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(54) **ULTRASONIC SENSING SYSTEM**

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CPC ***G05B 15/02*** (2013.01)

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CPC H05B 47/115; H05B 47/11; H05B 47/13; H05B 47/19; H05B 19/0423;
(Continued)

(56) **References Cited**

U.S. PATENT DOCUMENTS

4,254,483 A 3/1981 Vidovic
4,360,905 A 11/1982 Hackett
(Continued)

FOREIGN PATENT DOCUMENTS

EP 0958562 B1 * 11/2005

OTHER PUBLICATIONS

Peter Hauptmann et al., Applicaiton of ultrasonic sensors in the process industry, 2002, Institute of Physics Publishing, Measurement Science and technology 13, pp R73-R83, PII:S0957-0233(02)34745-3.*

(Continued)

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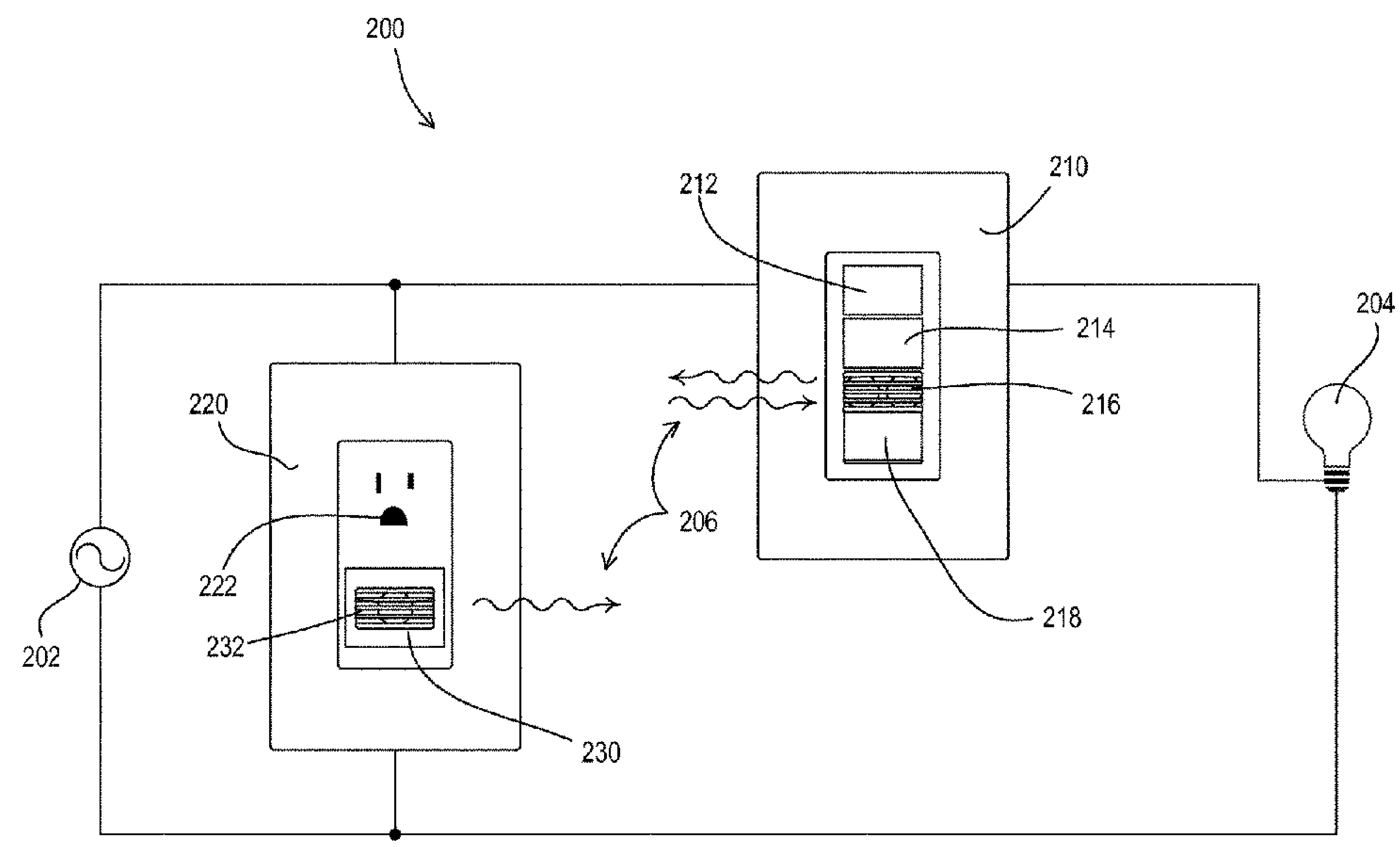
(57) **ABSTRACT**

A low-cost, simple ultrasonic sensing system has an increased detection range. The ultrasonic sensing system may be implemented as part of a load control system for controlling the power delivered from an AC power source to an electrical load. The load control system may comprise a load control device for controlling the power delivered to the electrical load, an ultrasonic receiver for receiving ultrasonic waves characterized by an ultrasonic frequency, and an ultrasonic transmitter located remotely from the ultrasonic receiver. The load control device controls the power delivered to the electrical load in response to the ultrasonic waves received by the ultrasonic receiver. The load control device may include the ultrasonic receiver and may be a wall-mounted load control device. The ultrasonic receiver may be a wireless ultrasonic receiver for transmitting wireless signals to the load control device in response to the ultrasonic waves received by the ultrasonic receiver.

37 Claims, 15 Drawing Sheets



(58) **Field of Classification Search**
CPC H05B 45/396; H04B 10/114; H03B 5/362; H08B 13/2417; H03K 17/94; G01S 7/521; G01S 15/87; F24F 11/30
USPC .... 340/540, 541, 8.1, 573.1, 539.3; 307/117, 326; 315/159, 151; 367/93; 331/116 R; 320/166, 134; 385/125
See application file for complete search history.

(56) **References Cited**

U.S. PATENT DOCUMENTS

4,661,720	A *	4/1987	Cameron, Jr.	H03K 17/94 307/117
4,864,256	A *	9/1989	Barnert	H03B 5/362 331/116 R
4,973,837	A	11/1990	Bradbeer	
5,081,406	A *	1/1992	Hughes	B23D 59/005 318/478
5,210,484	A	5/1993	Remillard et al.	
5,850,045	A	12/1998	Harada et al.	
5,987,205	A *	11/1999	Moseley	H04B 10/114 385/125
6,697,757	B2	2/2004	Eckel et al.	
6,759,954	B1 *	7/2004	Myron	H05B 37/0227 315/294
6,914,552	B1	7/2005	McEwan	
7,211,798	B2	5/2007	Wu et al.	
7,884,727	B2	2/2011	Tran	
8,009,042	B2 *	8/2011	Steiner	H05B 47/115 340/541
8,514,075	B1	8/2013	Steiner	
9,157,996	B1 *	10/2015	Elwell	G01S 15/87
2002/0167417	A1 *	11/2002	Welles, II	G08B 13/2417 340/8.1
2009/0072766	A1 *	3/2009	Null	H05B 37/0218 315/361
2010/0052574	A1	3/2010	Blakeley et al.	
2010/0052576	A1	3/2010	Steiner et al.	
2010/0052894	A1	3/2010	Steiner et al.	
2010/0207759	A1	8/2010	Sloan et al.	H05B 47/115 340/540
2010/0270982	A1 *	10/2010	Hausman, Jr.	H02J 7/00 320/166
2010/0277306	A1 *	11/2010	Leinen	H05B 47/19 340/539.3
2011/0012433	A1 *	1/2011	Parsons	H05B 47/19 307/117
2011/0034300	A1 *	2/2011	Hall	A63B 5/11 482/1
2011/0156911	A1 *	6/2011	Caglianone	G05B 19/0423 340/573.1
2012/0098440	A1 *	4/2012	Yen	H05B 45/395 315/159
2012/0286676	A1 *	11/2012	Saveri, III	H05B 47/13 315/159
2012/0313456	A1 *	12/2012	Baragona	H05B 47/19 307/326
2012/0313588	A1 *	12/2012	Carberry	F24F 11/30 320/134
2014/0062340	A1 *	3/2014	Elgayyar	H05B 37/0245 315/360
2014/0088904	A1 *	3/2014	Covaro	G05B 15/02 702/94
2014/0119160	A1 *	5/2014	Shilling	G01S 7/521 367/93
2015/0334809	A1 *	11/2015	Mans	H05B 47/11 315/151

OTHER PUBLICATIONS

Wattstopper, DW-103 Dual Technology Multi-way Wall Switch Sensor, Pub .No. 34702 rev. Sep. 2010.

* cited by examiner

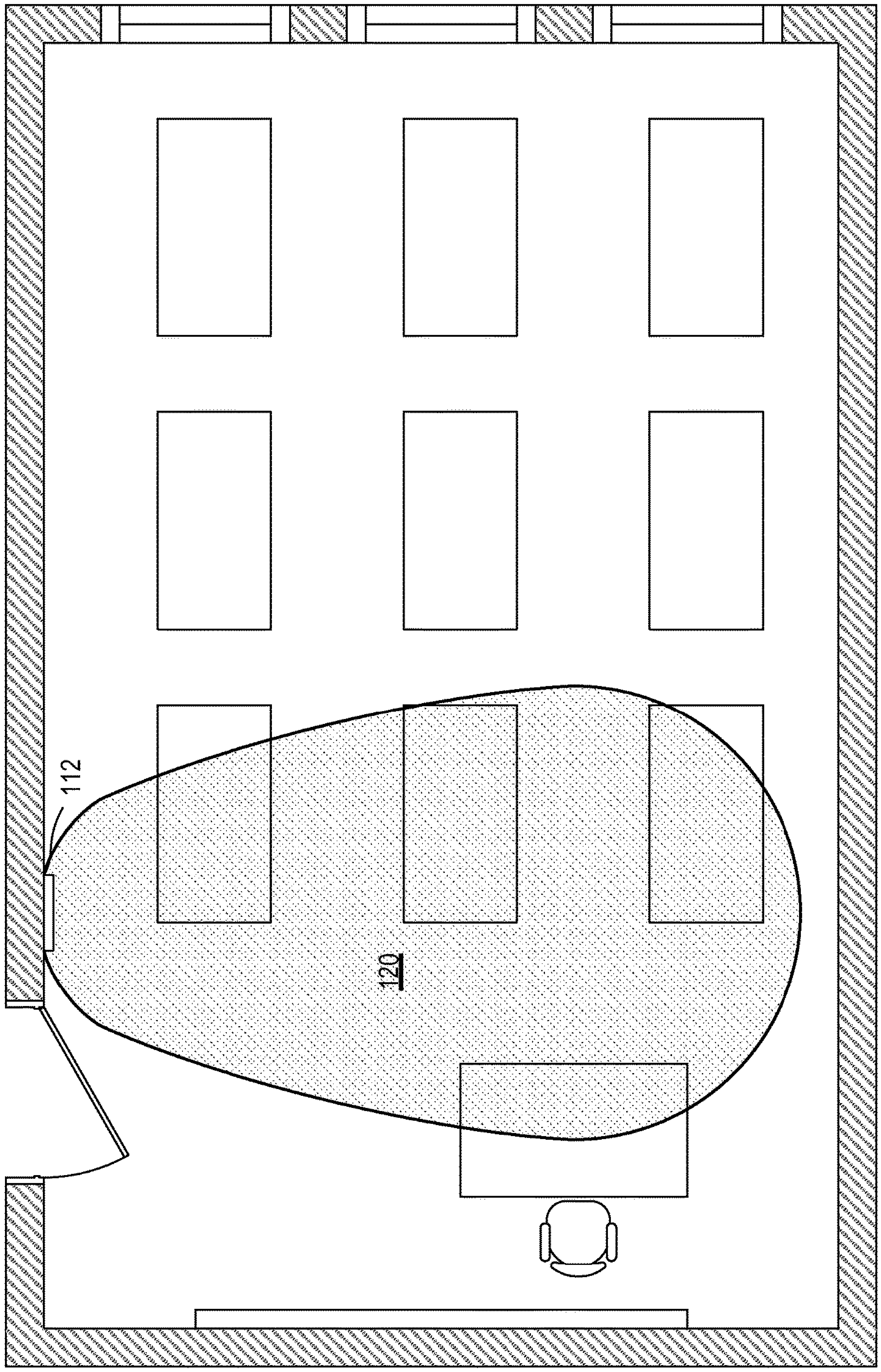


Fig. 1
(Prior Art)

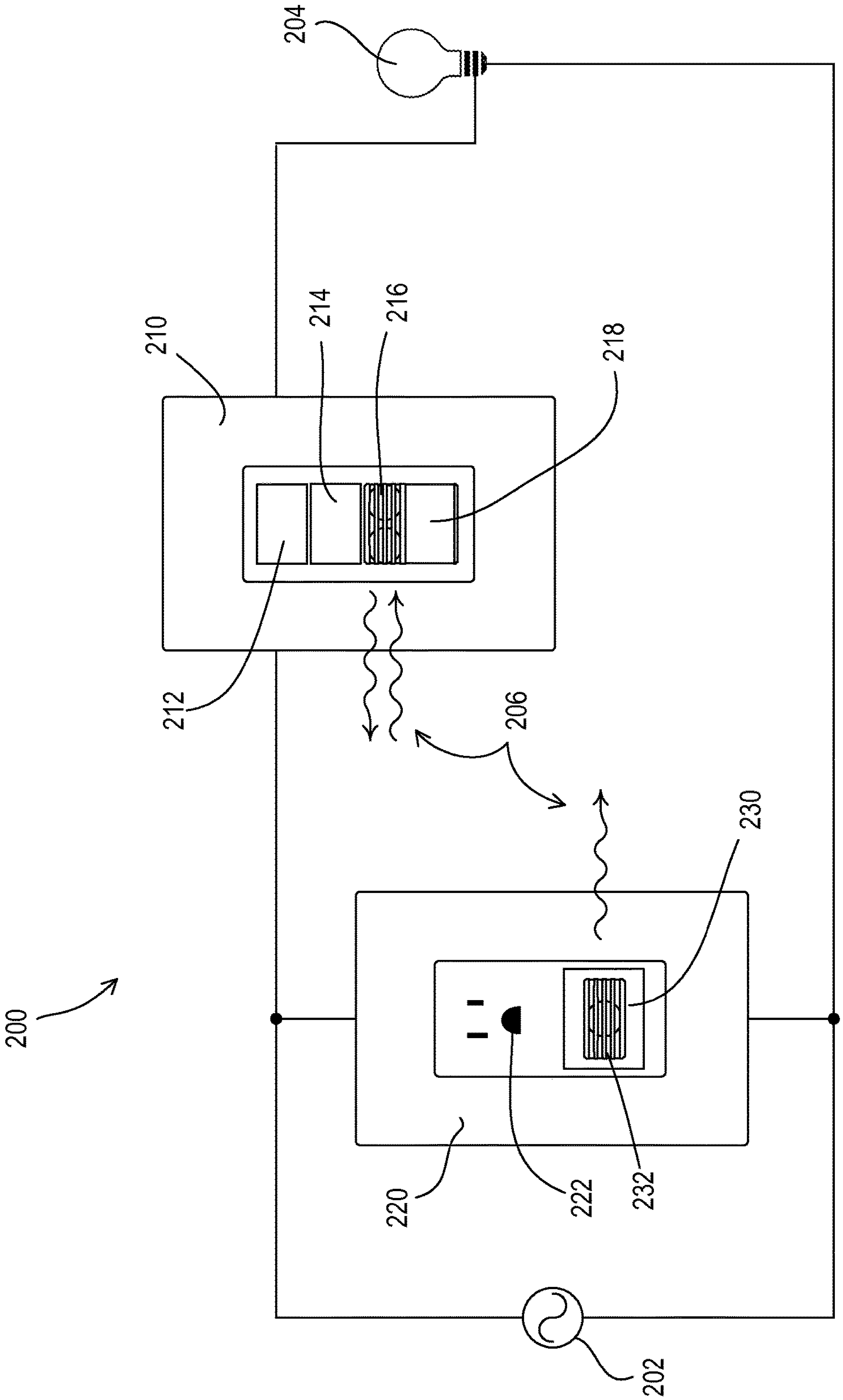


Fig. 2

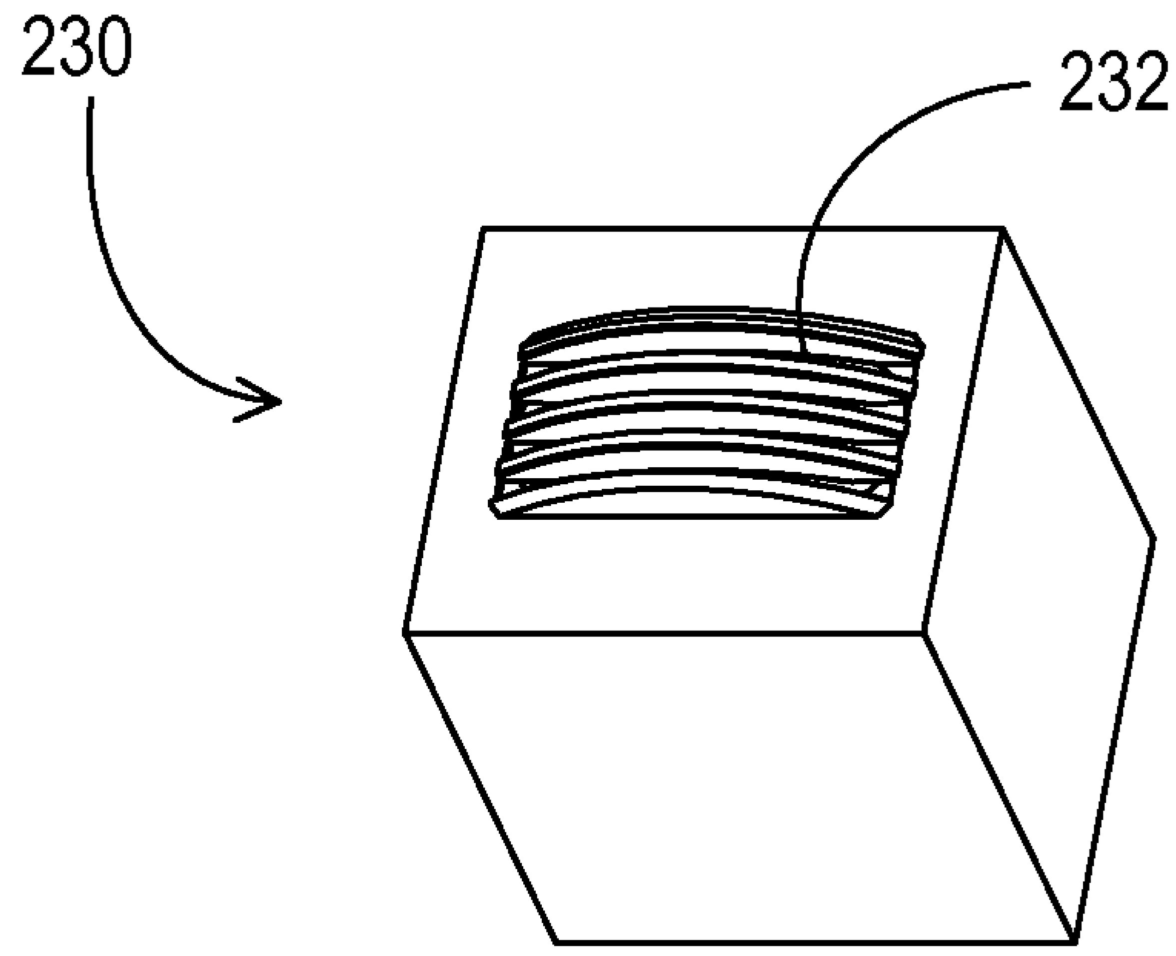


Fig. 3

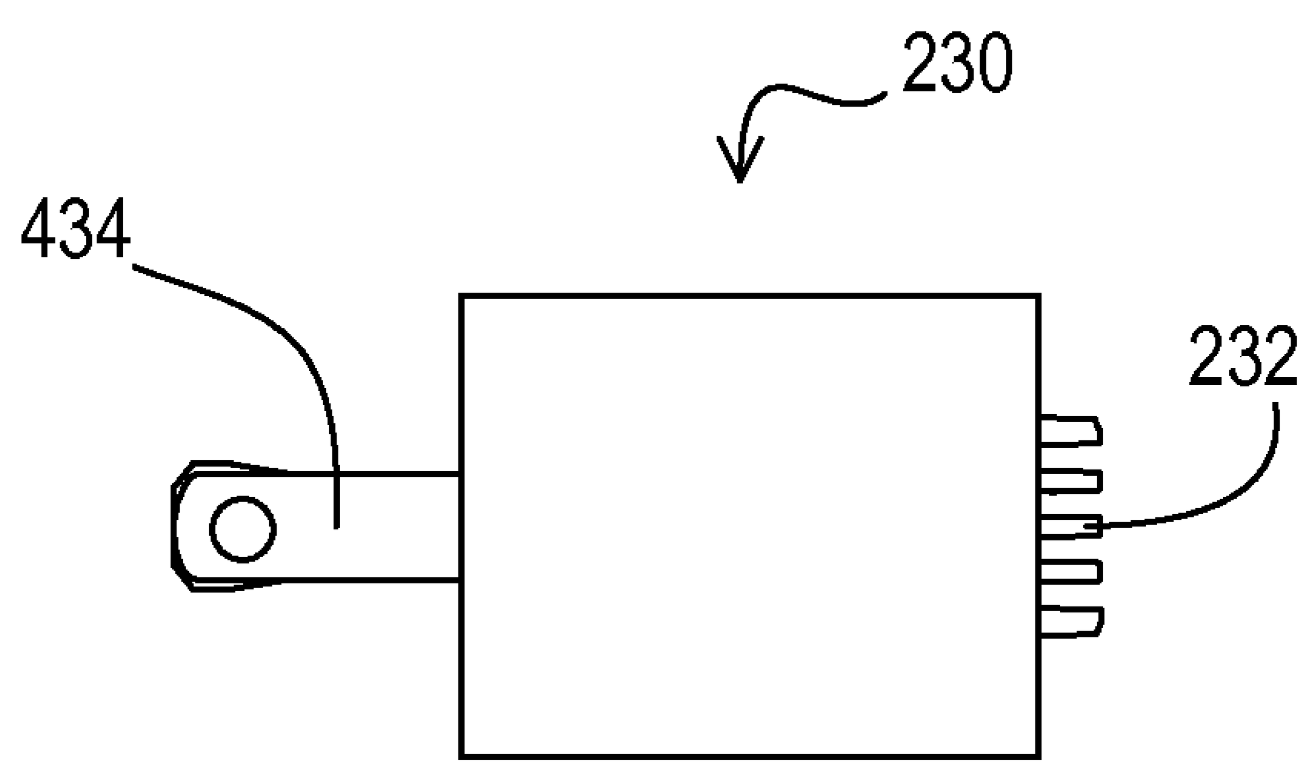


Fig. 4

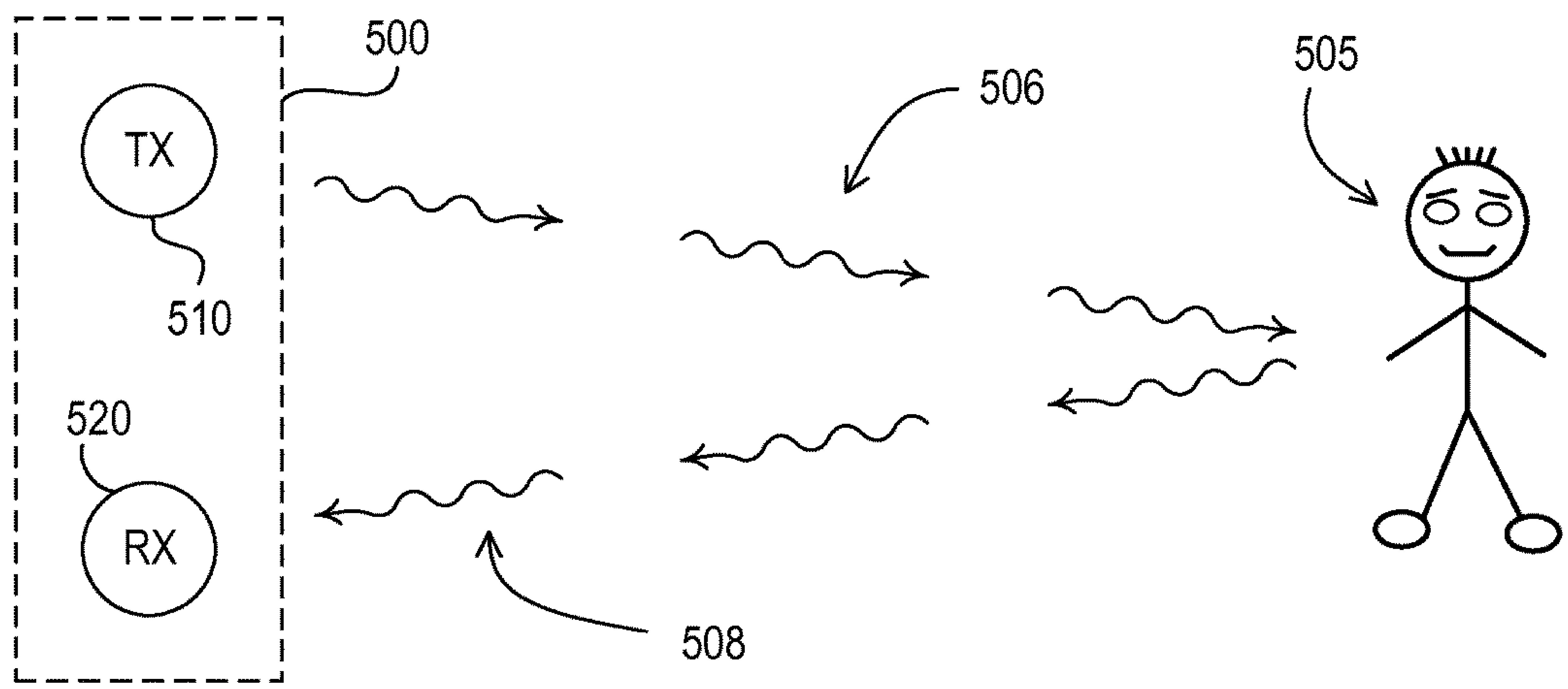

500
TX
510
520
RX
506
508
505

Fig. 5A

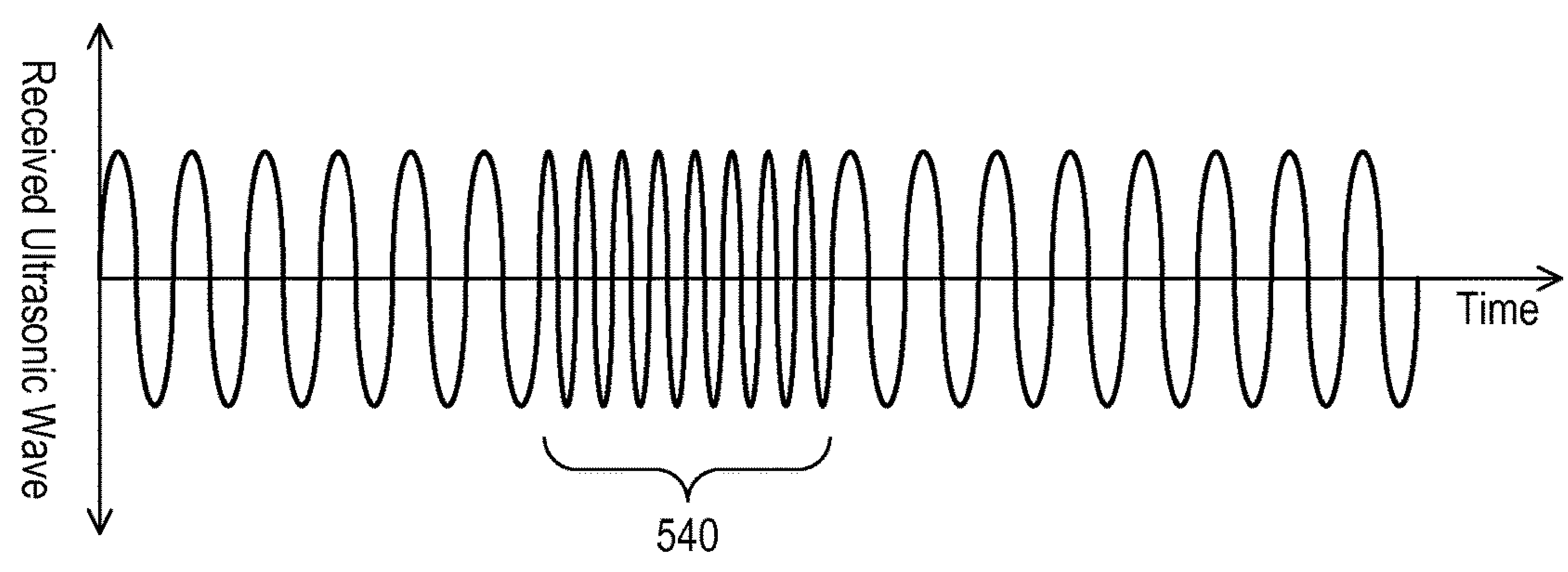

Received Ultrasonic Wave
Time
540

Fig. 5B

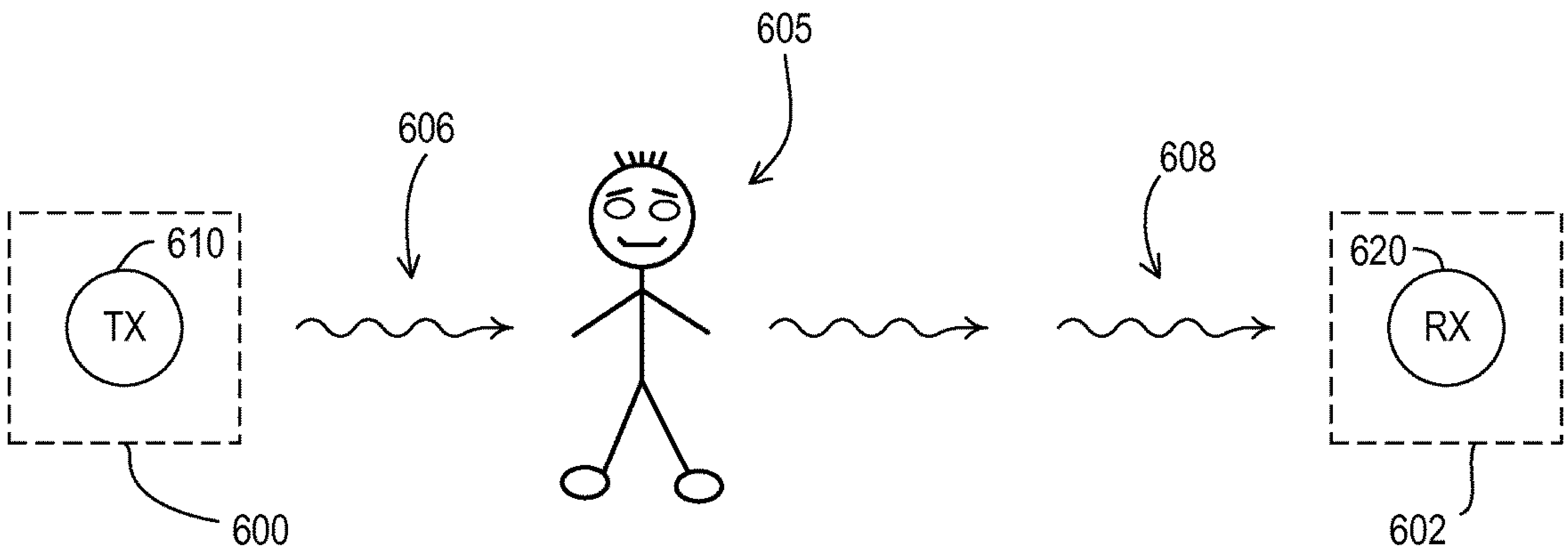

605
606
608
610
TX
620
RX
600
602

Fig. 6A

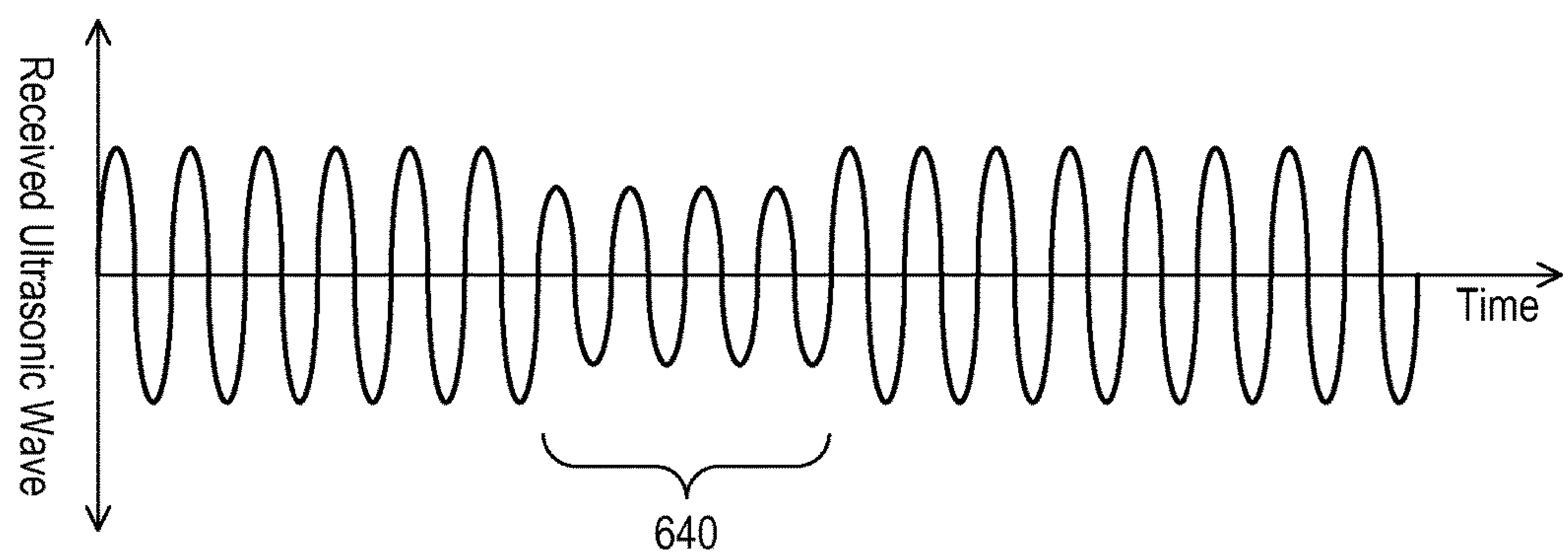

Received Ultrasonic Wave
Time
640

Fig. 6B

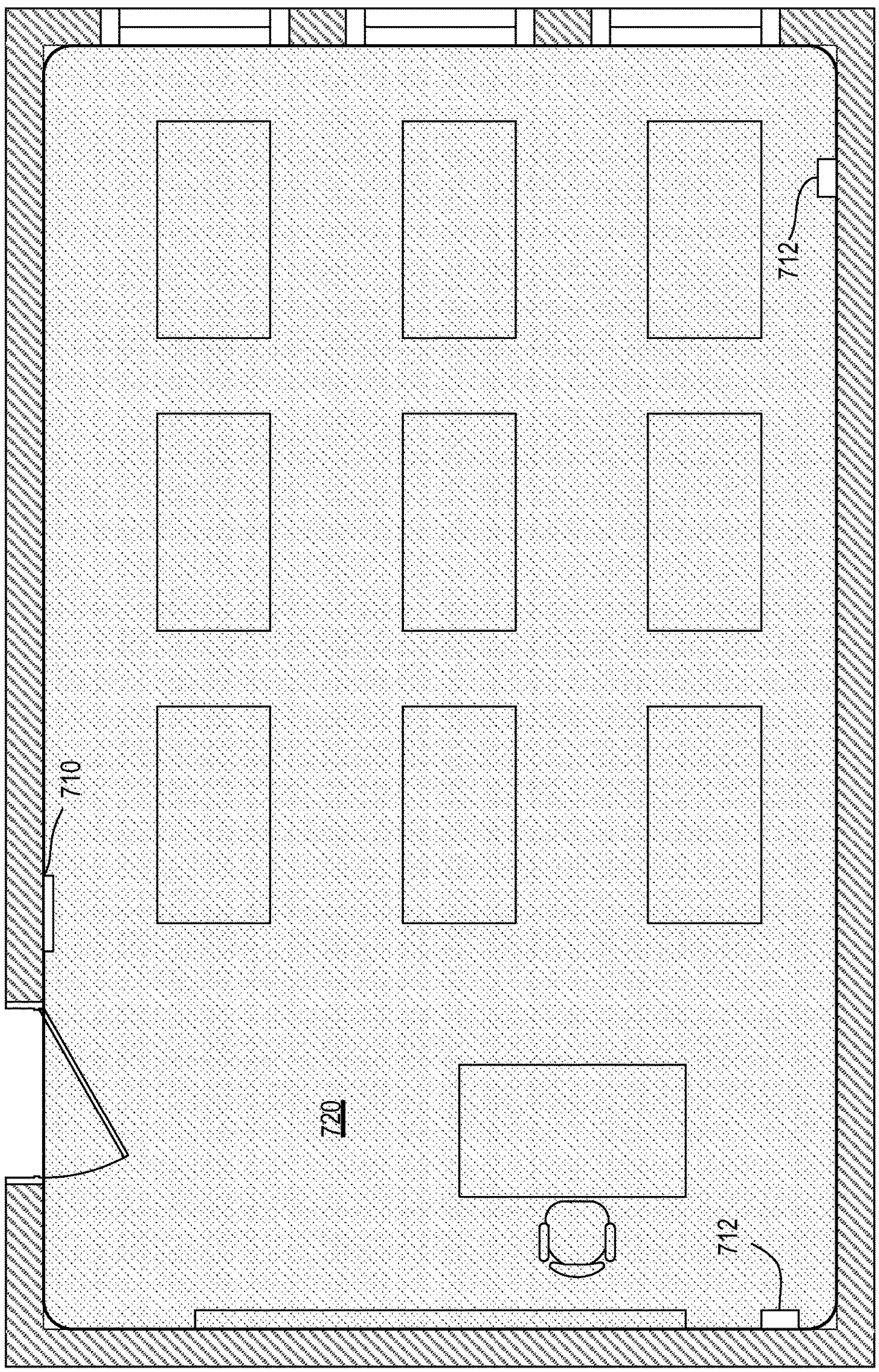


Fig. 7

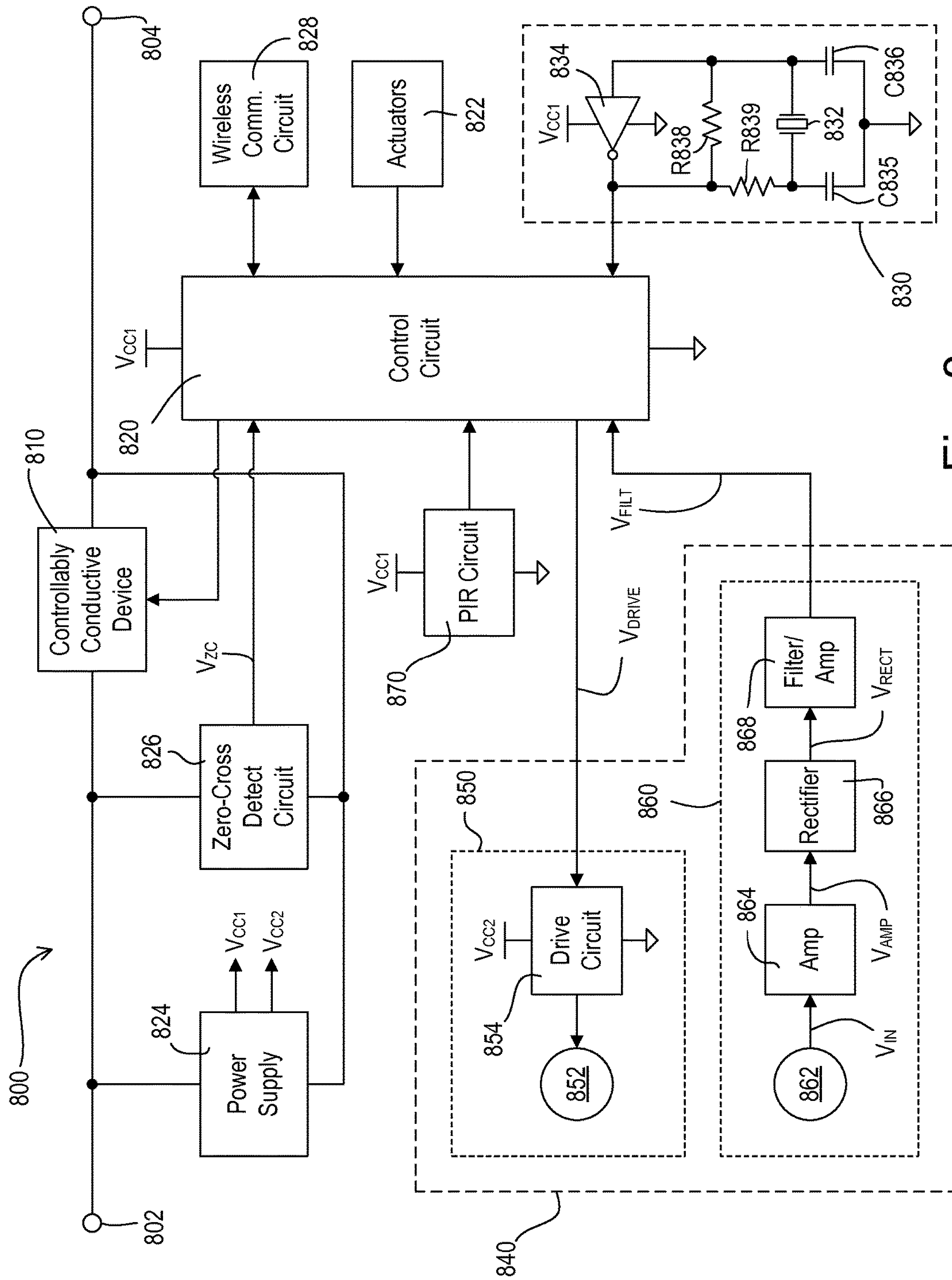

800
802
804
810
Controllably Conductive Device
820
Control Circuit
822
Actuators
824
Power Supply
826
Zero-Cross Detect Circuit
828
Wireless Comm. Circuit
830
832
834
R838
R839
C835
C836
840
850
852
854
Drive Circuit
860
862
864
Amp
866
Rectifier
868
Filter/ Amp
870
PIR Circuit
V_{CC1}
V_{CC2}
V_{ZC}
V_{DRIVE}
V_{FILT}
V_{IN}
V_{AMP}
V_{RECT}

Fig. 8

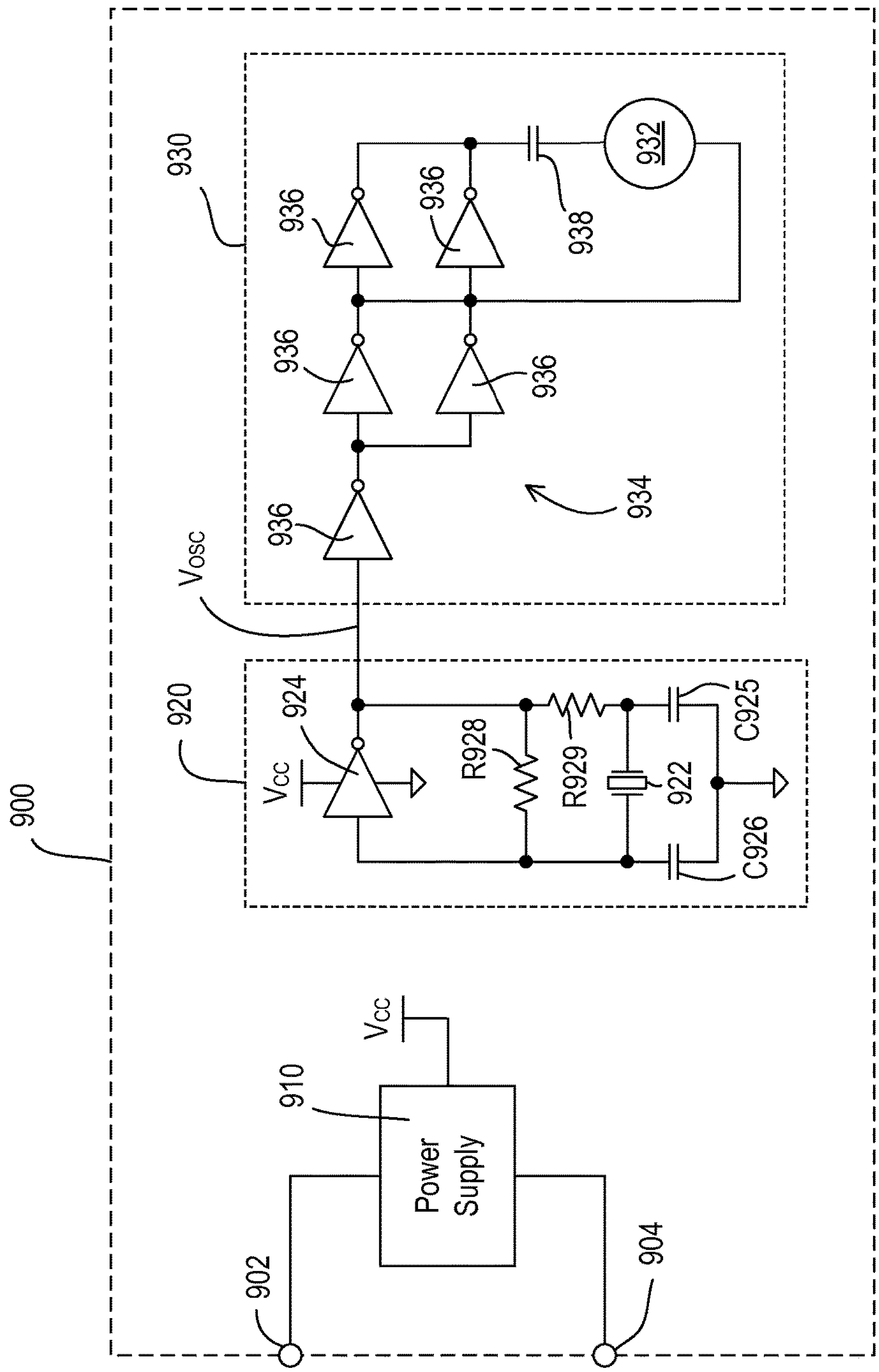

900
902
904
910
Power Supply
Vcc
920
924
Vcc
R928
R929
922
C925
C926
Vosc
930
936
936
936
936
936
938
932
934

Fig. 9

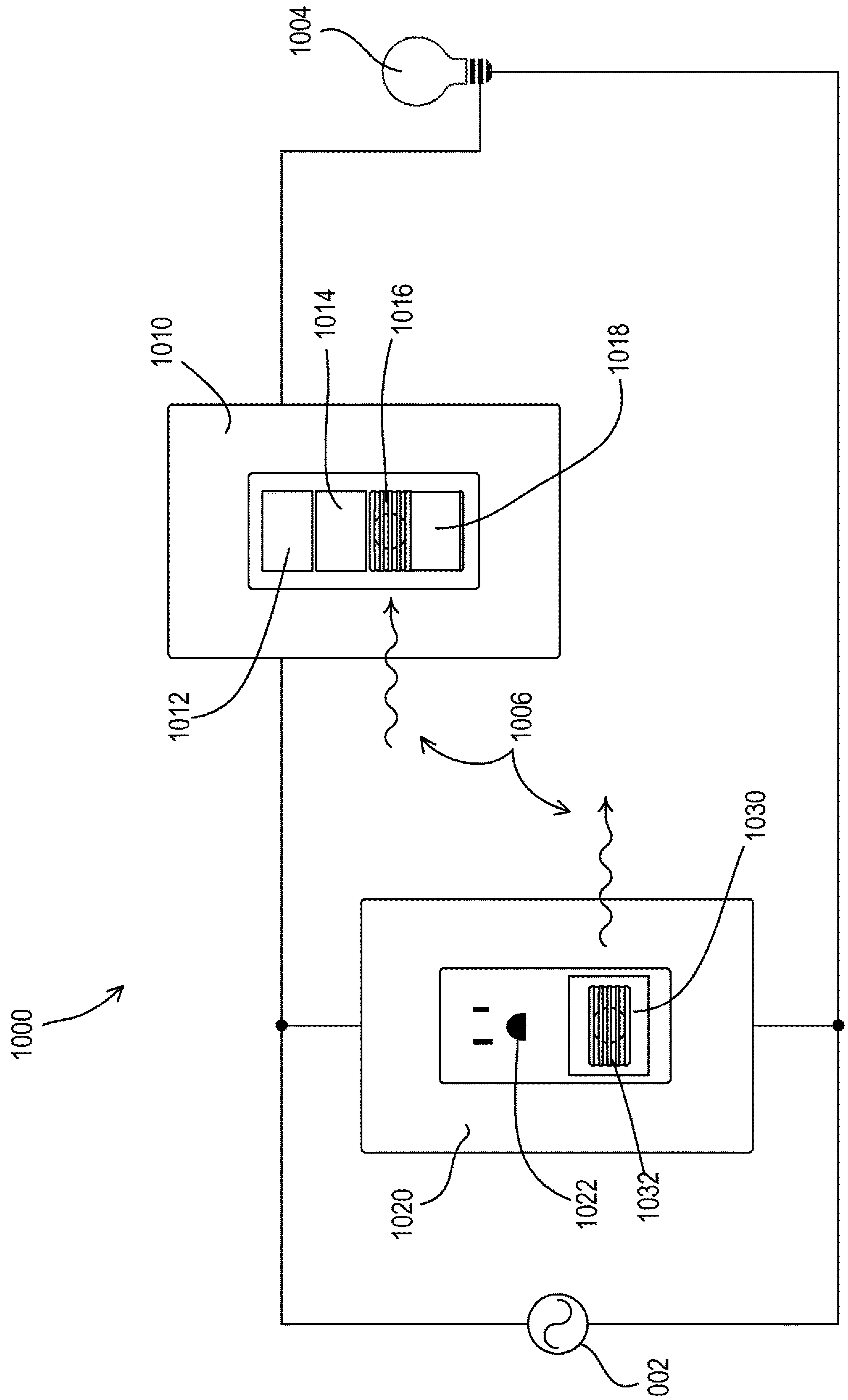

1000
1002
1004
1006
1010
1012
1014
1016
1018
1020
1022
1030
1032

Fig. 10

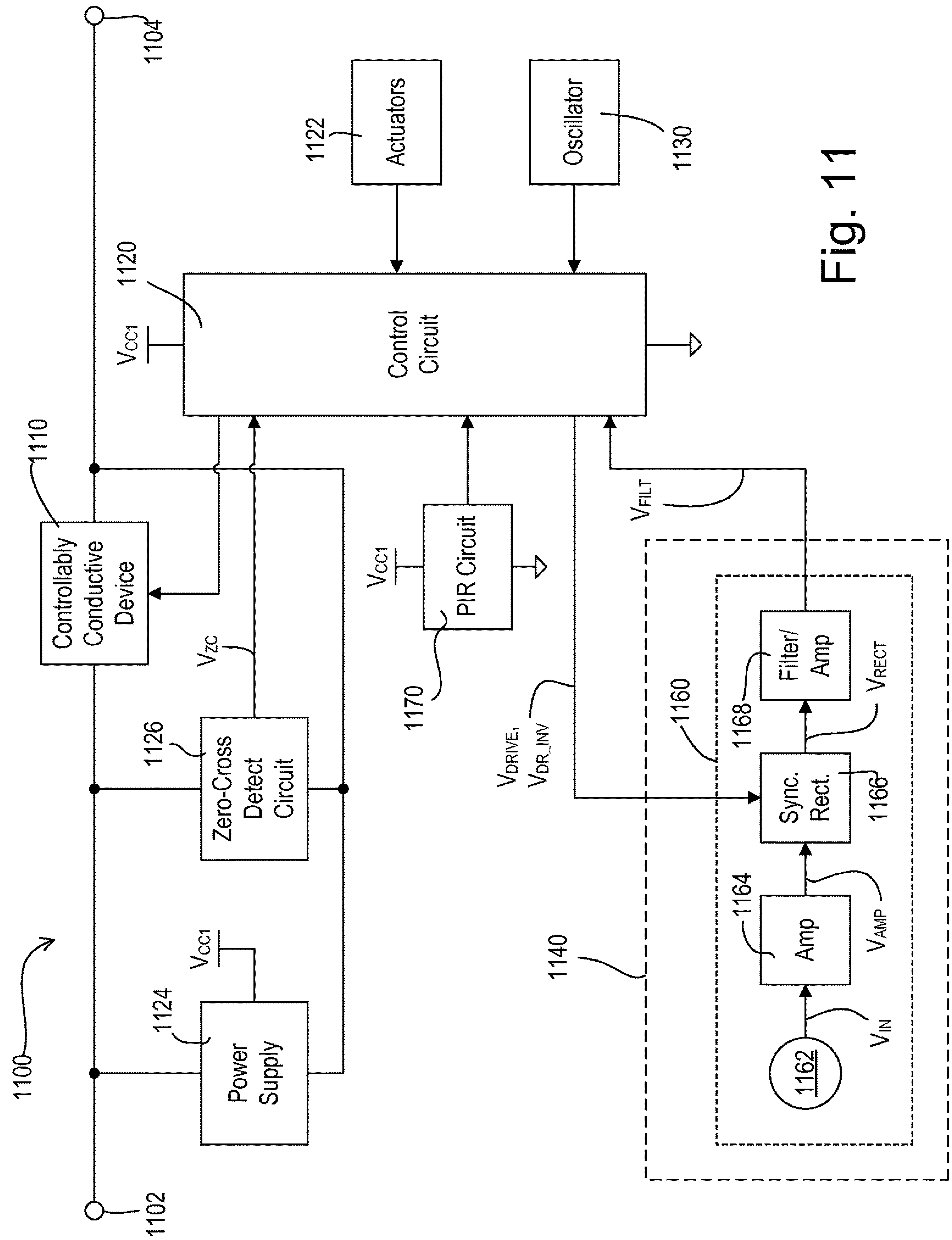

1104
1102
1100
1110
Controllably Conductive Device
1120
Control Circuit
1122
Actuators
1130
Oscillator
1124
Power Supply
1126
Zero-Cross Detect Circuit
1170
PIR Circuit
1140
1160
1162
1164
Amp
1166
Sync. Rect.
1168
Filter/ Amp
V_{CC1}
V_{ZC}
V_{FILT}
V_{DRIVE}, V_{DR_INV}
V_{IN}
V_{AMP}
V_{RECT}

Fig. 11

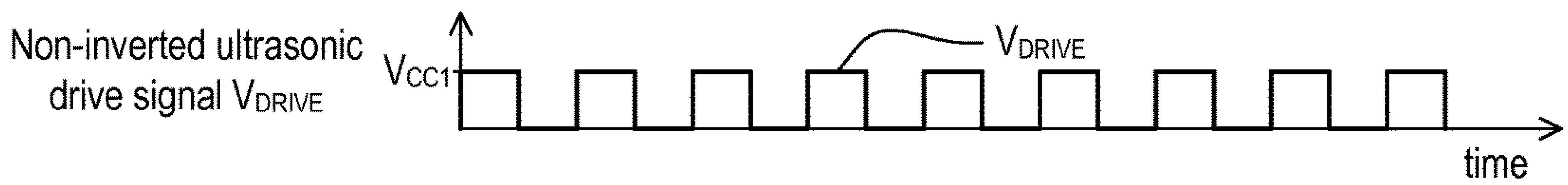


Fig. 12A

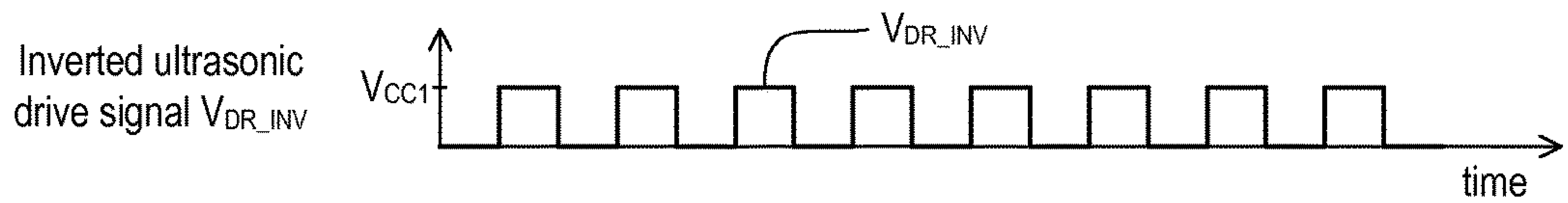


Fig. 12B

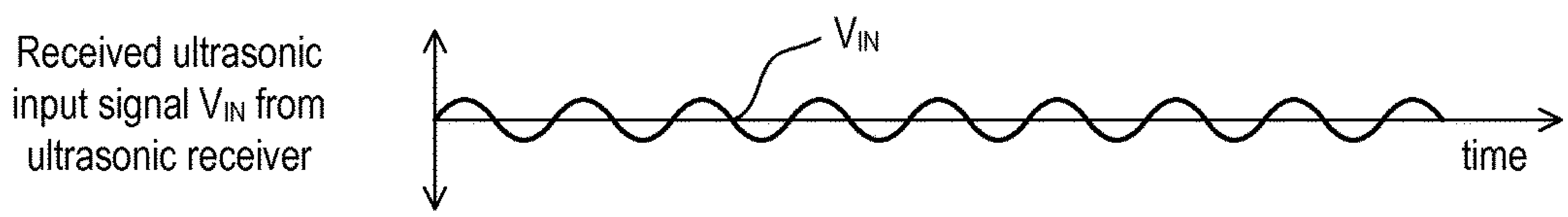


Fig. 12C

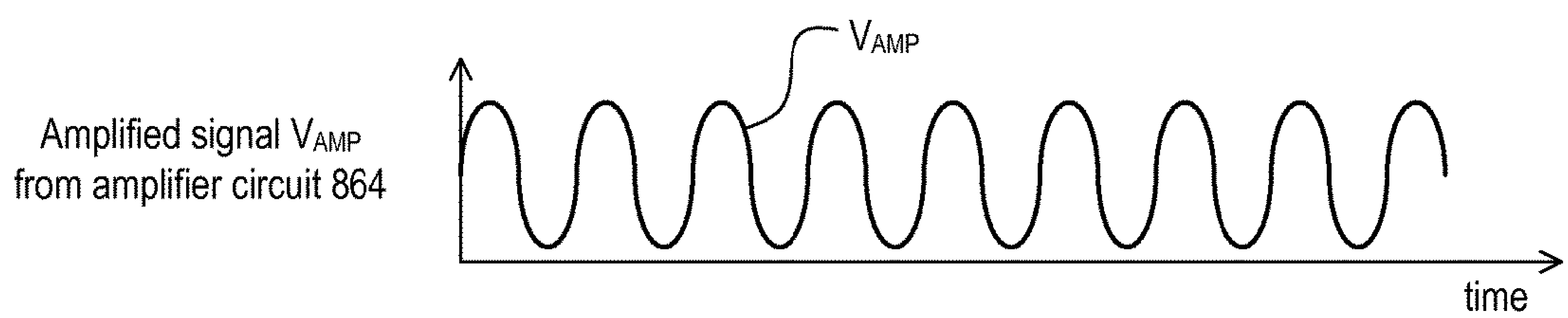


Fig. 12D

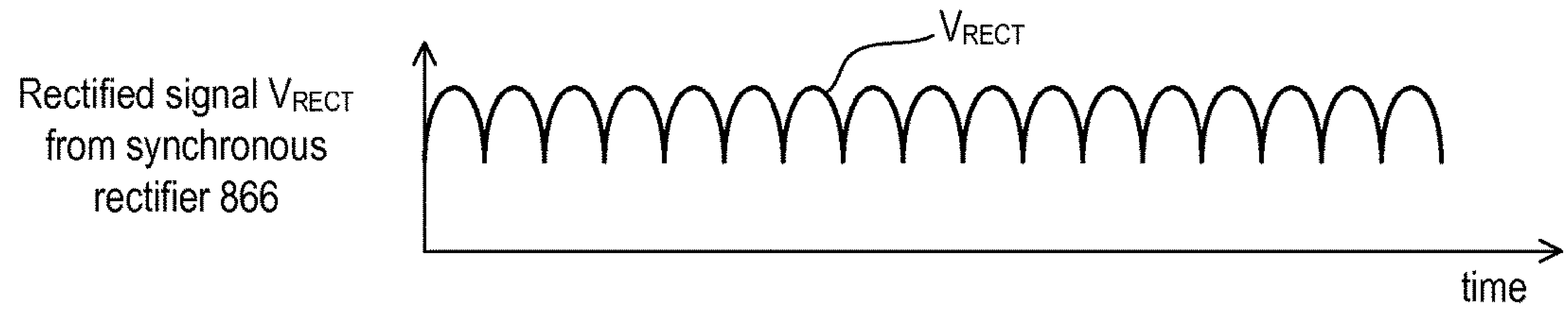


Fig. 12E

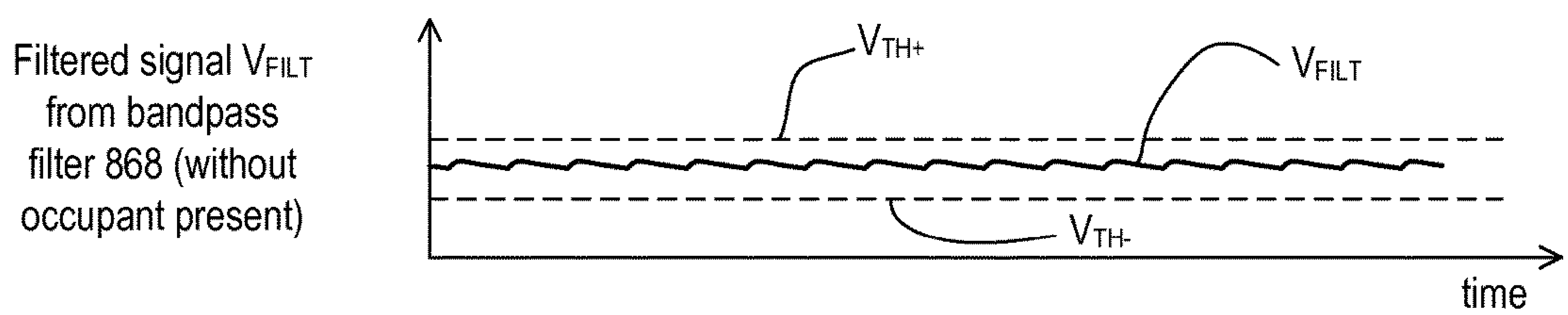


Fig. 12F

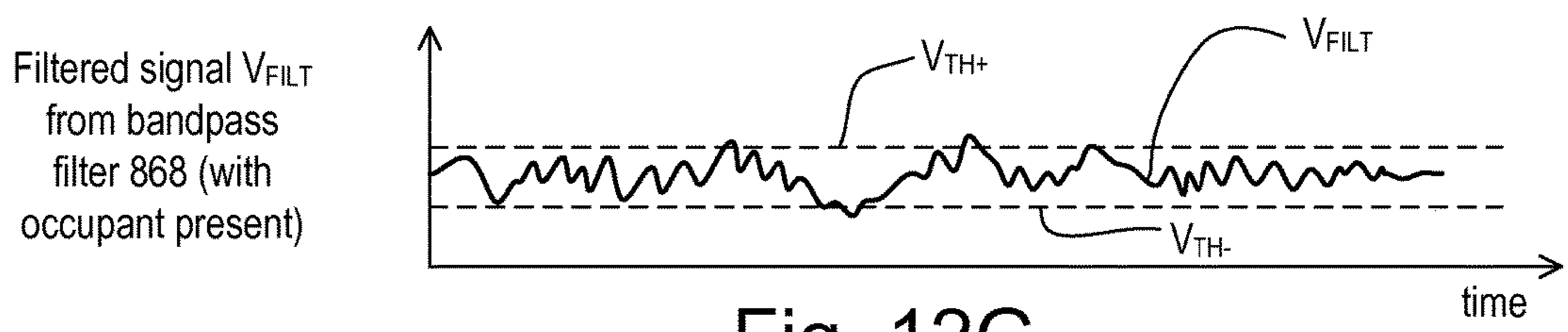


Fig. 12G

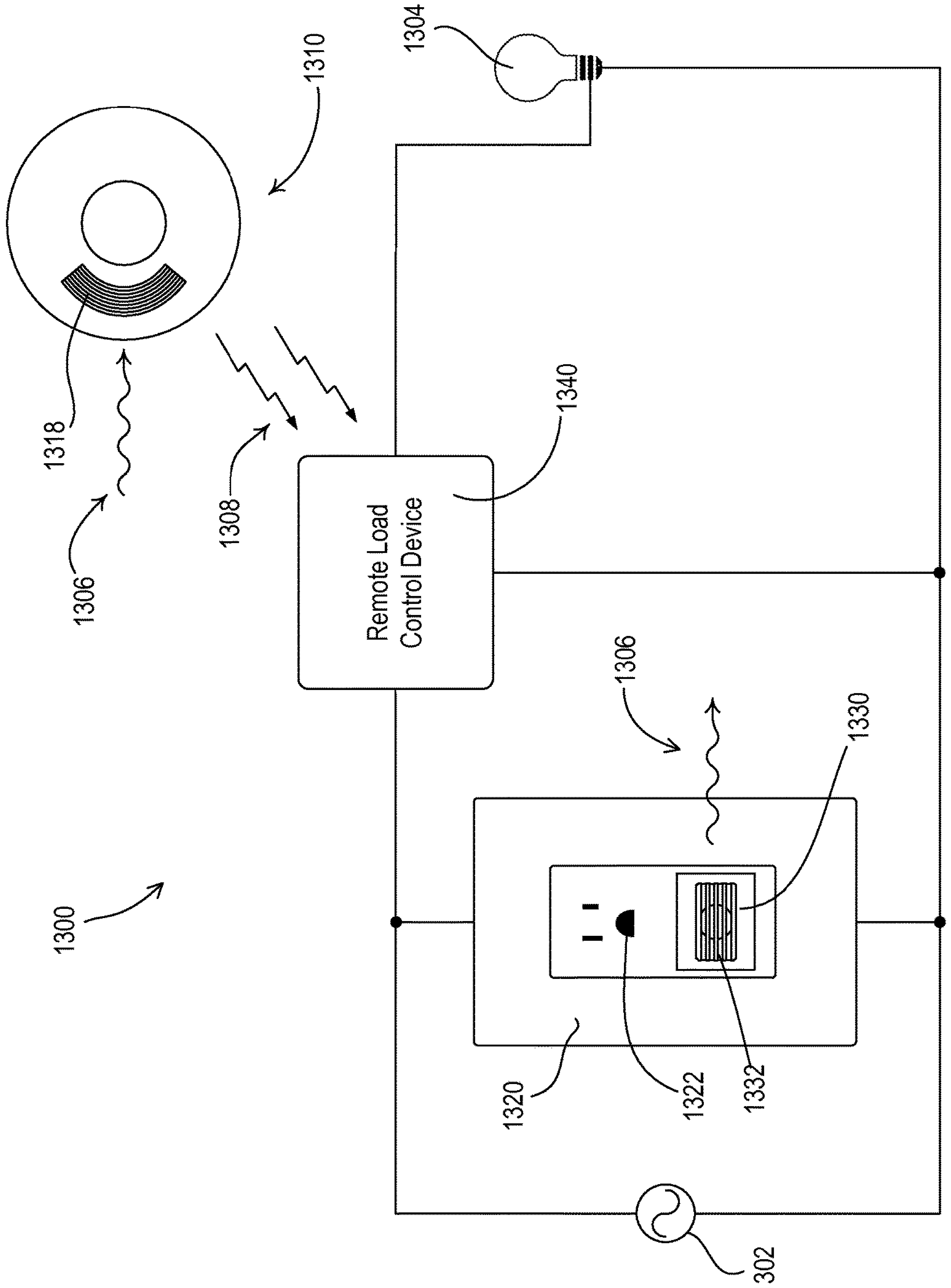

1300
1306
1318
1310
1308
1304
1340
Remote Load Control Device
1306
1330
1320
1322
1332
1302

Fig. 13

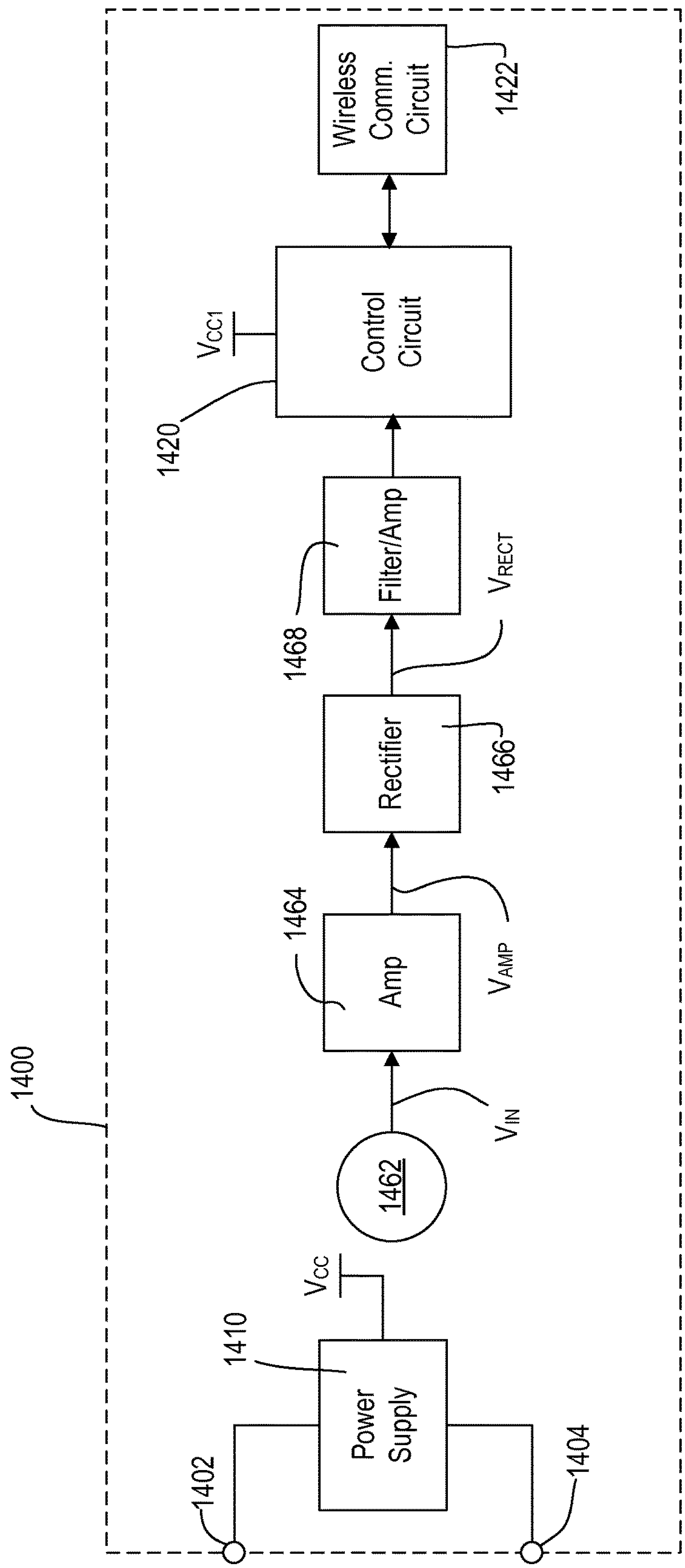

1400
Wireless Comm. Circuit
1422
Control Circuit
V_{CC1}
1420
Filter/Amp
1468
V_{RECT}
Rectifier
1466
Amp
1464
V_{AMP}
1462
V_{IN}
Power Supply
1410
V_{CC}
1402
1404

Fig. 14

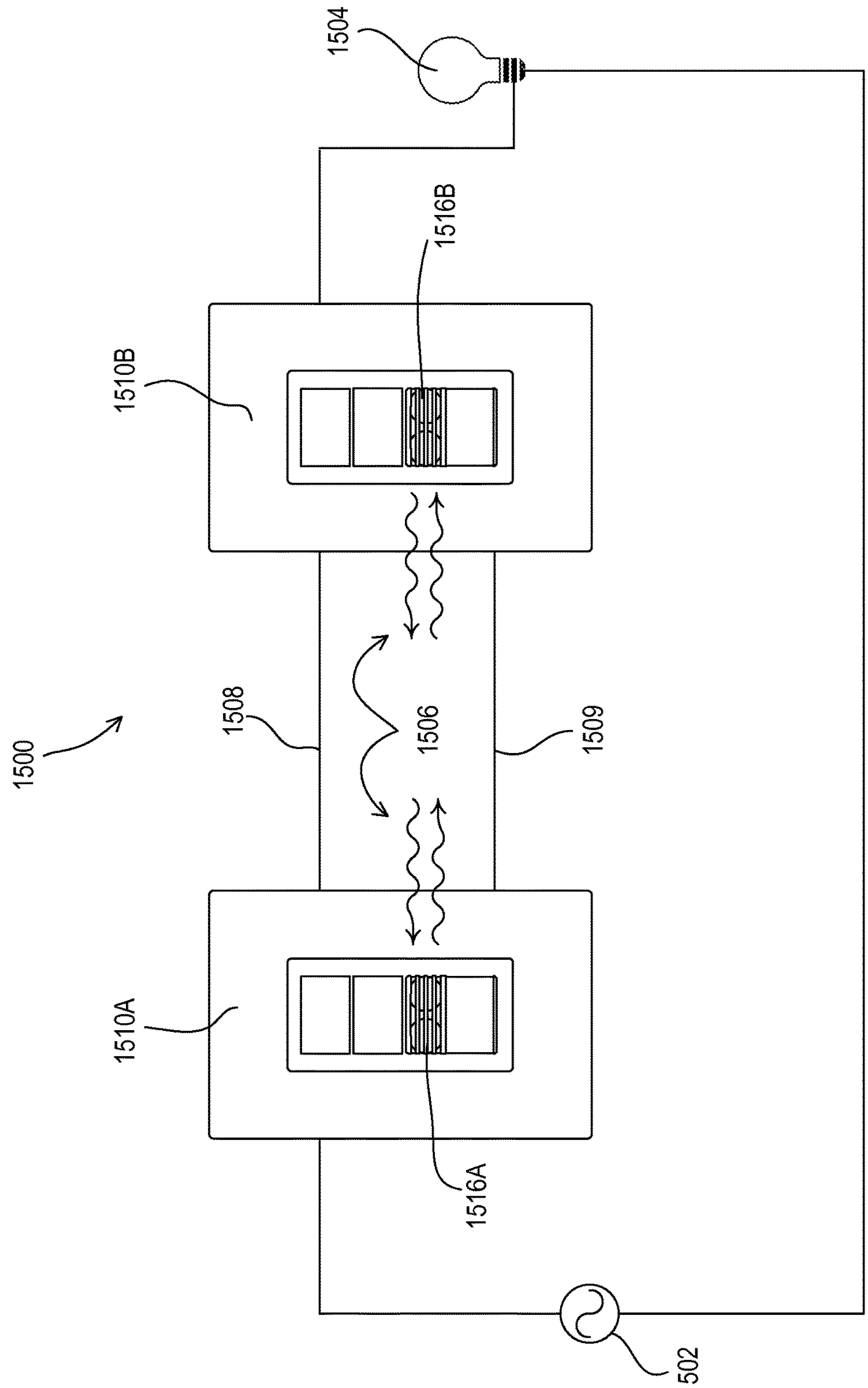


Fig. 15

ULTRASONIC SENSING SYSTEM

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

CROSS REFERENCE TO RELATED APPLICATIONS

This application *is a reissue of U.S. Pat. No. 10,054,916, issued Aug. 21, 2018 from U.S. patent application Ser. No. 14/569,618, filed Dec. 12, 2014, which is hereby incorporated by reference in its entirety. U.S. Pat. No. 10,054,916* claims the benefit of U.S. Provisional Application No. 61/918,008, filed Dec. 12, 2013, which is incorporated by reference herein as if fully set forth.

BACKGROUND

Occupancy and vacancy sensors are often used to detect occupancy and/or vacancy conditions in a space in order to control an electrical load, such as a lighting load. An occupancy sensor typically operates to turn on the lighting load when the occupancy sensor detects the presence of a user in the space (i.e., an occupancy event) and then to turn off the lighting load when the occupancy sensor detects that the user has left the space (i.e., a vacancy event). A vacancy sensor may only operate to turn off the lighting load when the vacancy sensor detects a vacancy in the space. Therefore, when using a vacancy sensor, the lighting load must be turned on manually (e.g., in response to a manual actuation of a control actuator).

Occupancy and vacancy sensors have often been provided in wall-mounted load control devices that are coupled between an alternating-current (AC) power source and an electrical load for control of the amount of power delivered to the electrical load. Some occupancy and vacancy sensors have been provided as part of lighting control systems. These sensors are often coupled via a wired control link to a lighting controller (e.g., a central processor), which then controls the lighting loads accordingly. Alternatively, the sensors may be battery-powered and may be operable to transmit wireless signals, such as radio-frequency (RF) signals, to load control devices, such as dimmer switches. These occupancy and vacancy sensors are not required to be mounted in electrical wallboxes, but may be mounted to the ceiling or high on a wall. Therefore, the occupancy and vacancy sensors may be positioned optimally to detect the presence of the user in all areas of the space.

Occupancy and vacancy sensors typically include internal detectors, such as a pyroelectric infrared (PIR) detector and a lens for directing energy to the PIR detector for detecting the presence of the user in the space. Some occupancy and vacancy sensors have included ultrasonic transmitting and receiving circuits for detecting the presence of the user in the space. Ultrasonic sensors transmit ultrasonic waves at a predetermined frequency and analyze received ultrasonic waves to determine if there is an occupant in the space. The received ultrasonic waves that are reflected off of moving objects will be characterized by a Doppler shift with respect to the transmitted ultrasonic waves, while the received ultrasonic waves that are produced by reflections off of the walls, ceiling, floor, and other stationary objects of the room

will not have a Doppler shift. Therefore, ultrasonic occupancy and vacancy sensors are able to determine if there is an occupant in the space if there is a Doppler shift between the frequencies of the transmitted and received ultrasonic waves.

Generally, the size of the objects that produce the ultrasonic waves having the Doppler shift (i.e., a moving hand) are very small and produce reflected ultrasonic waves having small magnitudes. One of the issues with detecting ultrasonic waves having a Doppler shift is that these received ultrasonic waves can be difficult to distinguish from the received ultrasonic waves that do not have a Doppler shift. A figure of merit for occupancy detection limits can be described using the signal-to-interference ratio (SIR), which is the ratio of the Doppler-shifted ultrasonic waves expressed in sound pressure level (SPL) to the non-Doppler-shifted ultrasonic waves.

One prior art implementation for detecting Doppler shifts in ultrasonic waves uses a phase-lock-loop (PLL) integrated circuit (IC), such as part number CD74HC7046, manufactured by Texas Instruments Incorporated. In this implementation, the received ultrasonic waves are amplified by a pre-amplifier and then compared with a single fixed threshold (e.g., 100 mV) using a comparator to yield a binary waveform. The binary waveform is then applied to an exclusive- or (XOR) gate where the second input to the XOR is a clock input (e.g., a 40-kHz clock signal) that also drives the ultrasonic transmitting circuit. The resulting signal is then passed through a band-pass filter to extract the Doppler signal. The resulting Doppler signal is then compared to a fixed threshold using another comparator to detect an occupancy or vacancy condition. A drawback of this implementation is that the circuit is very sensitive to the thresholds of the comparators and only works on signals with an SIR greater than approximately −40 dB.

Another prior art implementation for detecting Doppler shift utilizes the detection algorithm primarily within a microcontroller. In this implementation, the received ultrasonic waves are amplified by a preamplifier and then sampled using an analog-to-digital converter (e.g., an 8- to 12-bit ADC) in the microcontroller. The remainder of the algorithm is essentially the same as in the first form for detecting Doppler shift described above, except that the remainder of the algorithm of the second form is executed in the software of the microcontroller. This implementation depends on the accuracy of the ADC of the microcontroller and is limited by numerical noise due to the ADC quantization and the numerical precision used to calculate the results, which thus limits the ability to detect small-magnitude ultrasonic waves that have a Doppler shift.

An amplitude-modulation (AM) demodulator may be used to detect Doppler shift. An AM demodulator, in its simplest form, uses a diode and a low-pass filter to form an envelope detector. The limitation of this circuit is that the received ultrasonic signal must have a minimum amplitude to render the diode conductive, thereby reducing the ability of the circuit to detect small-magnitude ultrasonic waves that have a Doppler shift.

FIG. **1** is a diagram of a room **100** (e.g., a classroom) illustrating a detection range **120** of a prior art ultrasonic occupancy sensor **112**. For example, the prior art ultrasonic occupancy sensor **112** may be wall-mounted in an electrical wallbox and may be coupled in series electrical connection between an AC power source and an electrical load (e.g., the lights of the room **100**) for turning the electrical load on and off. The detection range **120** extends from the ultrasonic occupancy sensor **112** into the room. There are large areas of the room, however, that are not covered by the detection range **120** of the single ultrasonic occupancy sensor **112**. Additional ultrasonic occupancy sensors may be added to the room to increase the total detection range. However, this can become costly, as well as complicate installation since there may not be electrical wallboxes or electrical wires installed at the desired locations for the additional ultrasonic occupancy sensors.

SUMMARY

As described herein, a low-cost, simple ultrasonic sensing system may have an increased detection range. The ultrasonic sensing system may be implemented as part of a load control system for controlling the power delivered from an AC power source to an electrical load. The load control system may include a load control device adapted to be coupled in series electrical connection between the AC power source and the electrical load for controlling the power delivered to the electrical load, an ultrasonic receiver for receiving ultrasonic waves characterized by an ultrasonic frequency, and an ultrasonic transmitter located remotely from the ultrasonic receiver. The ultrasonic transmitter is operable to transmit ultrasonic waves at approximately the ultrasonic frequency. The load control device is configured to control the power delivered to the electrical load in response to the ultrasonic waves received by the ultrasonic receiver. For example, the load control device may include the ultrasonic receiver and may be a wall-mounted load control device. Alternatively, the ultrasonic receiver may be a wireless ultrasonic receiver for transmitting wireless signals to the load control device in response to the ultrasonic waves received by the ultrasonic receiver.

An ultrasonic transmitter, as described herein, may include: (1) an ultrasonic transmitting element for transmitting ultrasonic waves; (2) a drive circuit coupled to the ultrasonic transmitting element for energizing the ultrasonic transmitting element; and (3) a low phase-noise oscillator circuit generating an oscillating signal. The oscillator circuit direct drives the drive circuit to cause the ultrasonic transmitting element to transmit the ultrasonic waves at an ultrasonic transmission frequency.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a diagram of a room illustrating a detection range of a prior art ultrasonic occupancy sensor.

FIG. **2** is a simple diagram of an example of a load control system (e.g., an ultrasonic sensing system) comprising a load control device (e.g., an ultrasonic sensor) and a remote ultrasonic transmitter.

FIG. **3** is an example perspective view of a remote ultrasonic transmitter.

FIG. **4** is an example left side view of the remote ultrasonic transmitter of FIG. **3**.

FIG. **5**A is a diagram illustrating ultrasonic waves transmitted by an ultrasonic transmitter and received by an ultrasonic receiver located in a single device, where the ultrasonic waves are reflected off of an occupant.

FIG. **5**B is an example waveform of the ultrasonic waves of FIG. **5**A as reflected off of the occupant.

FIG. **6**A is a diagram illustrating ultrasonic waves transmitted by an ultrasonic transmitter located in a first device and ultrasonic waves received by an ultrasonic receiver located in a second device, where the ultrasonic waves are attenuated by an occupant.

FIG. **6**B is an example waveform of the ultrasonic waves of FIG. **6**A as attenuated by the occupant.

FIG. **7** is a diagram of a room illustrating a detection range of an example ultrasonic sensing system having a load control device and at least one ultrasonic transmitter.

FIG. **8** is a simplified block diagram of an example load control device (e.g., an ultrasonic sensor).

FIG. **9** is a simplified block diagram of an example remote ultrasonic transmitter.

FIG. **10** is a simple diagram of another example of a load control system (e.g., an ultrasonic sensing system) comprising a load control device (e.g., an ultrasonic receiver) and a remote ultrasonic transmitter.

FIG. **11** is a simplified block diagram of another example load control device.

FIG. **12**A shows an example waveform illustrating the operation of the ultrasonic receiving circuit **1160** when there may be a non-inverted ultrasonic drive signal V_{DRIVE}.

FIG. **12**B shows an example waveform illustrating the operation of the ultrasonic receiving circuit **1160** when there may be an inverted ultrasonic drive signal V_{DR_INV}.

FIG. **12**C shows an example waveform illustrating the operation of the ultrasonic receiving circuit **1160** when the ultrasonic receiving circuit **1160** may have received an ultrasonic input signal V_{IN} from an ultrasonic receiver.

FIG. **12**D shows an example waveform illustrating the operation of the ultrasonic receiving circuit **1160** when the ultrasonic receiving circuit **1160** may have received an amplified signal V_{AMP} from the amplified circuit **1164**.

FIG. **12**E shows an example waveform illustrating the operation of the ultrasonic receiving circuit **1160** when the ultrasonic receiving circuit **1160** may have received a rectified signal V_{RECT} from the synchronous rectifier **1166**.

FIG. **12**F shows example waveforms that illustrate the operation of an ultrasonic receiving circuit when there is not an occupant in a space.

FIG. **12**G shows an example waveform that illustrates the operation of an ultrasonic receiving circuit when there is an occupant in a space.

FIG. **13** is a simple diagram of an example load control system (e.g., an ultrasonic sensing system) comprising a wireless ultrasonic sensor (e.g., an ultrasonic receiver) and a remote ultrasonic transmitter.

FIG. **14** is a simplified block diagram of an example remote ultrasonic receiver.

FIG. **15** is a simple diagram of an example three-way load control system (e.g., an ultrasonic sensing system) comprising first and second load control devices (e.g., ultrasonic sensors).

DETAILED DESCRIPTION

FIG. **2** is a simple diagram of an example of a load control system **200** (e.g., an ultrasonic sensing system) comprising a load control device **210** (e.g., an ultrasonic sensor) and a remote ultrasonic transmitter **230**. The load control device **210** may be adapted to be coupled in series electrical connection between an alternating-current (AC) power source **202** and an electrical load (e.g., a lighting load **204**) for controlling the power delivered to the lighting load. For example, the load control device **210** may be adapted to be wall-mounted in a standard electrical wallbox. The load control device **210** may be implemented as a table-top load control device. The load control device **210** may operate as an electronic switch to simply turn on and off the lighting load **204**. The load control device **210** may operate as a dimmer switch to adjust the amount of power delivered to the lighting load **204** and the intensity of the lighting load. The load control device **210** may be coupled to the neutral side of the AC power source **202** and/or an earth ground connection.

As shown in FIG. **2**, the load control device **210** may include two actuators, e.g., an on button **212** and an off button **214**, for respectively turning the electrical load on and off. The load control device **210** may include a single toggle actuator for turning the electrical load on and off, for example, in response to successive actuations. The load control device **210** may include an intensity adjustment actuator (not shown) to allow for adjustment of the intensity of the lighting load **204**. The load control device **210** may include one or more visual indicators (not shown), such as light-emitting diodes (LEDs) arranged in a linear array and illuminated to provide feedback of the intensity of the lighting load **204**. The load control device **210** may be configured to raise the intensity of the lighting load **204** in response to actuations of the upper button (e.g., the on button **212**) and to lower the intensity of the lighting load **204** in response to actuations of the lower button (e.g., the off button **214**).

The load control device **210** may operate as an occupancy sensor to turn the lighting load **204** on in response to the presence of an occupant in the vicinity of the load control device (e.g., an occupancy condition), or off in response to the absence of the occupant (e.g., a vacancy condition). The load control device **210** may include an internal ultrasonic occupancy detection circuit operable to transmit and receive ultrasonic waves **206** via an acoustic grill **216** (e.g., a vent) for detecting the presence or absence of the occupant. The load control device **210** may be operable to determine whether an occupancy condition or a vacancy condition is presently occurring in the space in response to the ultrasonic waves received by the ultrasonic occupancy detection circuit, as will be described in greater detail below. The load control device **210** may operate as a vacancy sensor. When operating as a vacancy sensor, the load control device **210** may only operate to turn off the lighting load **204** in response to detecting a vacancy condition in the space. For example, the load control device **210** would not turn on the lighting load **204** in response to detecting an occupancy condition. When the load control device **210** operates as a vacancy sensor, the lighting load **204** must be turned on manually (e.g., in response to a manual actuation of the on button **212**).

The load control device **210** may include an internal passive infrared (PIR) occupancy detection circuit for detecting the presence or absence of the occupant, i.e., the load control device **210** may be a dual-tech occupancy sensor. The load control device **210** may include a lens **218** for directing the infrared energy from the occupant to the internal PIR occupancy detection circuit. Examples of occupancy and vacancy sensors having PIR occupancy detection circuits are described in greater detail in commonly-assigned U.S. Pat. No. 8,009,042, issued Aug. 30, 2013, entitled RADIO-FREQUENCY LIGHTING CONTROL SYSTEM WITH OCCUPANCY SENSING, the entire disclosure of which is hereby incorporated by reference. The load control device **210** may include a microwave detector, or any suitable detector or combination of detectors, for detecting the presence or absence of the occupant.

The load control system **200** may include an electrical outlet **220** that is coupled in parallel with the AC power source **202** and has, for example, two electrical receptacles **222**. The remote ultrasonic transmitter **230** may be plugged into one of the electrical receptacles **222** of the electrical outlet **220** as shown in FIG. **2**. FIG. **3** is an example perspective view, and FIG. **4** is an example left side view of the remote ultrasonic transmitter **230**. The ultrasonic transmitter **230** may be operable to transmit ultrasonic waves **206** via an acoustic grill **232** (e.g., a vent). The ultrasonic waves **206** transmitted by the ultrasonic transmitter **230** may be received by the ultrasonic occupancy detection circuit of the load control device **210** for improving the ability of the load control device to detect the presence or absence of the occupant, as described herein. The ultrasonic transmitter may have electrical prongs **434** (e.g., blades) adapted to be plugged into the electrical receptacle **222**, such that the ultrasonic transmitter **230** may be powered from the AC power source **202**. The ultrasonic transmitter **230** may be battery powered and located at a position distinct from the electrical outlet **220**. The ultrasonic transmitter **230** may be powered by an external direct-current (DC) power supply (not shown) plugged into the electrical outlet **220**, or plugged into a Universal Serial Bus (USB) port on a device capable of supplying power to the ultrasonic transmitter.

FIG. **5**A is a diagram illustrating ultrasonic waves **506**, **508** transmitted by an ultrasonic transmitter **510** and received by an ultrasonic receiver **520** located in a single device **500** (e.g., the load control device **200** shown in FIG. **2**). The transmitted ultrasonic waves **506** are emitted by the ultrasonic transmitter **510** and are reflected off of an occupant **505**. FIG. **5**B is an example waveform of the received (e.g., reflected) ultrasonic waves **508** as reflected off of the occupant **505**. The example waveform of the received ultrasonic waves **508** shown in FIG. **5**B is characterized by a period **540** of frequency modulation (e.g., a Doppler shift) due to the reflection off of the occupant **505**. The ultrasonic transmitter **510** may continuously transmit ultrasonic waves. When ultrasonic waves **506** reflect off of an occupant **505**, the ultrasonic waves experience a frequency modulation which the ultrasonic receiver **520** detects. The load control device may be responsive to the frequency modulation of the received ultrasonic waves that is detected by the ultrasonic receiver **520**.

FIG. **6**A is a diagram illustrating ultrasonic waves **606** transmitted by an ultrasonic transmitter **610** located in a first device **600** (e.g., the ultrasonic transmitter **230** of FIG. **2**) and ultrasonic waves **608** received by an ultrasonic receiver **620** located in a second device **602** (e.g., the load control device **200** of FIG. **2**). The ultrasonic transmitter **610** may continuously transmit ultrasonic waves **606**. The transmitted ultrasonic waves **606** may be emitted by the ultrasonic transmitter **610**. The ultrasonic waves **606** may be momentarily attenuated by an occupant **605**.

FIG. **6**B is an example waveform of the received ultrasonic waves **608** as attenuated by the occupant **605**. The example waveform of the received ultrasonic waves **608** shown in FIG. **6**B may be characterized by a period **640** of amplitude modulation due to the attenuation by the occupant **605**. The received ultrasonic waves **608** may also be characterized by a Doppler shift.

FIG. **7** is a diagram of a room **700** (e.g., a classroom) illustrating a detection range **720** of an example ultrasonic sensing system (e.g., the load control system **200** of FIG. **2**). The ultrasonic sensing system installed in the room **700** may have a wall-mounted ultrasonic sensor **710** (e.g., the load control device **210** of FIG. **2**) and two ultrasonic transmitters **712** (e.g., the ultrasonic transmitter **230** of FIG. **2** and/or the ultrasonic transmitter **610** of FIG. **6**A). For example, the wall-mounted ultrasonic sensor **710** may be mounted in an electrical wallbox and may be coupled in series electrical connection between an AC power source and an electrical load (e.g., the lights of the room **700**) for turning the electrical load on and off. The wall-mounted ultrasonic sensor **710** may include an ultrasonic transmitter (e.g., the ultrasonic transmitter **510** of FIG. **5**A) and an ultrasonic receiver (e.g., the ultrasonic receiver **520** of FIG. **5**A and/or the ultrasonic receiver **620** of FIG. **6**A). The ultrasonic waves transmitted by the ultrasonic transmitter of the wall-mounted ultrasonic sensor **710** may be reflected off of an occupant of the room **700** and received by the ultrasonic receiver of the wall-mounted ultrasonic sensor **710** (e.g., as shown in FIGS. **5**A and **5**B).

The ultrasonic transmitters **712** are simple, low-cost devices and operate to transmit the ultrasonic waves. The ultrasonic transmitters **712** may be spaced about the room **700** and may be, for example, plugged into electrical outlets in the room. The ultrasonic transmitters **712** may be located on a surface, such as a tabletop or a chair, or in a wallbox housing a switch for an LED light bulb (e.g., as described with reference to FIG. **13**). The ultrasonic waves transmitted by the ultrasonic transmitters **712** may be momentarily attenuated by an occupant of the room **700** and received by the ultrasonic receiver of the wall-mounted ultrasonic sensor **710** (e.g., as shown in FIGS. **6**A and **6**B). The resulting detection range **720** of the example ultrasonic sensing system having the wall-mounted ultrasonic sensor **710** and the two ultrasonic transmitters **712** may include, for example, substantially all of the area of the room **700** as shown in FIG. **7**. Since the ultrasonic transmitters **712** are simple, low-cost devices, the ultrasonic transmitters allow for an increased detection range (e.g., detection range **720**) without greatly increasing the total cost of the ultrasonic sensing system since multiple wall-mounted ultrasonic sensors do not need to be installed around the room **700**.

FIG. **8** is a simplified block diagram of an example load control device **800** (e.g., the load control device **210** of FIG. **2** and/or the wall-mounted ultrasonic sensor **710** of FIG. **7**). The load control device **800** may include a first electrical connection (e.g., a hot terminal **582**) adapted to be coupled to an AC power source (e.g., the AC power source **202** of FIG. **2**) and a second electrical connection (e.g., a load terminal **804**) adapted to be coupled to an electrical load (e.g., the lighting load **204** of FIG. **2**). The load control device **800** may include a neutral terminal (not shown) adapted to be coupled to the neutral side of the AC power source and/or an earth ground connection (not shown) adapted to be coupled to earth ground.

The load control device **800** may include a controllably conductive device **810** coupled in series electrical connection between the hot terminal **802** and the load terminal **804** for controlling the power delivered to the electrical load. The controllably conductive device **810** may include, for example, a relay, a bidirectional semiconductor switch (such as, a triac, a FET in a rectifier bridge, two FETs in anti-series connection, or one or more insulated-gate bipolar junction transistors), or any other suitable switching circuit.

The load control device **800** may include a control circuit **820** that is coupled to the controllably conductive device **810** for rendering the controllably conductive device conductive and/or non-conductive to control the power delivered to the electrical load. For example, the control circuit **820** may include a microcontroller, a programmable logic device (PLD), a microprocessor, an application specific integrated circuit (ASIC), a field-programmable gate array (FPGA), or any suitable processing device, controller, or control circuit. The control circuit **820** may receive inputs from actuators **822** (e.g., the on button **212** and the off button **214** of the load control device of FIG. **2**). The control circuit **820** may be

coupled to a memory (not shown) for storage of the operational characteristics of the load control device **800**. The memory may be implemented as an external integrated circuit (IC) or as an internal circuit of the control circuit **820**. A power supply **824** may generate a first DC supply voltage V_{CC1} (e.g., approximately 3 volts) for powering the control circuit **820**. The power supply **824** may generate a second DC supply voltage V_{CC2} (e.g., approximately 12 volts) for powering other circuitry of the load control device **800**, for example, as described herein.

A zero-cross detect circuit **826** may be coupled between the hot terminal **802** and the load terminal **804**. The zero-cross detect circuit **826** may generate a zero-cross control signal V_{ZC}. The zero-cross control signal V_{ZC} may be representative of the zero-crossings of an AC source voltage of the AC power source. A zero-crossing may be defined at the time at which the AC source voltage transitions from positive to negative polarity, at the time at which the AC source voltage transitions from negative to positive polarity, or at the beginning of each half-cycle. The zero-cross control signal V_{ZC} may be received by the control circuit **820**. The control circuit **820** may control the controllably conductive device **810** to be conductive and/or non-conductive at predetermined times relative to the zero-crossing points of the AC source voltage.

The load control device **800** may include a wireless communication circuit **828**, for example, including a radio-frequency (RF) transceiver coupled to an antenna for transmitting and receiving wireless signals (e.g., RF signals from a remote ultrasonic receiver or a remote ultrasonic transmitter). The communication circuit **828** may comprise an RF transmitter for transmitting RF signals, an RF receiver for receiving RF signals, or an infrared (IR) transmitter and/or receiver for transmitting and/or receiving IR signals. The wireless communication circuit **828** may be in electrical communication with the control circuit **820** of the load control device **800**, such that one or more wireless signals received from the ultrasonic receiver may cause the load control device to adjust the lighting on or off. The antenna of the wireless communication circuit **828** may be enclosed in the housing of the load control device **800** or coupled to the exterior portion of the housing.

The control circuit **820** may be coupled to a low phase-noise oscillator circuit **530** for setting an internal operating frequency for of the control circuit (e.g. approximately 40 kHz±2 Hz). The low phase-noise oscillator circuit **830** may include, for example, a Pierce oscillator circuit (as shown in FIG. **8**) having a crystal **832**, such as a 40-kHz piezoelectric crystal, e.g., part number CM250C, manufactured by Citizen Crystal. For example, the low phase-noise oscillator circuit **830** may be characterized by a spectral purity of approximately −60 dBc at 5 Hz from the rated frequency (i.e., 40 kHz±2 Hz). The low phase-noise oscillator circuit **830** may include an inverter **834**, two capacitors C**835**, C**836** (e.g., each having a capacitance of approximately 12 pF), and two resistors R**838**, R**839** (e.g., having resistances of approximately 10 MΩ and 392 kΩ, respectively). The low phase-noise oscillator circuit **830** may include any suitable external low phase-noise oscillator circuit, or an internal low phase-noise oscillator circuit of the control circuit **820**.

The load control device **800** may include an ultrasonic sensing circuit **840** having an ultrasonic transmitting circuit **850** and an ultrasonic receiving circuit **860**. The ultrasonic transmitting circuit **850** may include a drive circuit **854** (e.g., an H-bridge drive circuit). The drive circuit **854** may receive the second DC supply voltage V_{CC2} for energizing a piezoelectric element **852**, for example, in order to transmit ultrasonic waves from the load control device **800** (e.g., via an acoustic grill, such as the acoustic grill **216** of the load control device **200** shown in FIG. **2**). The control circuit **820** may drive the drive circuit **854** with an ultrasonic drive signal V_{DRIVE}, such as a square wave signal having an ultrasonic transmission frequency f_{OP} that may be equal to the operating frequency f_{OP} of the control circuit (e.g., approximately 40 kHz±2 Hz). Since the operating frequency for of the control circuit **820** is derived from the low phase-noise oscillator circuit **830**, the ultrasonic drive signal V_{DRIVE} and the ultrasonic transmission frequency f_{US} may be characterized by low phase noise.

The ultrasonic receiving circuit **860** may include a piezoelectric element **862**. The piezoelectric element **862** may generate a received ultrasonic input signal V_{IN} in response to the received ultrasonic waves (e.g., the received ultrasonic waves shown in FIGS. **5**B and **6**B). The input signal V_{IN} may be received by an amplifier **864** (e.g., a non-linear amplifier). The amplifier **864** may generate an amplified signal V_{AMP} and may be characterized by a gain of approximately 20 dB. The ultrasonic receiving circuit **860** may include a rectifier circuit **866** (e.g., an asynchronous rectifier). The rectifier circuit **866** may receive the amplified signal V_{AMP} from the amplifier circuit **864** and generate a rectified signal V_{RECT}. For example, the rectifier circuit **866** may include a diode feeding the parallel combination of a resistor and a capacitor. Since the ultrasonic receiving circuit **860** of the load control device **800** may receive some of the unreflected ultrasonic waves transmitted by the ultrasonic transmitting circuit **850**, the magnitude of the amplified signal V_{AMP} received by the rectifier circuit **866** may be greater than the forward drop of the diode of the rectifier circuit, such that the rectifier circuit may properly generate the rectified signal V_{RECT}. The rectifier circuit **866** may include a synchronous rectifier as described in commonly-assigned U.S. Pat. No. 8,514,075, issued Aug. 20, 2013, entitled ULTRASONIC RECEIVING CIRCUIT, the entire disclosure of which is hereby incorporated by reference.

A filter and amplifier circuit **868** (e.g., an anti-aliasing filter, such as a bandpass filter) may generate a filtered signal V_{FILT} from the rectified signal V_{RECT}. The filter and amplifier circuit **868** may have a bandwidth of approximately 50-500 Hz. The filter and amplifier **868** may be characterized by a gain of approximately 60 dB. The control circuit **820** may receive the filtered signal V_{FILT} from the filter and amplifier circuit **868**. The control circuit **820** may sample the filtered signal using, for example, an analog-to-digital converter (ADC). The control circuit **820** is operable to detect the presence of the occupant in the space, for example, if the magnitude of the filtered signal V_{FILT} rises above an upper voltage threshold or falls below a lower voltage threshold. In addition, the control circuit **820** may be operable to digitally filter the filtered signal V_{FILT} received from the filter and amplifier circuit **868** to provide additional filtering of the signal before determining if the space is occupied or unoccupied.

The load control device **800** may include a passive infrared (PIR) sensing circuit **870**, e.g., comprising a pyroelectric infrared detector for receiving infrared energy of the occupant through a lens of the load control device (e.g., the lens **218** of the load control device **200** shown in FIG. **2**). The PIR sensing circuit **870** may generate a PIR sense signal V_{PIR} representative of the magnitude of the received infrared energy. The control circuit **820** may analyze both the filtered signal V_{FILT} received from the ultrasonic receiving circuit **860** and the PIR sense signal V_{PIR} received from the PIR sensing circuit **870**, for example, to determine if an occupancy condition or a vacancy condition is presently occurring in the space. Examples of PIR sensing circuits are described in greater detail in commonly-assigned U.S. Pat. No. 8,228,184, issued Jul. 24, 2012, entitled BATTERY-POWERED OCCUPANCY SENSOR, the entire disclosure of which is hereby incorporated by reference.

FIG. **9** is a simplified block diagram of an example remote ultrasonic transmitter **900** (e.g., the remote ultrasonic transmitter **230** of FIG. **2** and/or the ultrasonic transmitters **712** of FIG. **7**). The ultrasonic transmitter **900** may include a power supply **910** operable to receive power via electrical connections **902**, **904**. The ultrasonic transmitter **900** may include a power supply **910** to generate a DC supply voltage V_{CC} (e.g., approximately 12 volts). For example, the electrical connections **902**, **904** may have prongs (e.g., the prongs **434** shown in FIG. **4**) adapted to be plugged into a receptacle of an electrical outlet for powering the ultrasonic transmitter **900** from an AC power source. The power supply **910** may be operable to convert the AC source voltage of the AC power source to the DC supply voltage V_{CC}. The electrical connections **902**, **904** may be adapted to be coupled to an external DC power supply for receiving a DC source voltage. The power supply **910** may be a DC-to-DC converter for converting the DC source voltage to the DC supply voltage V_{CC}. The power supply **910** may be replaced by one or more batteries.

The ultrasonic transmitter **900** may include a low phase-noise oscillator circuit **920**, such as for driving an ultrasonic transmitting circuit **930**. The oscillator circuit **920** may generate an oscillating signal V_{OSC} (e.g., a square wave) at an ultrasonic transmission frequency f_{US} (e.g., approximately 40 kHz±2 Hz) for driving the ultrasonic transmitting circuit **930**. As shown in FIG. **9**, the oscillator circuit **920** may comprise, for example, a Pierce oscillator circuit having a crystal **922**, such as a 40-kHz piezoelectric crystal, e.g., part number CM250C, manufactured by Citizen Crystal. For example, the low phase-noise oscillator circuit **920** may be characterized by a spectral purity of approximately −60 dBc at 5 Hz from the rated frequency (i.e., 40 kHz±2 Hz). The low phase-noise oscillator circuit **920** may include an inverter **924**, two capacitors C**925**, C**926** (e.g., each having a capacitance of approximately 12 pF), and two resistors R**628**, R**629** (e.g., having resistances of approximately 10 MΩ and 392 kΩ, respectively). The oscillating signal V_{OSC} may be generated at an output of the oscillator circuit **920** (e.g., the output of the inverter **924**).

The ultrasonic transmitting circuit **930** may include a drive circuit **932** for energizing a piezoelectric element **934**, for example, to transmit ultrasonic waves from the ultrasonic transmitter **900** (e.g., through an acoustic grill, such as the acoustic grill **232** of the ultrasonic transmitter **230** shown in FIG. **2**). The drive circuit **932** may receive the oscillating signal V_{OSC} from the oscillator circuit **920** (e.g., the drive circuit **932** may be directly driven by the output of the oscillator circuit). The drive circuit **932** may have a plurality of inverters **936** that may be coupled to the piezoelectric element **934**, for example, to generate the ultrasonic waves at the ultrasonic transmission frequency f_{US}. The piezoelectric element **934** may be coupled in series with a capacitor **938** (e.g., having a capacitance of approximately 1 μF). The inverter **924** of the oscillator circuit **920** and the inverters **936** of the ultrasonic transmitter circuit **930** may be implemented on a single integrated circuit (e.g., part number CD4049UB, manufactured by Texas Instruments), which may be powered by the DC supply voltage V_{CC}.

FIG. **10** is a simple diagram of another example of a load control system **1000** (e.g., an ultrasonic sensing system) comprising a load control device **1010** (e.g., an ultrasonic receiver) and a remote ultrasonic transmitter **1030** (e.g., the ultrasonic transmitter **900** shown in FIG. **9**). The load control device **1010** may be adapted to be coupled in series electrical connection between an AC power source **1002** and an electrical load (e.g., a lighting load **1004**) for controlling the power delivered to the lighting load. The remote ultrasonic transmitter **1030** may be operable to be plugged into a receptacle **1022** of an electrical outlet **1020**. The remote ultrasonic transmitter **1030** may transmit ultrasonic waves **1006** via an acoustic grill **1032** at an ultrasonic transmission frequency f_{US} (e.g., approximately 40 kHz±2 Hz).

The load control system **1000** of FIG. **10** may be similar to the load control system **200** shown in FIG. **2**. The load control device **1010** of the load control system **1000** of FIG. **10** may include an ultrasonic occupancy detection circuit having an ultrasonic receiver, such that the load control system **1000** operates, for example, as shown in FIGS. **6**A and **6**B. Because the load control device **1010** may not have an ultrasonic transmitter and the ultrasonic receiver of the load control device may only receive the ultrasonic waves transmitted by the remote ultrasonic transmitter **1030** (e.g., ultrasonic waves having small magnitudes), the ultrasonic receiver includes a synchronous rectifier. The synchronous rectifier may be responsive to small signals, as described herein. The ultrasonic receiver of the load control device **1010** may be operable to receive ultrasonic waves via an acoustic grill **1016**. The load control device **1010** may include a PIR occupancy detection circuit operable to detect the presence of an occupant via infrared energy received through a lens **1018**. The load control device **1010** may be operable to turn the lighting load **1004** on and off in response to the ultrasonic occupancy detection circuit and/or the PIR occupancy detection circuit (e.g., as described above with reference to the load control device **800** of FIG. **8**). The load control device **1010** may have an on button **1012** and an off button **1014** to provide manual control of the lighting load **1004**.

FIG. **11** is a simplified block diagram of a load control device **1100** (e.g., the load control device **1010** of FIG. **10**). The load control device **1100** may include a hot terminal **1102** adapted to be coupled to an AC power source (e.g., the AC power source **1002** of FIG. **10**). The load control device **1100** may include a load terminal **1104** adapted to be coupled to an electrical load (e.g., the lighting load **1004** of FIG. **10**). The load control device **1100** may include a controllably conductive device **1110** coupled in series electrical connection between the hot terminal **1102** and the load terminal **1104**, for example, to control the power delivered to the electrical load. The controllably conductive device **1110** may comprise, for example, a relay, a bidirectional semiconductor switch (such as, a triac, a FET in a rectifier bridge, two FETs in anti-series connection, or one or more insulated-gate bipolar junction transistors), or any other suitable switching circuit.

The load control device **1100** may include a control circuit **1120** for controlling the controllably conductive device **1110** to be conductive and/or non-conductive to control the power delivered to the electrical load. For example, the control circuit **1120** may have a microcontroller, a programmable logic device (PLD), a microprocessor, an application specific integrated circuit (ASIC), a field-programmable gate array (FPGA), or any suitable processing device, controller, or control circuit. The control circuit **1120** may receive inputs from actuators **1122** (e.g., the on button **1012** and the off button **1014** of the load control device **1010** of FIG. **10**). The control circuit **1120** may receive a zero-cross control signal V_{ZC} that may be representative of the zero-crossings of an AC source voltage of the AC power source from a zero-cross detect circuit **1126**. The control circuit **1120** may be coupled to an internal or external memory (not shown) for storage of the operational characteristics of the load control device **1100**. The control circuit **1120** may be coupled to a low phase-noise oscillator circuit **1130** (e.g., similar to the low phase-noise oscillator circuit **820** shown in FIG. **8**), for example, to set an internal operating frequency f_{OP} of the control circuit (e.g., approximately 40 kHz±2 Hz). A power supply **1124** may generate a DC supply voltage V_{CC} (e.g., approximately 3 volts) for powering the control circuit **1120** and/or other low-voltage circuitry of the load control device **1100**.

The load control device **1100** may have an ultrasonic sensing circuit **1140**. The ultrasonic sensing circuit **1140** may include an ultrasonic receiving circuit **1160**. For example, the ultrasonic sensing circuit **1140** may include an ultrasonic receiving circuit **1160**. FIG. **12**A shows an example waveform illustrating the operation of the ultrasonic receiving circuit **1160** when there may be a non-inverted ultrasonic drive signal V_{DRIVE}.

FIG. **12**B shows an example waveform illustrating the operation of the ultrasonic receiving circuit **1160** when there may be an inverted ultrasonic drive signal V_{DR_INV}.

FIG. **12**C shows an example waveform illustrating the operation of the ultrasonic receiving circuit **1160** when the ultrasonic receiving circuit **1160** may have received an ultrasonic input signal V_{IN} from an ultrasonic receiver.

FIG. **12**D shows an example waveform illustrating the operation of the ultrasonic receiving circuit **1160** when the ultrasonic receiving circuit **1160** may have received an amplified signal V_{AMP} from the amplified circuit **1164**.

FIG. **12**E shows an example waveform illustrating the operation of the ultrasonic receiving circuit **1160** when the ultrasonic receiving circuit **1160** may have received a rectified signal V_{RECT} from the synchronous rectifier **1166**.

FIG. **12**F shows example waveform illustrating the operation of the ultrasonic receiving circuit **1160** when the space around the load control device **1100** is vacant. For example, FIG. **12**F may show an example waveform illustrating the operation of the ultrasonic receiving circuit **1160** when the ultrasonic receiving circuit **1160** may have received a filtered signal V_{FILT} from the bandpass filter **1168** without an occupant present.

FIG. **12**G shows an example waveform illustrating the operation of the ultrasonic receiving circuit **1160** when there is an occupant in the space. For example, FIG. **12**G may show an example waveform illustrating the operation of the ultrasonic receiving circuit **1160** when the ultrasonic receiving circuit **1160** may have received a filtered signal V_{FILT} from the bandpass filter **1168** with an occupant present.

The ultrasonic receiving circuit **1160** may have a piezoelectric element **1162**. The piezoelectric element **1162** may generate a received ultrasonic input signal V_{IN}, for example, in response to the received ultrasonic waves (e.g., the received ultrasonic waves shown in FIGS. **6**A and **6**B). An amplifier circuit **1164** (e.g., a non-linear amplifier) may receive the input signal V_{IN}. The amplifier circuit **1164** may generate an amplified signal V_{AMP} (e.g., as shown in FIG. **12**F). A gain GNL of the amplifier circuit **1164** may be approximately 11, for example, when the magnitude of the AC component of the input signal V_{IN} is small (e.g., less than approximately 1.2 volts), and approximately 2, for example, when the magnitude of the AC component of the input signal V_{IN} is large (e.g., greater than approximately 1.2 volts).

The ultrasonic receiving circuit **1160** may include a synchronous rectifier **1166** (i.e., a lock-in amplifier). The synchronous rectifier **1166** may be responsive to signals having small magnitudes. The synchronous rectifier **1166** may receive the amplified signal V_{AMP} from the amplifier circuit **1164**. The synchronous rectifier **1166** may generate a rectified signal V_{RECT}, for example, as shown in FIG. **12**E. The control circuit **1120** may generate a non-inverted ultrasonic drive signal V_{DRIVE}, for example, as shown in FIG. **12**A. The control circuit **1120** may generate an inverted ultrasonic drive signal V_{DR_INV}, for example, as shown in FIG. **12**B) at the operating frequency for of the oscillator circuit **1130**, which may be approximately equal to an ultrasonic transmission frequency f_{US} of the received ultrasonic waves (e.g., as transmitted by the ultrasonic transmitter **1030** shown in FIG. **10**). The synchronous rectifier **1166** may receive the non-inverted ultrasonic drive signal V_{DRIVE} and the inverted ultrasonic drive signal V_{DR_INV}, and the synchronous rectifier **1166** may use these signals to generate the rectified signal V_{RECT}. A filter and amplifier circuit **1168** (e.g., an anti-aliasing filter, such as a bandpass filter) may generate a filtered signal V_{FILT} from the rectified signal V_{RECT} and may have a bandwidth of approximately 50-500 Hz. The filter and amplifier **1168** may be characterized by a gain of approximately 60 dB. The control circuit **1120** may be operable to digitally filter the filtered signal V_{FILT} received from the bandpass filter **1168** to provide additional filtering of the signal.

The control circuit **1120** may receive the filtered signal V_{FILT} from the bandpass filter **1168**. The control circuit **1120** may sample the filtered signal using an ADC. The control circuit **1120** may be operable to detect the presence of the occupant in the space by comparing the magnitude of the filtered voltage V_{FILT} to an upper voltage threshold V_{TH+} (e.g., approximately 0.25 volts) and a lower voltage threshold V_{TH-} (as shown in FIGS. **12**F and **12**G). The synchronous rectifier **1166** may properly rectify the amplified signal V_{AMP}, and the filtered voltage V_{FILT} may stay between the upper voltage threshold V_{TH+} and the lower voltage threshold V_{TH-}, for example, when the space is vacant. Since the filtered signal V_{FILT} is biased to approximately one-half of the supply voltage V_{CC1} (i.e., approximately 1.5 volts), the filtered signal V_{FILT} may have a DC magnitude equal to approximately 1.5 volts and the filtered signal V_{FILT} may remain between the upper voltage threshold V_{TH+} and the lower voltage threshold V_{TH-}, for example, if the space is vacant (as shown in FIG. **12**F). If there is an occupant in the space, there may be a Doppler shift in the received ultrasonic waves as compared to the transmitted ultrasonic waves, and the magnitude of the filter voltage V_{FILT} may rise above the upper voltage threshold V_{TH+} and/or fall below the lower voltage threshold V_{TH-} (e.g., as shown in FIG. **12**G). The upper voltage threshold V_{TH+} and the lower voltage threshold V_{TH-} may be predetermined fixed values or may be adjustable by the control circuit **1120**.

In FIG. **11**, the load control device **1100** may include a passive infrared (PIR) sensing circuit **1170**, which may, for example, comprise a pyroelectric infrared detector for receiving infrared energy of the occupant through a lens of the load control device (e.g., the lens **1018** of the load control device **1000** shown in FIG. **10**). The PIR sensing circuit **1170** may generate a PIR sense signal V_{PIR} representative of the magnitude of the received infrared energy. The control circuit **1120** may be able to analyze both the filtered signal V_{FILT} received from the ultrasonic receiving circuit **1160** and the PIR sense signal V_{PIR} received from the PIR sensing circuit **1170** to determine if an occupancy condition or a vacancy condition is presently occurring in the space.

FIG. **13** is a simple diagram of an example load control system **1300** (e.g., an ultrasonic sensing system) comprising a wireless ultrasonic sensor **1310** and a remote ultrasonic transmitter **1330** (e.g., the ultrasonic transmitter **900** shown in FIG. **9**). The wireless ultrasonic sensor **1310** may be a remote ultrasonic receiver (e.g., the remote ultrasonic receiver **1400** shown in FIG. **14**). The remote ultrasonic transmitter **1330** may be operable to be plugged into a receptacle **1322** of an electrical outlet **1320**. The remote ultrasonic transmitter **1330** may transmit ultrasonic waves **1306** via an acoustic grill **1332** at an ultrasonic transmission frequency f_{US} (e.g., approximately 40 kHz). The wireless ultrasonic sensor **1310** may be operable to receive the ultrasonic waves **1306** transmitted by the ultrasonic transmitter **1330** via an acoustic grill **1318**. For example, the wireless ultrasonic sensor **1310** may have an ultrasonic occupancy detection circuit having an ultrasonic receiving circuit (e.g., only an ultrasonic receiving circuit), such that the remote ultrasonic transmitter **1330** and the wireless ultrasonic sensor **1310** operate as shown in FIGS. **6**A and **6**B. The wireless ultrasonic sensor **1310** may include an ultrasonic receiving circuit and an ultrasonic transmitting circuit. The ultrasonic receiving circuit of the wireless ultrasonic sensor **1310** may include a synchronous rectifier (e.g., similar to the synchronous rectifier of the load control device **1100** shown in FIG. **11**). The wireless ultrasonic sensor **1310** (e.g., the ultrasonic receiver **1400** as shown in FIG. **14**) may be configured to transmit wireless signals, e.g., radio-frequency (RF) signals **1308** in response to the received ultrasonic waves **1306**. For example, the wireless ultrasonic sensor **1310** may be battery-powered. An example of a battery-powered wireless ultrasonic sensor is described in greater detail in previously-referenced U.S. Pat. No. 8,514,075.

The load control system **1300** may include a remote load control device **1340**. The remote load control device **1340** may be coupled in series electrical connection between an AC power source **1302** and an electrical load (e.g., a lighting load **1304**), such as for controlling the intensity of the lighting load. The remote load control device **1340** may be electrically coupled to the neutral side of the AC power source **1302** or to an earth ground connection. The remote load control device **1340** may be adapted to be remotely mounted, for example, to a junction box above a ceiling or in an electrical closet, such that the remote load control device is not easily accessible by a user. The remote load control device **1340** may be configured to control the lighting load **1304** in response to digital messages transmitted by the wireless ultrasonic sensor **1310** via the RF signals **1308** (e.g., in a similar manner as the load control device **1100** of FIG. **11**). The load control system **1300** may include a wall-mounted load control device responsive to the RF signals **1308** transmitted by the wireless ultrasonic sensor **1310** (e.g., a wireless dimmer switch). The load control device **1340** and remote ultrasonic sensor **1310** may be located, for example, on a tabletop, a chair, or in a wallbox where a switch for an LED bulb is located.

FIG. **14** is a simplified block diagram of an example remote ultrasonic receiver **1400** (e.g., the remote ultrasonic sensor **1310** of the load control system **1300** of FIG. **13**). The ultrasonic receiver **1400** may include a power supply **1410** operable to receive power via electrical connections **1402**, **1404**. The ultrasonic receiver **1400** may include a power supply **1410** to generate a DC supply voltage V_{CC} (e.g., approximately 12 volts). For example, the electrical connections **1402**, **1404** may have prongs (e.g., the prongs **434** shown in FIG. **4**) adapted to be plugged into a receptacle of an electrical outlet for powering the ultrasonic receiver **1400** from an AC power source. The power supply **1410** may be operable to convert the AC source voltage of the AC power source to the DC supply voltage V_{CC}. The electrical connections **1402**, **1404** may be adapted to be coupled to an external DC power supply for receiving a DC source voltage. The power supply **1410** may be a DC-to-DC converter for converting the DC source voltage to the DC supply voltage V_{CC}. The power supply **1410** may be replaced by one or more batteries.

The ultrasonic receiving circuit **1460** may include a piezoelectric element **1462**. The piezoelectric element **1462** may generate a received ultrasonic input signal V_{IN} in response to the received ultrasonic waves (e.g., the received ultrasonic waves shown in FIGS. **5**B and **6**B). The input signal V_{IN} may be received by an amplifier **1464** (e.g., a non-linear amplifier). The amplifier **1464** may generate an amplified signal V_{AMP} and may be characterized by a gain of approximately 20 dB. The ultrasonic receiving circuit **1460** may include a rectifier circuit **1466** (e.g., an asynchronous rectifier). The rectifier circuit **1466** may receive the amplified signal V_{AMP} from the amplifier circuit **1464** and generate a rectified signal V_{RECT}. For example, the rectifier circuit **1466** may include a diode feeding the parallel combination of a resistor and a capacitor. Since the ultrasonic receiving circuit **1460** may receive some of the unreflected ultrasonic waves transmitted by an ultrasonic transmitter (e.g., the remote ultrasonic transmitter **230** of FIG. **2**, the ultrasonic transmitters **712** of FIG. **7**, and/or the ultrasonic transmitted **900** of FIG. **9**), the magnitude of the amplified signal V_{AMP} received by the rectifier circuit **1466** may be greater than the forward drop of the diode of the rectifier circuit, such that the rectifier circuit may properly generate the rectified signal V_{RECT}. The rectifier circuit **1466** may include a synchronous rectifier as described in previously-referenced U.S. Pat. No. 8,514,075.

The remote ultrasonic receiver **1400** may include a control circuit **1420**. The control circuit **1420** may include a microcontroller, a programmable logic device (PLD), a microprocessor, an application specific integrated circuit (ASIC), a field-programmable gate array (FPGA), or any suitable processing device, controller, or control circuit. The remote ultrasonic receiver **1400** may include a wireless communication circuit **1422**, for example, including a radio-frequency (RF) transceiver coupled to an antenna for transmitting and/or receiving wireless signals (e.g., RF signals). The communication circuit **1422** may comprise an RF transmitter for transmitting RF signals, an RF receiver for receiving RF signals, or an infrared (IR) transmitter and/or receiver for transmitting and/or receiving IR signals. The wireless communication circuit **1422** may be in electrical communication with the control circuit **1420**, such that one or more wireless signals received from the ultrasonic transmitter may cause the ultrasonic receiver **1400** to transmit signals to a load control device (e.g., such as the remote load control device **1340** of FIG. **13**). The antenna of the wireless communication circuit **1422** may be enclosed in the housing of remote ultrasonic receiver **1400** or coupled to the exterior portion of the housing.

FIG. **15** is a simple diagram of an example three-way load control system **1500** (e.g., an ultrasonic sensing system) comprising first and second load control devices **1510**A, **1510**B (e.g., ultrasonic sensors). The first and second load control devices **1510**A, **1510**B may be coupled together in series electrical connection between an alternating-current (AC) power source **1502** and an electrical load (e.g., a lighting load **1504**). The first and second load control devices **1510**A, **1510**B may be installed to replace two single-pole double-throw (SPDT) switches (e.g., three-way switches) of a three-way switching system. As shown in FIG. **15**, the first and second load control devices **1510**A, **1510**B may not be coupled to the neutral side of the AC power source **1502**. Examples of load control devices for three-way load control systems are described in greater detail in commonly-assigned U.S. Pat. No. 7,847,440, issued Dec. 7, 2010, entitled LOAD CONTROL DEVICE FOR USE WITH LIGHTING CIRCUITS HAVING THREE-WAY SWITCHES, the entire disclosure of which is hereby incorporated by reference. The load control devices **1510**A, **1510**B may be coupled to the neutral side of the AC power source **1502** and/or an earth ground connection.

The load control devices **1510**A, **1510**B may be similar to the load control devices **210**, **1010** shown in FIGS. **2** and **10**, respectively. The load control device **1510**A, **1510**B may operate together to control the power delivered to the lighting load **1504**. The load control devices **1510**A, **1510**B may be coupled together via a first electrical wire **1508** and a second electrical wire **1509**. The first electrical wire **1508** may conduct a load current from the AC power source **1502** to the lighting load **1504**. The second electrical wire **1509** may allow for communication between the load control devices. The first and second load control devices **1510**A, **1510**B may be identical devices (e.g., may have the same electrical circuitry). For example, the first and second load control devices **1510**A, **1510**B may have a controllable conductive device coupled in series with the first electrical wire **1508** for conducting the load current between the AC power source **1502** and the lighting load **1504**. The load control devices **1510**A, **1510**B may include internal ultrasonic occupancy detection circuits having ultrasonic transmitters and receivers. The load control devices **1510**A, **1510**B may transmit and receive ultrasonic waves **1506** via respective acoustic grills **1516**A, **1516**B. The load control devices **1510**A, **1510**B may be operable to detect the presence or absence of an occupant in the space surrounding the two load control devices in response to reflected and/or attenuated ultrasonic waves as shown in FIGS. **5**A-**6**B.

The load control devices **1510**A, **1510**B may be operable to communicate with each other via the second electrical wire **1509**, for example, to determine how to control the lighting load **1504** in response to detecting the presence or absence of an occupant. For example, the second load control device **1510**B may establish itself as a master device in the load control system **1500**. The first load control device **1510**A may render its controllably conductive device conductive substantially fully conductive. The first load control device **1510**A may transmit digital messages to the second load control device **1510**B via the second electrical wire **1509** in response to detecting the presence or absence of an occupant. The second load control device **1510**B may control its controllably conductive device to control the power delivered to the lighting load **1504** in response to its internal ultrasonic occupancy detection circuit and/or the digital messages received from the first load control device **1510**A.

The load control system **1500** may include one or more ultrasonic transmitters (e.g., the ultrasonic transmitter **230** shown in FIG. **2** or the ultrasonic transmitter **900** shown in FIG. **9**). The first load control device **1510**A may include only an ultrasonic transmitter and/or the second load control device **1510**B may include only an ultrasonic receiver, such that the load control system **1500** may operate, for example, as shown in FIGS. **6**A and **6**B. In addition, the first load control device **1510**A may operate as the master device of the load control system **1500**.

What is claimed is:

1. A load control system for controlling power delivered from a power source to an electrical load, the system comprising:

a load control device configured to be coupled in series between the power source and the electrical load for controlling the power to the electrical load *via a switching circuit*, the load control device comprising a *load control device* communication circuit;

a remote ultrasonic transmitter configured to transmit ultrasonic waves characterized by an ultrasonic frequency and an amplitude, wherein the remote ultrasonic transmitter does not include a receiver for receiving ultrasonic waves transmitted by the remote ultrasonic transmitter; and

a sensor comprising:

a *sensor* communication circuit;

a local ultrasonic transmitter configured to transmit ultrasonic waves at the ultrasonic frequency;

an ultrasonic receiver configured to receive attenuated ultrasonic waves from the remote ultrasonic transmitter and configured to*:*

receive reflections of the ultrasonic waves transmitted by the local ultrasonic transmitter;

convert a change in amplitude of the attenuated ultrasonic waves received from the remote ultrasonic transmitter and the change in frequency of the received reflected ultrasonic waves from the local transmitter to a voltage signal; and

a control circuit coupled to the *sensor* communication circuit and to the ultrasonic receiver, the control circuit configured to:

[receive, via the ultrasonic receiver, signals representing the attenuated ultrasonic waves and the reflected ultrasonic waves;

determine occupancy from the received signals based on at least one of (i) a change in amplitude between the attenuated ultrasonic waves and the characterized amplitude and (ii) a change in frequency between the reflected ultrasonic waves and the characterized ultrasonic frequency**]**

determine whether the voltage signal is at least one of: greater than upper voltage threshold value or less than a lower voltage threshold value;

determine an occupancy condition exists responsive to at least one of: the voltage signal being greater than the upper voltage threshold value or the voltage signal being less than a lower voltage threshold value; and

transmit a command via the *sensor* communication circuit to the load control device based on the determination of occupancy;

wherein the load control device, the remote ultrasonic transmitter **[**device**]**, and the sensor are each separate devices; and

further wherein the load control device is configured to receive the command via the communication circuit of the load control device and to control the power delivered *via the switching circuit* to the electrical load in response to the command.

2. The system of claim **1**, wherein the remote ultrasonic transmitter comprises an ultrasonic transmitting element, a drive circuit for energizing the ultrasonic transmitting element, and a low phase-noise oscillator circuit directly driving the drive circuit to cause the ultrasonic transmitting element to transmit ultrasonic waves at the ultrasonic frequency.

3. The system of claim **2**, wherein the remote ultrasonic transmitter further comprises an internal power supply generating a supply voltage for powering the oscillator circuit and the drive circuit.

4. The system of claim **3**, wherein the power supply of the remote ultrasonic transmitter is configured to generate the supply voltage from an AC line voltage of an AC power source.

5. The system of claim **4**, wherein the remote ultrasonic transmitter is configured to be plugged into an electrical outlet.

6. The system of claim **3**, further comprising:

an external power supply configured to generate a DC voltage from an AC line voltage of an AC power source;

wherein the power supply of the remote ultrasonic transmitter is configured to generate the supply voltage from the DC voltage of the external power supply.

7. The system of claim **2**, wherein the remote ultrasonic transmitter further comprises a battery configured to produce a battery voltage for powering the oscillator circuit and the drive circuit.

8. The system of claim **2**, wherein the low phase-noise oscillator circuit comprises a Pierce oscillator circuit having a crystal.

9. The system of claim **1**, wherein the load control device comprises a ceiling mounted load control device.

10. The system of claim **1**, wherein the load control device is configured to turn the electrical load on and off in response to the ultrasonic waves received by the ultrasonic receiver.

11. The system of claim **1**, wherein the ultrasonic frequency is 40 kHz±2 Hz.

12. The system of claim **1**, wherein the electrical load comprises a lighting load.

13. The system of claim **1**, wherein the remote ultrasonic transmitter and the local ultrasonic transmitter each continuously transmit the respective ultrasonic waves.

14. The system of claim **1**, wherein the sensor is configured to be mounted to a ceiling.

15. The system of claim **14**, wherein the sensor is a powered by a battery.

16. The system of claim **1**, wherein the *sensor* communication circuit is a wireless communication circuit.

17. The system of claim **1**, further comprising at least two remote ultrasonic transmitters.

18. The system of claim **17**, wherein the at least two remote ultrasonic transmitters and the sensor each comprises an ultrasonic coverage pattern based on the transmission of the respective ultrasonic waves from the respective ultrasonic transmitter, and

wherein the at least two remote ultrasonic transmitters and the sensor are placed in a room such that the respective ultrasonic coverage patterns of each of the at least two remote ultrasonic transmitters and the sensor overlap to substantially fill the room with ultrasonic waves.

19. The system of claim **18**, wherein the at least two remote ultrasonic transmitters are configured to increase a range of occupancy detection within the room.

20. The system of claim **19**, wherein the room comprises **[**at least**]***:*

a first**[**,**]** *wall including the sensor;*

a second *wall including at least one remote transmitter;* and a third wall[, wherein each wall has at least one of: the at least two] *including at least one* remote ultrasonic [transmitters and the sensor] *transmitter*.

21. The system of claim **1**, wherein the remote ultrasonic transmitter is configured to be located on a first wall, and the sensor is configured to be located on a second wall, the first wall being different from the second wall.

22. A load control system for controlling [the] power delivered from a power source to an electrical load, the system comprising:

a remote ultrasonic transmitter configured to transmit ultrasonic waves characterized by an ultrasonic frequency, wherein the remote ultrasonic transmitter does not include a receiver for receiving ultrasonic waves transmitted by the remote ultrasonic transmitter, and wherein the remote ultrasonic transmitter is configured to be plugged into an electrical outlet; [and]

a load control device that is a separate device from the remote ultrasonic transmitter and that is adapted to be coupled in series electrical connection between the power source and the electrical load for controlling the power delivered to the electrical load *via a switching circuit*, the load control device comprising a *load control device* communication circuit; *and*

a sensor comprising:

a *sensor* communication circuit;

a local ultrasonic transmitter configured to transmit ultrasonic waves at the ultrasonic frequency;

an ultrasonic receiver configured to*:*

receive ultrasonic waves from the remote ultrasonic transmitter [and to]*;*

receive ultrasonic waves from the local ultrasonic transmitter;

convert a change in amplitude of the attenuated ultrasonic waves received from the remote ultrasonic transmitter and the change in frequency of the received reflected ultrasonic waves from the local transmitter to a voltage signal; and

a control circuit operatively coupled to the ultrasonic receiver, the control circuit configured to:

[(i) detect occupancy based on the received ultrasonic waves by at least one of:

(a) detecting a period of amplitude modulation from the ultrasonic waves received from the remote ultrasonic transmitter, and

(b) detecting a Doppler shift of the ultrasonic frequency from the ultrasonic waves received from the local ultrasonic transmitter;]

determine whether the voltage signal is at least one of: greater than upper voltage threshold value or less than a lower voltage threshold value;

determine an occupancy condition exists responsive to at least one of: the voltage signal being greater than the upper voltage threshold value or the voltage signal being less than a lower voltage threshold value; and

[(ii)] transmit a command via the *sensor* communication circuit to the load control device based on the determination of occupancy;

wherein the sensor is separate from the load control device and the remote ultrasonic transmitter [device];

further wherein the load control device is configured to receive the command via the communication circuit of the load control device and to control the power delivered *via the switching circuit* to the electrical load in response to the command.

23. The system of claim **22**, wherein the load control device further comprises a controllably conductive device comprising a relay.

24. The system of claim **22**, wherein the remote ultrasonic transmitter is configured to be located on a first wall, and the load control device is configured to be located on a second wall, the first wall being different from the second wall.

25. A system comprising:

a remote ultrasonic transmitter configured to transmit ultrasonic waves characterized by an ultrasonic frequency, wherein the remote ultrasonic transmitter does not include a receiver for receiving ultrasonic waves transmitted by the remote ultrasonic transmitter; and

a sensor comprising:

a sensor communication circuit;

a local ultrasonic transmitter configured to transmit ultrasonic waves at the ultrasonic frequency;

an ultrasonic receiver configured to:

receive ultrasonic waves, wherein the received ultrasonic waves comprise attenuated ultrasonic waves transmitted by the remote ultrasonic transmitter and reflected ultrasonic waves transmitted by the local ultrasonic transmitter;

convert a change in amplitude of the attenuated ultrasonic waves received from the remote ultrasonic transmitter and the change in frequency of the received reflected ultrasonic waves from the local transmitter to a voltage signal;

generate one or more ultrasonic sense signals in response to determining whether there are periods of frequency modulation in the received ultrasonic waves; and

a control circuit operatively coupled to the sensor communication circuit and the ultrasonic receiver, the control circuit configured to:

receive the voltage signal generated by the ultrasonic receiver;

determine whether the voltage signal is at least one of: greater than upper voltage threshold value or less than a lower voltage threshold value;

determine an occupancy condition exists responsive to at least one of: the voltage signal being greater than the upper voltage threshold value or the voltage signal being less than a lower voltage threshold value;

transmit a command via the sensor communication circuit that indicates the space is occupied in response to the determination that an occupany condition exists within the space;

wherein the remote ultrasonic transmitter and the sensor are separate devices.

26. The system of claim 25, further comprising:

wherein the remote ultrasonic transmitter comprises a first remote ultrasonic transmitter, the system further comprising a second remote ultrasonic transmitter configured to transmit ultrasonic waves characterized by the ultrasonic frequency; and

wherein the ultrasonic receiver is further configured to:

receive ultrasonic waves transmitted by the local ultrasonic transmitter; and

determine whether there are periods of frequency modulation in the received ultrasonic waves transmitted by the local ultrasonic transmitter.

27. The system of claim 25,

wherein each of the plurality of remote ultrasonic transmitters further comprises an ultrasonic transmitting element, a drive circuit configured to energize the *ultrasonic transmitting element, and a low phase-noise oscillator circuit configured to directly drive the drive circuit to cause the ultrasonic transmitting element to transmit the ultrasonic waves at the ultrasonic frequency.*

28. The system of claim 27,

wherein each of the plurality of remote ultrasonic transmitters further comprises a power supply configured to generate a supply voltage for powering the low phase-noise oscillator circuit and the drive circuit.

29. The system of claim 28, wherein the power supply of each of the plurality of remote ultrasonic transmitters is further configured to generate the supply voltage from an AC line voltage of an AC power source.

30. The system of claim 27,

wherein each of the plurality of remote ultrasonic transmitters is further configured to power the low phase-noise oscillator circuit and the drive circuit from a battery.

31. The system of claim 25, wherein the sensor is configured to be mounted to a ceiling.

32. A system comprising:

a plurality of remote ultrasonic transmitters, each configured to transmit ultrasonic waves characterized by an ultrasonic frequency, wherein each of the plurality of remote ultrasonic transmitters does not include a receiver for receiving ultrasonic waves; and

a sensor comprising:

a sensor communication circuit;

a local ultrasonic transmitter disposed proximate the ultrasonic receiver;

an ultrasonic receiver configured to:

receive ultrasonic waves, wherein the received ultrasonic waves comprise attenuated ultrasonic waves transmitted by the plurality of remote ultrasonic transmitters and reflected ultrasonic waves from the local ultrasonic transmitter; and

convert at least one of: a change in amplitude of the attenuated ultrasonic waves received from the remote ultrasonic transmitter or the change in frequency of the received reflected ultrasonic waves from the local transmitter to a voltage signal; and

a control circuit operatively coupled to the sensor communication circuit and the ultrasonic receiver, the control circuit configured to:

receive the voltage signal generated by the ultrasonic receiver;

determine whether the voltage signal is at least one of: greater than upper voltage threshold value or less than a lower voltage threshold value;

determine an occupancy condition exists responsive to at least one of: the voltage signal being greater than the upper voltage threshold value or the voltage signal being less than a lower voltage threshold value;

transmit a command via the sensor communication circuit that indicates the space is occupied in response to the determination that an occupancy condition exists within the space;

wherein each of the plurality of remote ultrasonic transmitters and the sensor are separate devices.

33. The system of claim 32,

wherein each of the plurality of remote ultrasonic transmitters further comprises an ultrasonic transmitting element, a drive circuit configured to energize the ultrasonic transmitting element, and a low phase-noise oscillator circuit configured to directly drive the drive circuit to cause the ultrasonic transmitting element to transmit the ultrasonic waves at the ultrasonic frequency.

34. The system of claim 33,

wherein each of the plurality of remote ultrasonic transmitters further comprises a power supply configured to generate a supply voltage for powering the low phase-noise oscillator circuit and the drive circuit.

35. The system of claim 34, wherein the power supply of each of the plurality of remote ultrasonic transmitters is further configured to generate the supply voltage from an AC line voltage of an AC power source.

36. The system of claim 33, wherein each of the plurality of remote ultrasonic transmitters is further configured to power the low phase-noise oscillator circuit and the drive circuit from a battery.

37. The system of claim 32, wherein the sensor is configured to be mounted to a ceiling.

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