on any number of communication protocols, such as Bluetooth®, Wireless Fidelity (Wi-Fi), Near-Field Communications (NFC), ZigBee, and others. However, it should be appreciated that the communications component **126** of the receiver **106** is not limited to radio-frequency based technologies, but may include radar, infrared, and other types of waves.

[0042] The data included within the communications signals generated by the communication component **126** of the receiver **106** may also include device status data, such as status information for the receiver **106**, status information for the electronic device **107** in which the receiver **106** may be embedded, status information for the power waves **110** being received from the transmitter **102**, and/or status information for the pockets of energy **118**. The receiver **106** may also provide data in the communications signals generated by the communication component **126** to the transmitter **102** regarding a present location of the receiver **106**, location data associated to the one or more objects **119**, the amount of charge received by the receiver **106**, the amount of charge used by the electronic device **107**, and certain user account information, among other types of information.

[0043] The data included within the communications signals generated by the communications component **126** of the receiver **106** and transmitted to the transmitter **102** may be used by the transmitter **102** to determine how the transmitter **102** may transmit safe and effective power waves that generate a pocket of energy, from which the receiver **100** may capture energy and convert it to useable alternating current or direct current electricity. In one embodiment, using the communications signal, the receiver **100** may communicate data that may be used, *e.g.,* to identify location of one or more objects within the transmission field, determine safe and effective waveform characteristics for the power waves, and hone the placement of pocket of energy, among other possible functions.

[0044] In some embodiments, the memory **128** is a non-volatile storage device for storing data and instructions, to be used by the processor **122**. In some embodiments, the memory **128** is implemented with a magnetic disk drive, an optical disk drive, a solid state device, or an attachment to a network storage. The memory **128** may comprise one or more memory devices to facilitate storage and manipulation of program code, set of instructions, tasks, pre-stored data including configuration files of receivers and electronic devices, and the like. Non-limiting examples of the memory **128** implementations may include, but are not limited to, a random access memory (RAM), a read only memory (ROM), a hard disk drive (HDD), a secure digital (SD) card, a magneto-resistive read/write memory, an optical read/write memory, a cache memory, or a magnetic read/write memory. Further, the memory **128** includes one or more instructions that are executable by the processor **122** to perform specific operations. The support circuits for the processor **122** include conventional cache, power supplies, clock circuits, data registers, I/O interfaces, and the like. The I/O interface may be directly coupled to the memory **128** or coupled through the processor **122**.

[0045] In some embodiments, the receiver **106** may be associated with the memory **128** that may further include one or more mapping-memories, which may be non-transitory machine-readable storage media configured to store location data which may be data describing aspects of position of the one or more objects when they enter a pre-defined distance to the receiver **106** and/or within the transmission field associated with the transmitter **102**. The memory **128** may also store mapping data that may comprise sensor data. The sensor data may be generated by processors of the receiver **106** and/or sensor processors to identify sensitive objects such as human beings and animals located in proximity to the receiver **106**. The transmitter **102** may query the location data of objects stored in the records of the memory unit **126**, so that the transmitter **102** may use the location data of objects as input parameters for determining the characteristics for transmitting the power waves **110** and where to form the pocket of energy within the transmission field.

[0046] As mentioned, in some implementations, the receiver **106** may be integrated into an electronic device **107**, such that for all practical purposes, the receiver **106** and the electronic device **107** would be understood to be a single unit or product, whereas in some embodiments, the receiver **106** may be coupled to the electronic device **107** after production. It should be appreciated that the receiver **106** may be configured to use the communications component of the electronic device **107** and/or comprise the communications component of its own. As an example, the receiver **106** might be an attachable but distinct unit or product that may be connected to an electronic device **107**, to provide wireless-power charging to the electronic device **107**. In the illustrated embodiment, the receiver **106** may comprise its own communications component **126** to communicate data with the transmitter **102**. Additionally or alternatively, in some embodiments, the receiver **106** may utilize or otherwise operate with the communications component of the electronic device. For example, the receiver **106** may be integrated into a laptop computer during manufacturing of the laptop or at some later time. In this example, the receiver **106** may use the laptop's communications component (e.g., Bluetooth®-based communications component) to communicate data with the transmitters, or the receiver **106** may be integrated into a smartphone case and may utilize connectivity of the phone.

[0047] In some embodiments, in operation of the receiver **106,** the object detection signals with different cycles are generated by the signal generator **124,** and are transmitted by the transmission antennas. The signal generator **124** may vary the frequency of each object detection signal it generates. The signal generator **124** may also use a signal switch that switches or otherwise manipulates the characteristics of the object detection signals at a predetermined interval. In some embodiments, the object detection signals that are reflected from one or more objects are then received by the receiver antennas, and are stored in the memory **128**. The processor **122** then accesses the memory **128** to process the reflected object detection signals. The processor **126** may obtain the reflected object detection signals data of each reflected object detection signal with different cycles from the memory **128.** In some embodiments, the processor **122** then generates the location data of the respective object by determining a lag time for each of the reflected object detection signals received at each of the antennas with different cycles from the receiver **102**. The processor **122** compares the lag time data obtained for each of the reflected object detection signals with different cycles as received at different antennas and calculates a distance of the object from the receiver **106** based on lag time data for each of reflected object detection signals with different cycles and the specific orientation of the antennas. The processor **122** then compares multiple distance values obtained of the object based on lag time data for each of reflected object detection signals as received at different antennas, and determines the exact location of the object. In an embodiment, the range of distance measured may be from millimeters to meters. In some embodiments, the location data of the object is saved in the memory **128.**

[0048] In one embodiment, the location data of the object is then automatically transmitted by the communications component **126** of the receiver **106** to the transmitter **102.** In another embodiment, the communications component **126** may send the location data of the object to the transmitter on receiving a request from the transmitter **102**. The transmitter

102 then transmits power waves having one or more characteristics based on the location data associated with the object. Based on the location of the object, the transmitter **102** may vary the one or more characteristics, e:g., frequency, amplitude, phase, gain, direction of the power waves **110** that are being transmitted by the transmitter **102** towards the location of the receiver **106** and/or location of the object **119**. In one example, when the location data indicates that the range or distance of the object **119** to the receiver **106** is within a pre-defined proximity to the receiver **106**, a null space may be formed at or nearby the location of the object and/or nearby the receiver **106**. The null space may have zero or negligible energy at the particular region in space, which may be caused by power waves converging at the region in space to form destructive interference patterns. When power waves destructively converge at the object location and their respective waveform characteristics are opposite each other (i.e., waveforms cancel each other out), the amount of energy concentrated at the object location diminishes. In another example, the transmitter **102** may form a null space at the location of the object irrespective of whether the object is within a pre-defined proximity or not from the receiver **106**. In yet another embodiment, the transmitter **102** may reduce the intensity of the power waves that are being transmitted to the receiver **100** when the object **119** is within a pre-defined proximity to the receiver **106**.

[0049] **FIG. 2** shows a method of transmission of power waves in a wireless power transmission system, according to an exemplary embodiment.

[0050] At step **202,** a receiver (RX) generates location data associated with one or more objects. In one example, the receiver generates the location data associated with the one or more objects when the receiver is receiving power waves from a transmitter and the one or more objects enter within a pre-defined distance from the receiver. In another example, the receiver is configured to continuously or periodically generate and update location data associated with the one or more objects.

[0051] The receiver generates the location data associated with the one or more objects based upon receiving one or more object detection signals reflected from each respective object of the one or more objects. The object detection signals received back from a particular object indicate a location of the particular object in relation to the receiver, allowing the receiver to generate location data based upon this relative location determined by the receiver. Because the transmitter may be aware of the location of the receiver, the location data of the particular object indicates to the transmitter the location of the respective object in relation to a transmitter. In some implementations, an object detection antenna coupled to the receiver may emit a plurality of object detection signals, where each respective object detection signal has a successively stepped frequency. The object detection antenna then receives at least one object detection signal reflected back from the object. In one example, a single object detection antenna or a set of object detection antennas may be utilized for both transmitting object detection signals and receiving reflected object detection signals. In another example, one set of object detection antennas may be utilized for transmitting object detection signals and another set of object detection antennas may be utilized for receiving reflected object detection signals.

[0052] A processor configured to control the receiver then generates the location of a respective object of the one or more objects in relation to the receiver based on at least one object detection signal being reflected back from the respective object. In one example, the location data of the respective object may be determined by measuring the lag time of reflected object detection signals from the respective object. The determined location of the object may then be saved in a memory of the receiver by the processor.

[0053] At step **204,** the receiver transmits the location data associated with the respective object to the transmitter (TX). The location data of the respective object is then transmitted by the receiver via one or more communications signals generated by a communications component of the receiver including the location data to the transmitter. In an embodiment, the communications component may send the location data of the object to the transmitter on receiving a request from the transmitter.

[0054] At step **206,** the receiver receives from one or more antennas of the transmitter, one or more power waves having one or more waveform characteristics causing the one or more power waves to converge at a location proximate to the receiver based on the location data generated for each respective object. The one or more power waves may also converge destructively to form one or more null spaces based on the one or more waveform characteristics of the one or more power waves. The receiver may be embedded in an electronic device that is being charged by the one or more power waves received from the one or more antennas of the transmitter. Alternatively, the receiver may stop receiving power waves altogether based on the sensed location of the object to the receiver.

[0055] **FIG. 3** illustrates a method of transmission of power waves in a wireless power transmission system, according to an exemplary embodiment.

[0056] At step **302,** a first set of one or more object detection antennas of a receiver (RX) emits a plurality of outbound object detection signals, where each respective object detection signal has a successively stepped frequency with respect to a preceding object detection signal.

[0057] In an embodiment, a signal generator of the receiver may be configured to generate object detection signals. In one example, the object detection signals generated may be tone waves that require minimal filtering. In another example, each object detection signal generated may not modulated. In yet another example, the object detection signals generated may be non-linear chirp signals, where the non-linear chirp signals are selected from the group consisting of exponential, logarithmic, and arbitrarily formulated chirp waveform. The signal generator may also randomly change a frequency of one or more outbound detection signals of the plurality of outbound detection signals. The frequency of the one or more outbound detection signals may be randomly changed at a random interval range of, for example, 1 to 1000 times per second.

[0058] At step **304**, a second set of one or more object detection antennas of the receiver receives one or more inbound object detection signals that are reflected from one or more objects. The characteristics and timing of inbound object detection signals may be used to determine various aspects of location data for an object, such as range or distance from the receiver. More antennas and more inbound object detection signals may permit the receiver to generate more sophisticated forms of location data, such as multiple dimensions and greater accuracy. For example, an inbound object detection signal reflected back from an object indicates a location of the object in relation to the receiver; in this case, the range or distance from the receiver. In some cases, multiple inbound object detection signals reflected back from an object may have different phase positions in relation to one another based on an angular position of the object in a spatial direction in relation to the receiver.

[0059] At step **306**, a processor of the receiver generates location data associated with each object based on the one or more inbound object detection signals reflected back from each particular object. The inbound object detection signals may reflect a location of each object in relation to the receiver, and thus the receiver may generate the location data based on the location of each object in relation to the receiver. When received by the transmitter, the location data associated• with each respective object indicates to the transmitter the location of each respective object in relation to a transmitter. In an embodiment, the processor of the receiver generates the location data of each respective object by determining a lag time between emitting the plurality of outbound object detection signals and receiving the at least one inbound object detection signal reflected from the respective object. The processor of the receiver also generates the location data associated with each respective object based on different phase positions of each of the at least one inbound object detection signal.

[0060] At step **308,** a communications component of the receiver transmits communication signals containing the location data associated with each of the one or more objects to a transmitter (TX). In some implementations, the communications component of the receiver automatically transmits communication signals containing the location data associated with each of the one or more objects to the transmitter. In some implementations, the communications component of the receiver transmits communication signals containing the location data associated with each of the one or more objects to the transmitter on receiving a request from the transmitter.

[0061] At step **310,** another antenna of the receiver receives from the transmitter one or more power waves having one or more characteristics based on the location data associated with the one or more objects. In an embodiment, based on the location of the object, the transmitter may vary the one or more characteristics, e.g., frequency, amplitude, phase, gain, direction of the power waves that are being transmitted by the transmitter towards the location of the receiver and/or location of the object. In one example, when the location of the object is within a pre-defined proximity to the receiver, a null space may be formed at the location of the object caused by destructive interference of waves at that location. The destructive interference may occur when power waves destructively converge at the object location and their respective waveform characteristics are opposite each other (i.e., waveforms cancel each other out), thereby diminishing the amount of energy concentrated at the object location. In another example, the transmitter may form a null space at the location of the object irrespective of whether the object is within a pre-defined proximity or not. In yet another embodiment, the transmitter may reduce the intensity of the power waves that are being transmitted to the receiver. In another example, the receiver may stop receiving power waves altogether based on the sensed location of the object to the receiver.

[0062] The foregoing method descriptions and the process flow diagrams are provided merely as illustrative examples and are not intended to require or imply that the steps of the various embodiments must be performed in the order presented. As will be appreciated by one of skill in the art the steps in the foregoing embodiments may be performed in any order. Words such as "then," "next," etc. are not intended to limit the order of the steps; these words are simply used to guide the reader through the description of the methods. Although process flow diagrams may describe the operations as a sequential process, many of the operations can be performed in parallel or concurrently. In addition, the order of the operations may be re-arranged. A process may correspond to a method, a function, a procedure, a subroutine, a subprogram, etc. When a process corresponds to a function, its termination may correspond to a return of the function to the calling function or the main function.

[0063] The various illustrative logical blocks, modules, circuits, and algorithm steps described in connection with the embodiments disclosed herein may be implemented as electronic hardware, computer software, or combinations of both. To clearly illustrate this interchangeability of hardware and software, various illustrative components, blocks, modules, circuits, and steps have been described above generally in terms of their functionality. Whether such functionality is implemented as hardware or software depends upon the particular application and design constraints imposed on the overall system. Skilled artisans may implement the described functionality in varying ways for each particular application, but such implementation decisions should not be interpreted as causing a departure from the scope of the present invention.

[0064] Embodiments implemented in computer software may be implemented in software, firmware, middleware, microcode, hardware description languages, or any combination thereof. A code segment or machine-executable instructions may represent a procedure, a function, a subprogram, a program, a routine, a subroutine, a module, a software package, a class, or any combination of instructions, data structures, or program statements. A code segment may be coupled to another code segment or a hardware circuit by passing and/or receiving information, data, arguments, parameters, or memory contents. Information, arguments, parameters, data, etc. may be passed, forwarded, or transmitted via any suitable means including memory sharing, message passing, token passing, network transmission, etc.

[0065] The actual software code or specialized control hardware used to implement these systems and methods is not limiting of the invention. Thus, the operation and behavior of the systems and methods were described without reference to the specific software code being understood that software and control hardware can be designed to implement the systems and methods based on the description herein.

[0066] When implemented in software, the functions may be stored as one or more instructions or code on a non-transitory computer-readable or processor-readable storage medium. The steps of a method or algorithm disclosed herein may be embodied in a processor-executable software module, which may reside on a computer-readable or processor-readable storage medium. A non-transitory computer-readable or processor-readable media includes both computer storage media and tangible storage media that facilitate transfer of a computer program from one place to another. A non-transitory processor-readable storage media may be any available media that may be accessed by a computer. By way of example, and not limitation, such non-transitory processor-readable media may comprise RAM, ROM, EEPROM, CD-ROM or other optical disk storage, magnetic disk storage or other magnetic storage devices, or any other tangible storage medium that may be used to store desired program code in the form of instructions or data structures and that may be accessed by a computer or processor. Disk and disc, as used herein, include compact disc (CD), laser disc, optical disc, digital versatile disc (DVD), floppy disk, and Blu-ray disc where disks usually reproduce data magnetically, while discs reproduce data optically with lasers. Combinations of the above should also be included within the scope of computer-readable media. Additionally, the operations of a method or algorithm may reside as one or any combination or set of codes and/or instructions on a non-transitory processor-readable medium and/or computer-readable medium, which may be incorporated into a computer program product.

CLAIMS

What is claimed is:

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

generating, by a receiver, location data associated with one or more objects based upon one or more object detection signals reflected from the one or more objects and indicating a location of each respective object of the one or more objects in relation to the receiver;

transmitting, by the receiver, one or more communications signals including the location data to the transmitter; and

receiving, by the receiver, from one or more antennas of the transmitter one or more power waves having one or more waveform characteristics, wherein the one or more waveform characteristics are based on the location data generated for each respective object.

2. The method of claim 1, wherein generating the location data associated with the one or more objects further comprises:

emitting, by a detection antenna coupled to the receiver, a plurality of object detection signals, each respective object detection signal having a successively stepped frequency.

3. The method of claim 2, wherein generating the location data associated with the one or more objects further comprises:

receiving, by the detection antenna coupled to the receiver, at least one detection signal reflected back from a respective object of the one or more objects.

4. The method of claim 3, wherein generating the location data associated with the one or more objects further comprises:

determining, by a processor configured to control the receiver, the location of a respective object of the one or more objects in relation to the receiver based on the at least one object detection signal reflected back from the respective object.

5. The method of any preceding claim, wherein the one or more power waves converge destructively to form one or more null spaces based on the one or more waveform characteristics of the one or more power waves.

6. The method of any preceding claim, wherein the receiver is coupled to a communications component configured to transmit the one or more communications signals including the location data to the transmitter.

7. The method of any preceding claim, wherein the receiver is embedded in an electronic device that is being charged by the one or more power waves received from the one or more antennas of the transmitter.

8. A method of wireless power transmission, the method comprising:

emitting, by a first antenna of a receiver, a plurality of outbound object detection signals, each respective outbound object detection signal having a successively stepped frequency with respect to a preceding outbound object detection signal;

receiving, by a second antenna of the receiver, one or more inbound object detection signals that are reflected from one or more objects, wherein at least one inbound object detection signal is reflected from a respective object of the one or more objects, and wherein the at least one inbound object detection signal indicates a location of the respective object in relation to the receiver;

generating, by a processor of the receiver, location data associated with the respective object based on the one or more inbound object detection signals;

transmitting, by a communications component of the receiver, to a transmitter one or more communications signals including the location data associated with the respective object of the one or more objects; and

receiving, by a third antenna of the receiver, from the transmitter one or more power waves having one or more characteristics, wherein the one or more characteristics are based on the location data associated with the respective object.

9. The method of claim 8, wherein each of the one or more inbound object detection signals received that are reflected from the one or more objects has a respective phase position based on an angular position of the object in relation to the receiver, and a respective spatial direction in relation to the receiver.

10. The method of claim 9, further comprising determining, by the receiver, the location data associated with the respective object of the one or more objects based on a respective phase position of the at least one inbound object detection signal reflected from the respective object.

11. The method of any one of claims 8-10, wherein generating the location data of the respective object further comprises determining, by the receiver, a lag time between emitting the plurality of outbound object detection signals and receiving the at least one inbound object detection signal reflected from the respective object.

12. The method of any one of claims 8-11, wherein the plurality of outbound object detection signals are generated as non-linear chirp signals, and wherein the non-linear chirp signals are a waveform selected from the group consisting of exponential, logarithmic, and arbitrarily formulated.

13. The method of any one of claims 8-12, wherein emitting the plurality of outbound detection signals further comprises randomly changing, by the first antenna of the receiver, a frequency of one or more outbound detection signals of the plurality of outbound detection signals, wherein the frequency of the one or more outbound detection signals is randomly changed at a random interval range of 1 to 1000 times per second.

14. The method of any one of claims 8-13, wherein the plurality of outbound detection signals are not modulated.

15. A receiver in a wireless power transmission system comprising:

a first antenna configured to emit a plurality of outbound detection signals, each respective outbound detection signal of the plurality of outbound detection signals having a successively stepped frequency;

a second antenna configured to receive a plurality of inbound detection signals reflected from one or more objects;

a processor configured to generate location data associated with each respective object of the one or more objects based on the plurality of inbound detection signals reflected from the one or more objects, wherein respective location data of a respective object indicates a location of the respective object in relation to the receiver;

a communications component configured to transmit to the transmitter communications signals including the location data associated with each respective object; and

a third antenna configured to receive from the transmitter one or more power waves having one or more characteristics causing the one or more power waves to converge at a location proximate to the receiver based on the location data associated with each respective object of the one or more objects.

16. The receiver of claim 15, wherein the plurality of outbound detection signals include chirp waves having a frequency that is continually varied.

17. The receiver of any one of claims 15-16, wherein a respective inbound detection signal of the one or more inbound detection signals is reflected from a respective object of the

one or more objects and has a phase position based on an angular position of the respective object in relation to the receiver, and a spatial direction of the respective object in relation to the receiver.

18. The receiver of claim 17, wherein the processor is further configured to determine respective location data associated with the respective object based on the phase position of the respective inbound detection signal.

19. The receiver of any one of claims 15-18, wherein the processor is further configured to determine respective location data for each respective object by measuring a lag time between emitting the plurality of outbound object detection signals and receiving the inbound detection signals reflected from each respective object of the one or more objects.

20. The receiver of any one of claims 15-19, wherein the one or more power waves are selected from the group consisting of electromagnetic wave, radio wave, microwave, acoustics, ultrasound, and magnetic resonance.

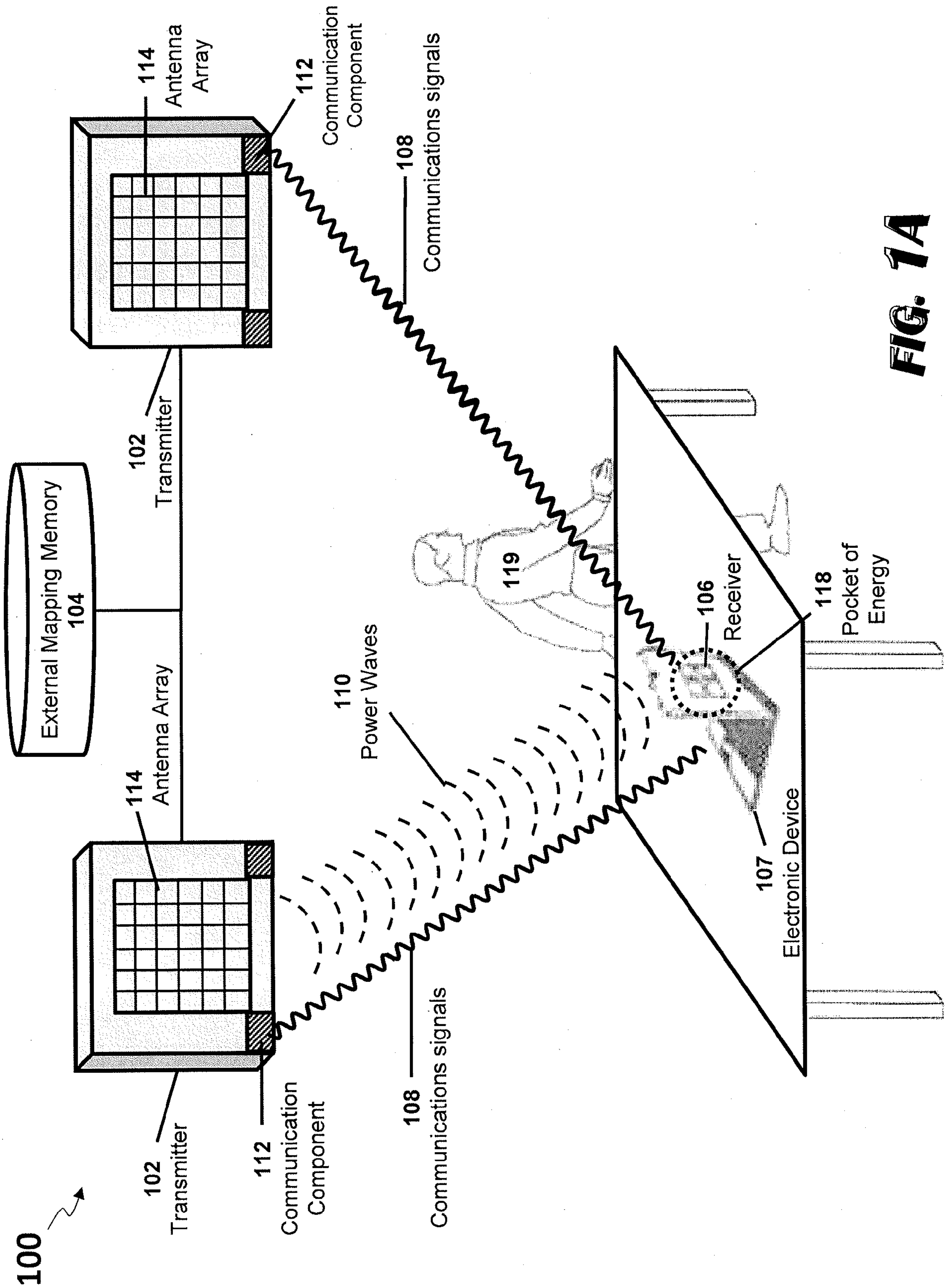
100
102
Transmitter
112
Communication Component
108
Communications signals
114
Antenna Array
External Mapping Memory
104
110
Power Waves
119
106
Receiver
118
Pocket of Energy
107
Electronic Device

FIG. 1A

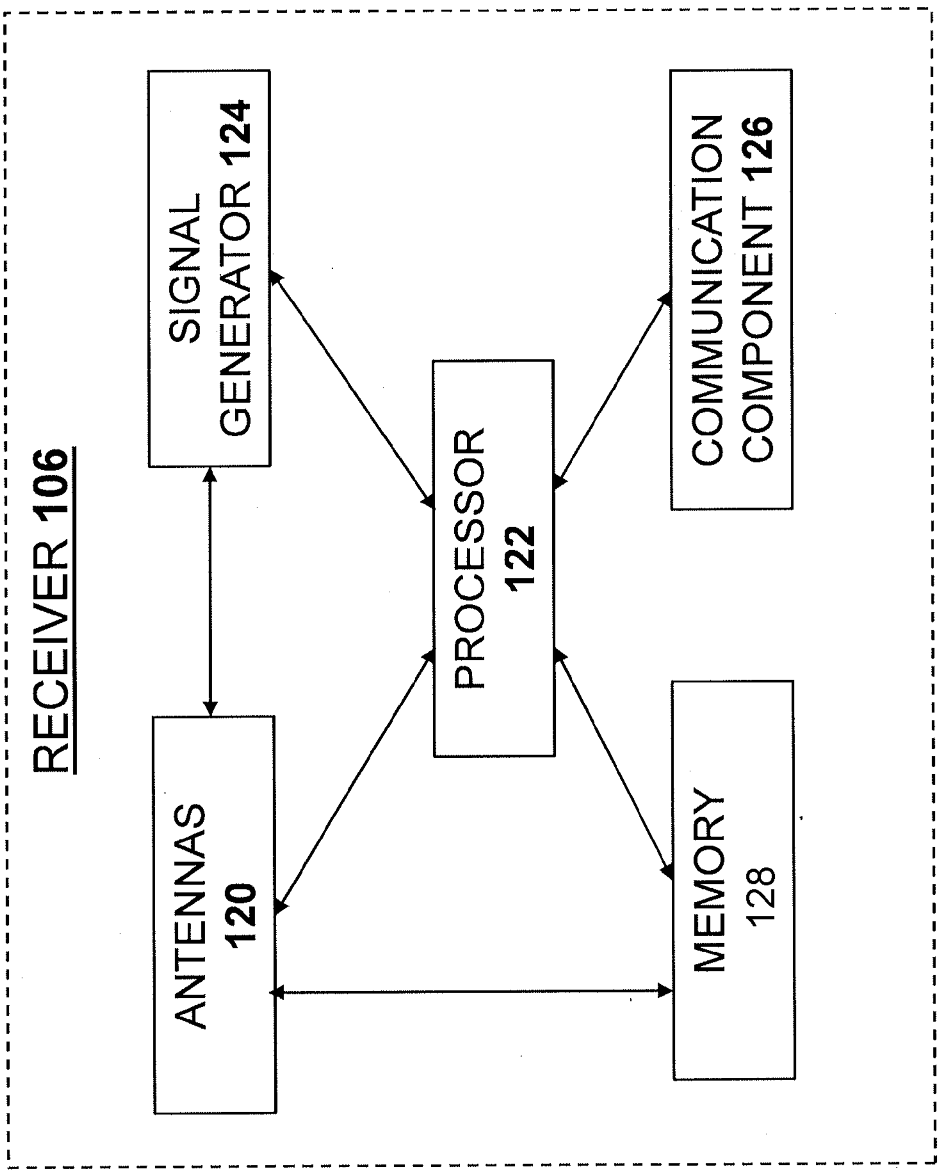
RECEIVER 106
SIGNAL GENERATOR 124
ANTENNAS 120
PROCESSOR 122
COMMUNICATION COMPONENT 126
MEMORY 128

FIG. 1B

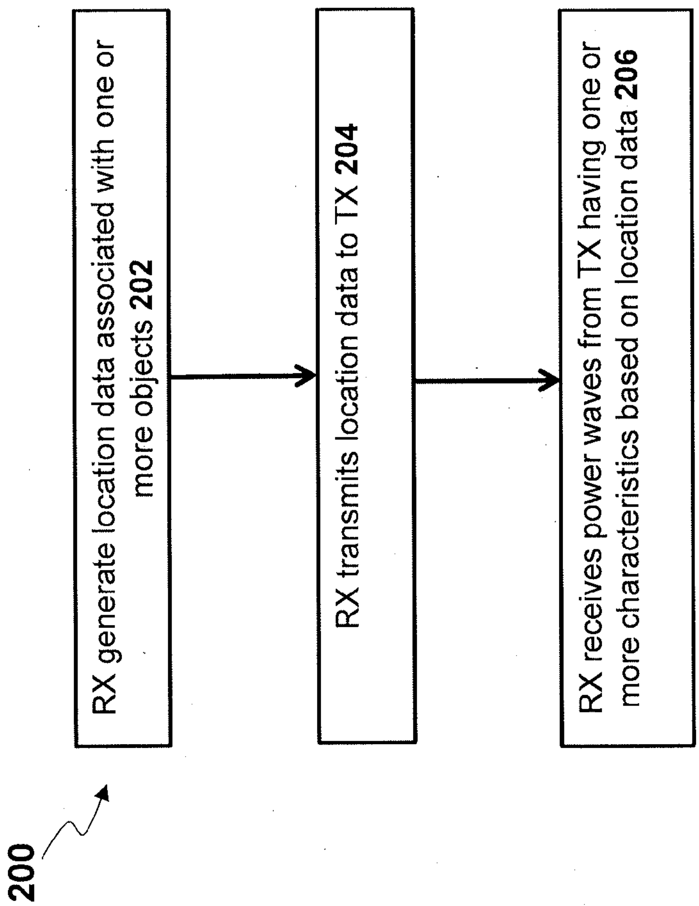
200
RX generate location data associated with one or more objects 202
RX transmits location data to TX 204
RX receives power waves from TX having one or more characteristics based on location data 206

FIG. 2

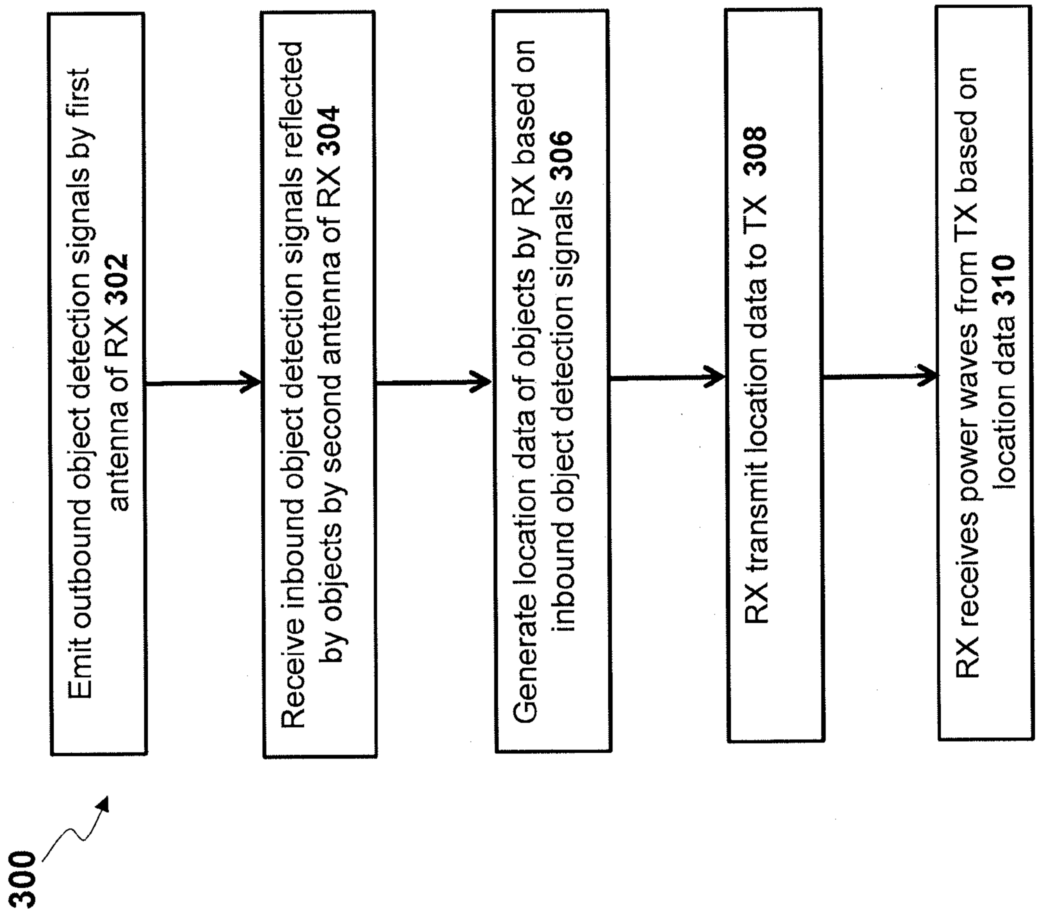
300
Emit outbound object detection signals by first antenna of RX 302
Receive inbound object detection signals reflected by objects by second antenna of RX 304
Generate location data of objects by RX based on inbound object detection signals 306
RX transmit location data to TX 308
RX receives power waves from TX based on location data 310

FIG. 3

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US2016/068993

A. CLASSIFICATION OF SUBJECT MATTER
IPC(8) - B60L 11/18; B60R 16/02; G01S 7/35; G01S 13/00; G01S 13/34; G01S 13/93 (2016.01)
CPC - B60L 11/1805; B60R 16/0373; F21V 23/00; G01S 7/032; G01S 7/285; G01S 7/4056; G01S 13/343; G06K 7/10207; G06K 7/10346; H02J 5/00; H02J 7/00; H02J 17/00; H03H 7/40; H04B 5/0037; H04B 5/02; H04Q 9/00 (2016.08)

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
See Search History document

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched
USPC - 307/104; 320/108; 340/10.100; 342/70; 342/129; 367/43; 455/41.100 (keyword delimited)

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
See Search History document

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X --- Y	US 2009/0264069 A1 (YAMASUGE) 22 October 2009 (22.10.2009) entire document	1 --- 2-5, 8-11, 15-18
Y	US 6,664,920 B1 (MOTT et al.) 16 December 2003 (16.12.2003) entire document	2-4, 8-11, 15-18
Y	US 2015/0061404 A1 (WITRICITY CORPORATION) 05 March 2015 (05.03.2015) entire document	5
Y	US 2011/0074620 A1 (WINTERMANTEL) 31 March 2011 (31.03.2011) entire document	9, 10, 17, 18
Y	US 4,944,036 A (HYATT) 24 July 1990 (24.07.1990) entire document	16
A	US 2013/0088331 A1 (CHO et al.) 11 April 2013 (11.04.2013) entire document	1-5, 8-11, 15-18
A	US 2009/0206791 A1 (JUNG) 20 August 2009 (20.08.2009) entire document	1-5, 8-11, 15-18
A	US 2015/0249484 A1 (POWERMAT TECHNOLOGIES LTD.) 03 September 2015 (03.09.2015) entire document	1-5, 8-11, 15-18
A	US 2015/0091520 A1 (SIEMENS AKTIENGESELLSCHAFT) 02 April 2015 (02.04.2015) entire document	1-5, 8-11, 15-18
A	US 2011/0127952 A1 (WALLEY et al.) 02 June 2011 (02.06.2011) entire document	1-5, 8-11, 15-18

☐ Further documents are listed in the continuation of Box C. ☐ See patent family annex.

* Special categories of cited documents:
"A" document defining the general state of the art which is not considered to be of particular relevance
"E" earlier application or patent but published on or after the international filing date
"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)
"O" document referring to an oral disclosure, use, exhibition or other means
"P" document published prior to the international filing date but later than the priority date claimed
"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
21 February 2017	13 MAR 2017

Name and mailing address of the ISA/US	Authorized officer
Mail Stop PCT, Attn: ISA/US, Commissioner for Patents P.O. Box 1450, Alexandria, VA 22313-1450 Facsimile No. 571-273-8300	Blaine R. Copenheaver PCT Helpdesk: 571-272-4300 PCT OSP: 571-272-7774

Box No. II Observations where certain claims were found unsearchable (Continuation of item 2 of first sheet)

This international search report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:

1. ☐ Claims Nos.:
because they relate to subject matter not required to be searched by this Authority, namely:

2. ☐ Claims Nos.:
because they relate to parts of the international application that do not comply with the prescribed requirements to such an extent that no meaningful international search can be carried out, specifically:

3. ☒ Claims Nos.: 6, 7, 12-14, 19, 20
because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a).

Box No. III Observations where unity of invention is lacking (Continuation of item 3 of first sheet)

This International Searching Authority found multiple inventions in this international application, as follows:

1. ☐ As all required additional search fees were timely paid by the applicant, this international search report covers all searchable claims.

2. ☐ As all searchable claims could be searched without effort justifying additional fees, this Authority did not invite payment of additional fees.

3. ☐ As only some of the required additional search fees were timely paid by the applicant, this international search report covers only those claims for which fees were paid, specifically claims Nos.:

4. ☐ No required additional search fees were timely paid by the applicant. Consequently, this international search report is restricted to the invention first mentioned in the claims; it is covered by claims Nos.:

Remark on Protest

☐ The additional search fees were accompanied by the applicant's protest and, where applicable, the payment of a protest fee.

☐ The additional search fees were accompanied by the applicant's protest but the applicable protest fee was not paid within the time limit specified in the invitation.

☐ No protest accompanied the payment of additional search fees.