US008912968B2

(12) **United States Patent**
Sharma et al.

(10) **Patent No.: US 8,912,968 B2**
(45) **Date of Patent: Dec. 16, 2014**

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(54) **TRUE OMNI-DIRECTIONAL ANTENNA**

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(73) Assignee: **SecureALL CORPORATION**, Mountain View, CA (US)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 262 days.

(21) Appl. No.: **13/340,520**

(22) Filed: **Dec. 29, 2011**

(65) **Prior Publication Data**

US 2012/0169543 A1 Jul. 5, 2012

Related U.S. Application Data

(60) Provisional application No. 61/428,155, filed on Dec. 29, 2010.

(51) **Int. Cl.**

H01Q 13/10	(2006.01)
H01Q 9/04	(2006.01)
H01Q 13/08	(2006.01)

(52) **U.S. Cl.**
CPC ***H01Q 13/085*** (2013.01); ***H01Q 9/0421*** (2013.01)
USPC .... **343/767**; 343/700 MS

(58) **Field of Classification Search**
CPC H01Q 13/085; H01Q 9/0421
USPC .... 343/700 MS, 767, 770
See application file for complete search history.

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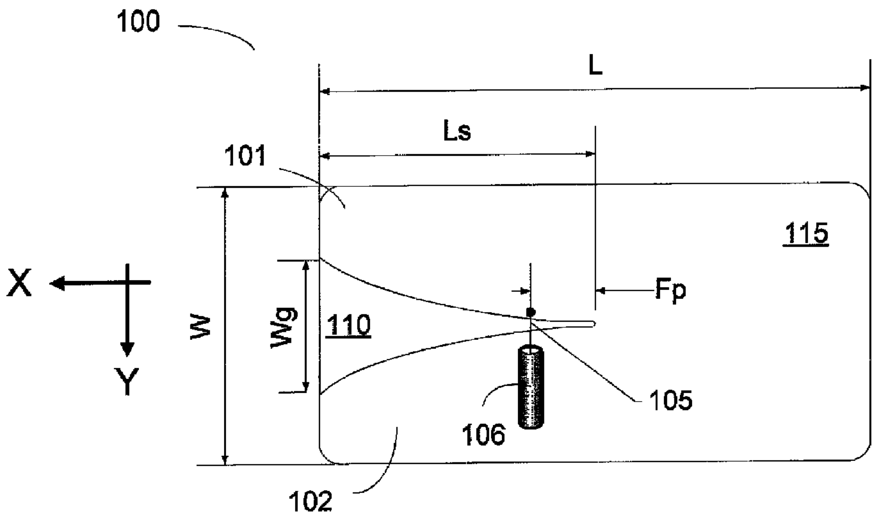
Primary Examiner — Tho G Phan
(74) *Attorney, Agent, or Firm* — Haynes and Boone, LLP

(57) **ABSTRACT**

An antenna and a method for using the antenna in a wireless appliance are provided. The antenna includes a conducting surface having a length and a width; a dielectric slit having a slit length portion oriented along either the length or the width, the slit forming two lips on the conducting surface; the slit having an opening on one of the length and the width, the opening having a flare size; a feed-point element connecting the two lips; wherein the dimensions of the length, the width, the slit length portion, and the flare size are smaller than an effective propagation wavelength of the RF radiation in the antenna. An antenna including a conducting surface having a conductive plate with a plate area defined by a plate perimeter overlaying a portion of a conducting surface is also provided. A method to provide an antenna as above is also disclosed.

24 Claims, 21 Drawing Sheets



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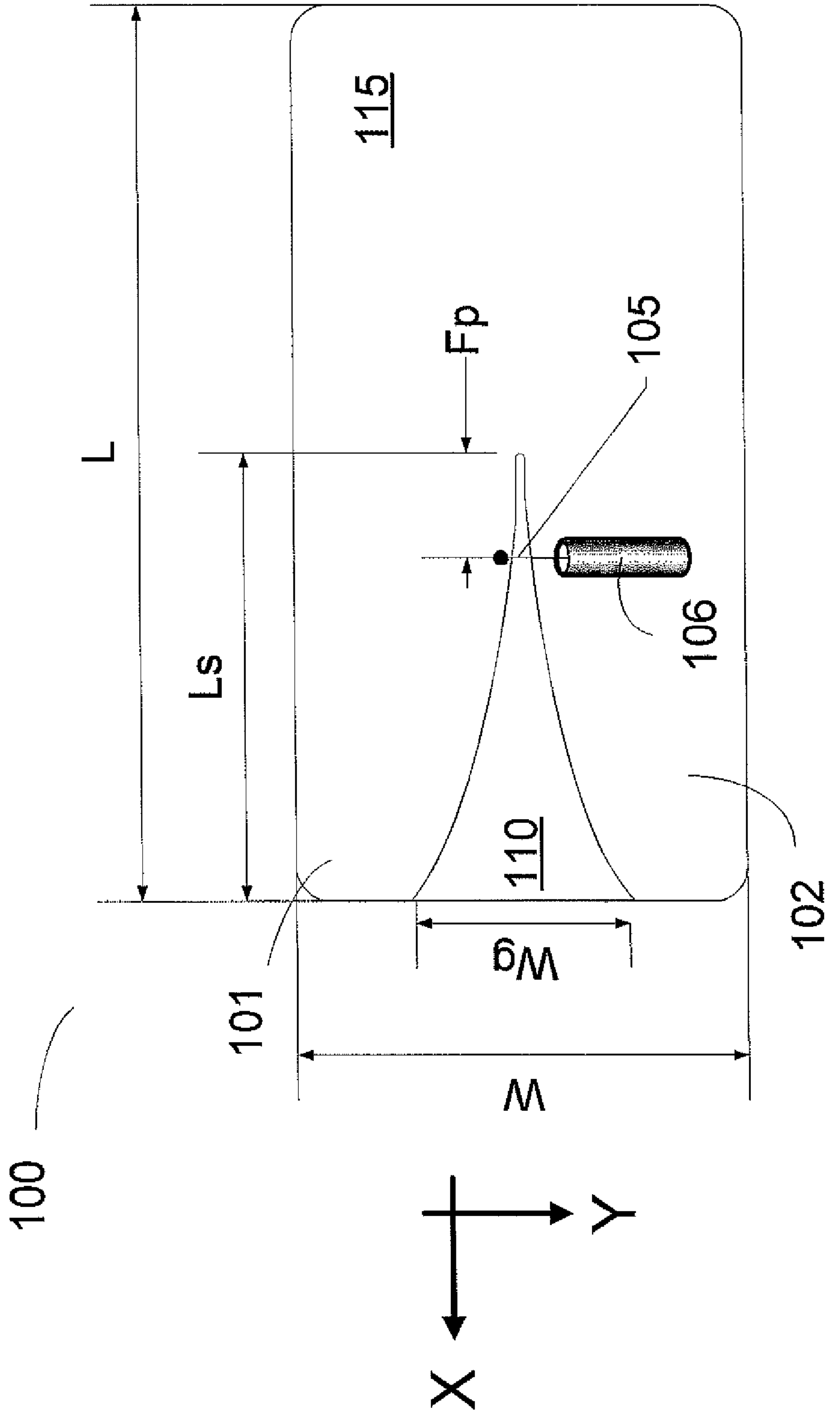


FIG. 1

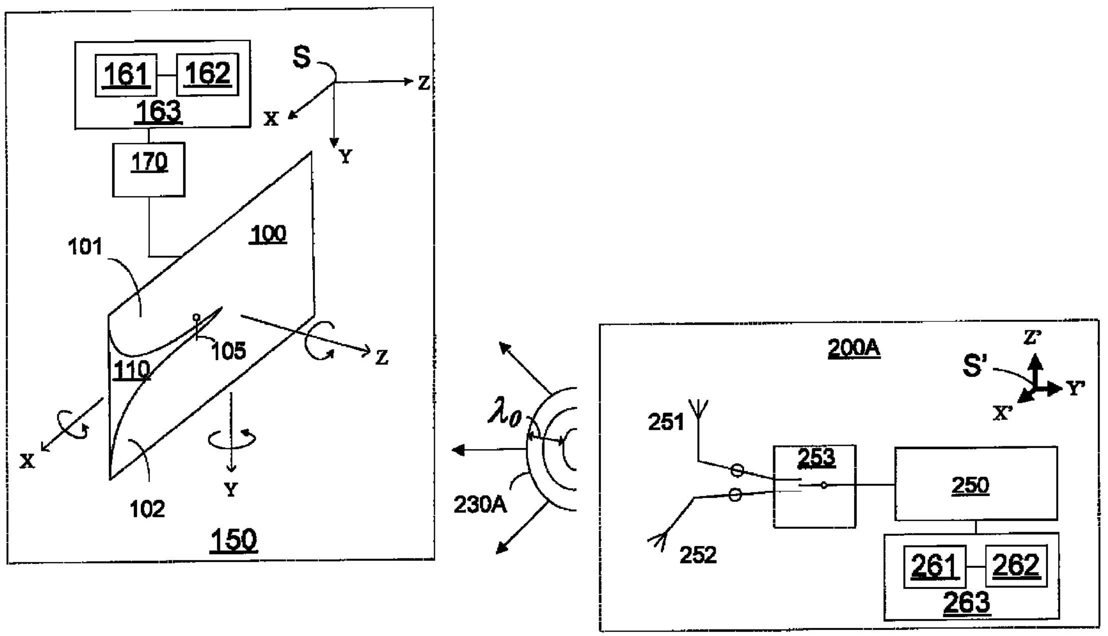

161
162
163
S
Z
X
Y
170
100
101
105
110
Z
X
Y
102
150
λ_0
230A
200A
S'
Z'
Y'
X'
251
253
250
252
261
262
263

FIG. 2A

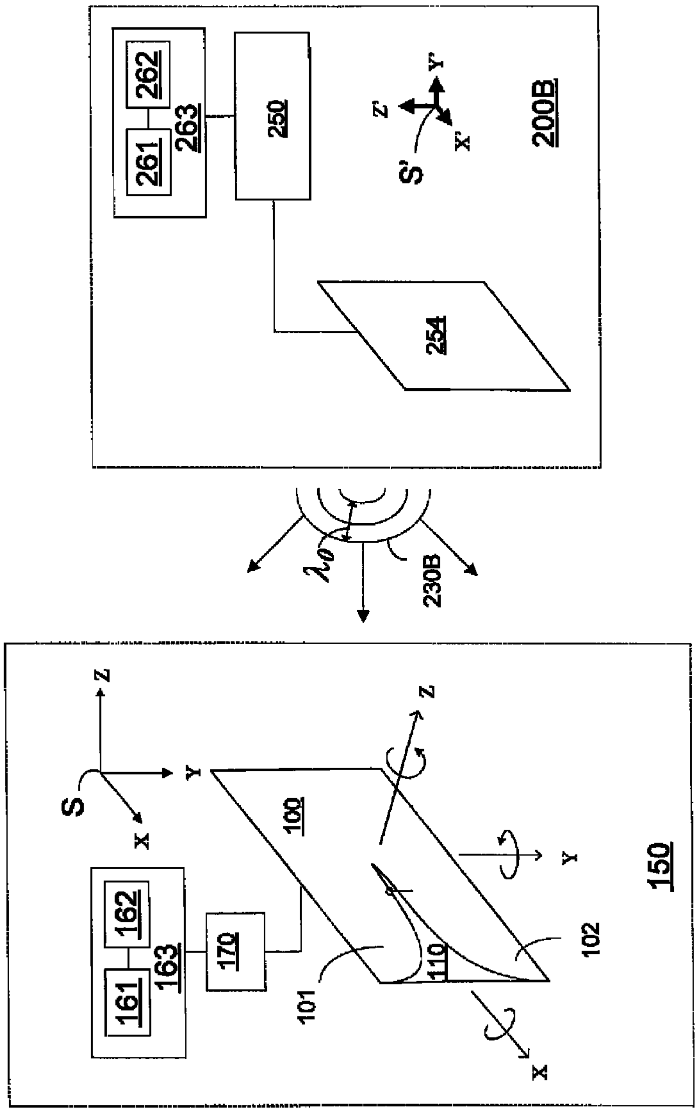

262
261
263
250
Z'
Y'
X'
S'
200B
254
λ_0
230B
161
162
163
170
S
X
Y
Z
100
Z
Y
X
101
110
102
150

FIG. 2B

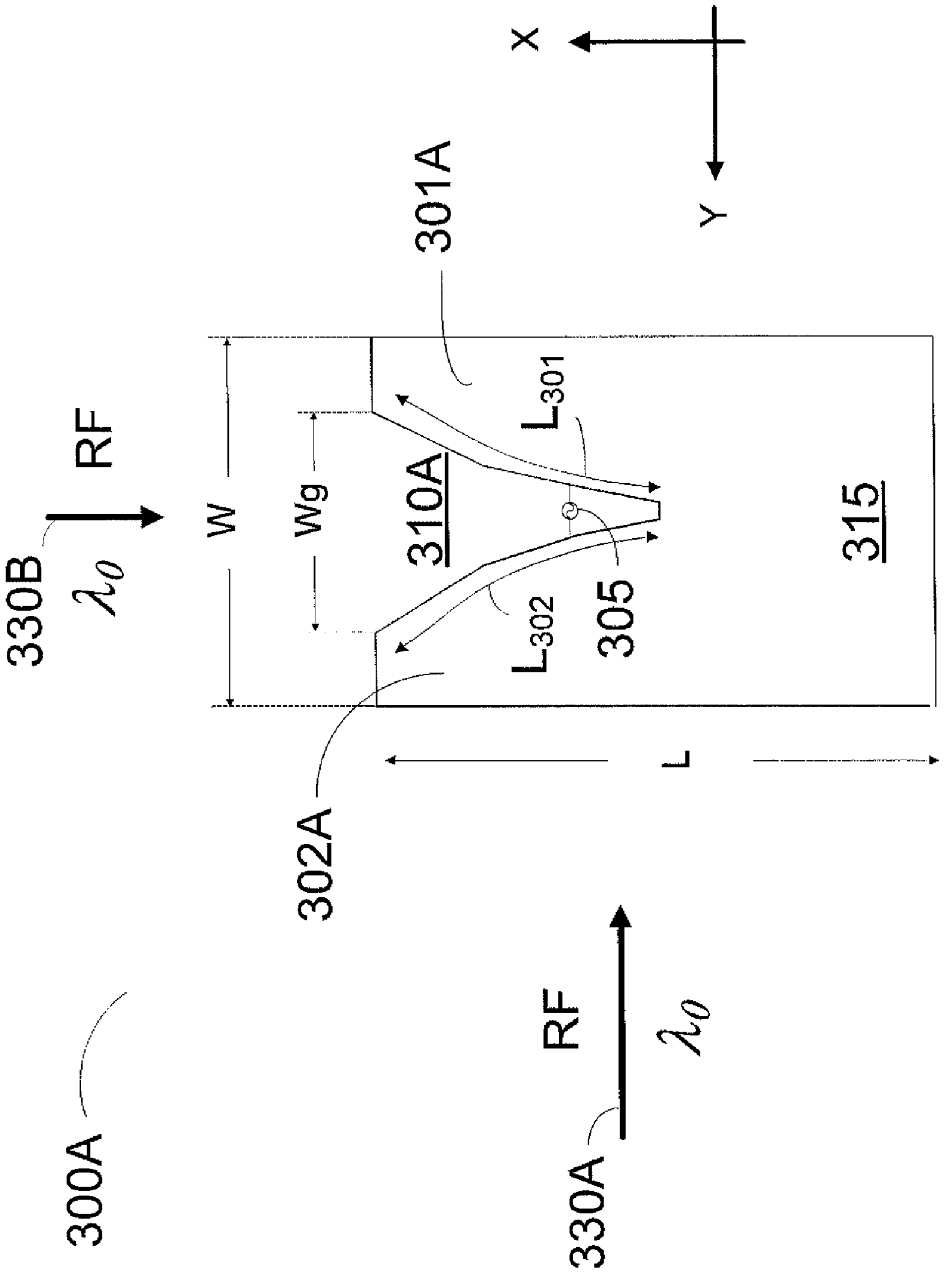

X
Y
301A
330B
λ_0
RF
W
Wg
310A
L_{301}
305
L_{302}
315
302A
L
300A
RF
λ_0
330A

FIG. 3A

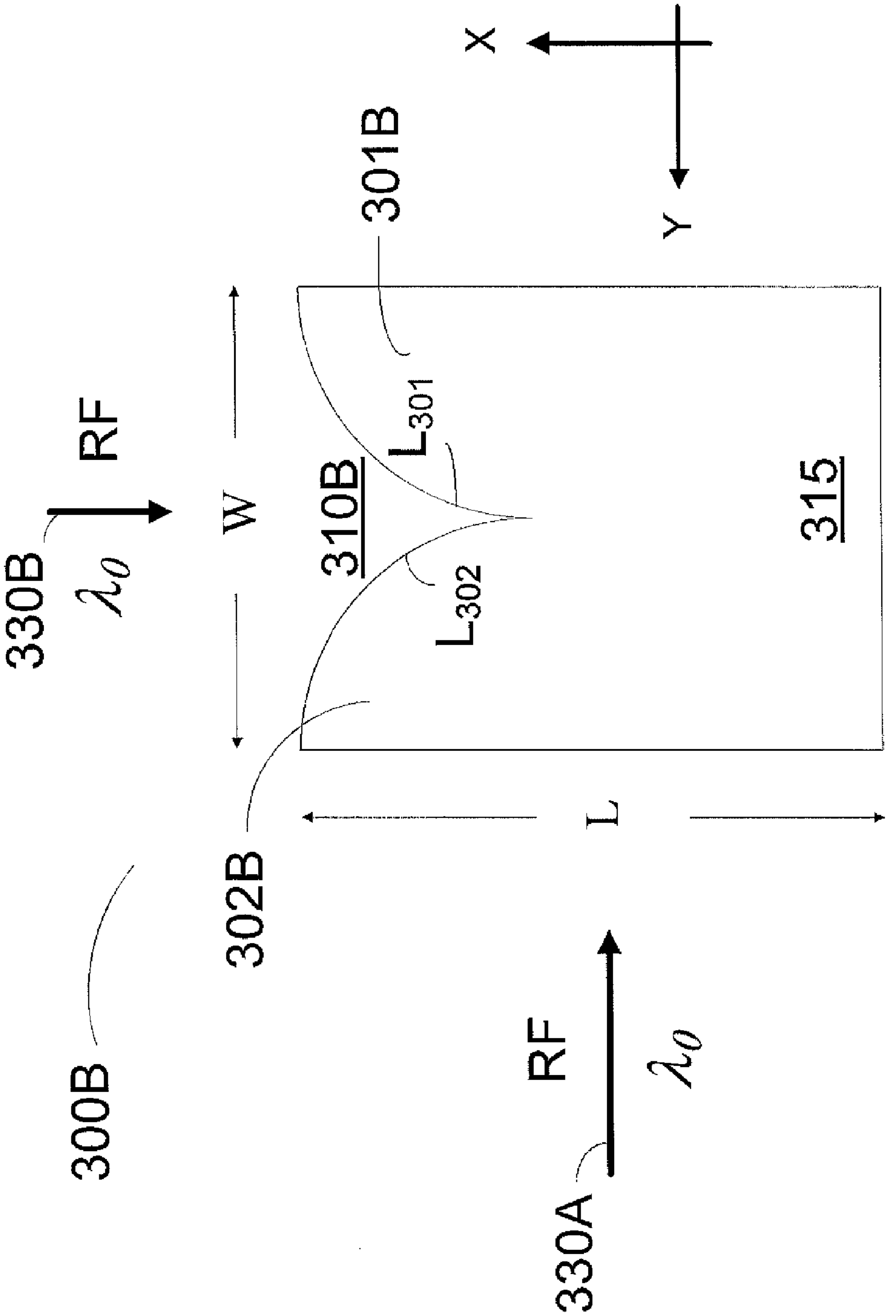

X
Y
301B
RF
330B
λ_0
W
310B
L_{301}
L_{302}
315
302B
L
300B
RF
λ_0
330A

FIG. 3B

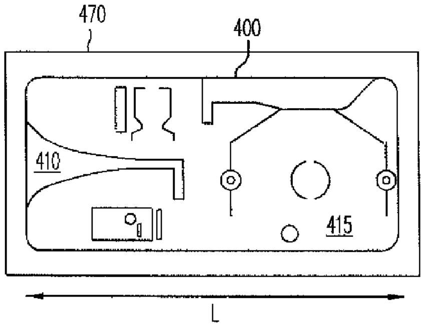
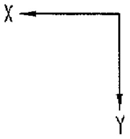


FIG. 4A



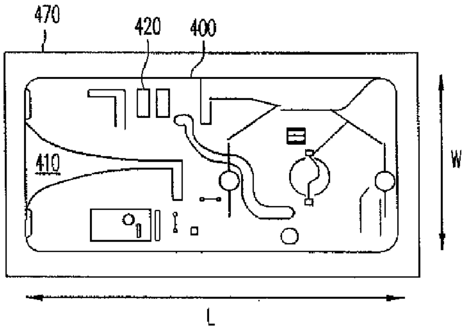


FIG. 4B

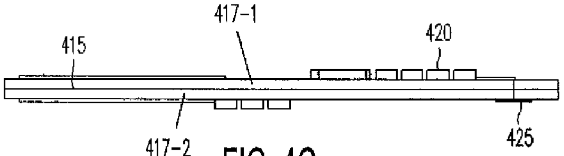


FIG. 4C

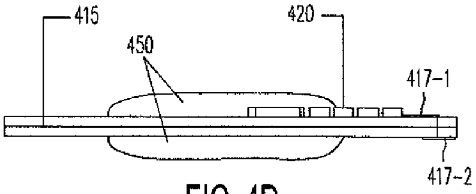


FIG. 4D

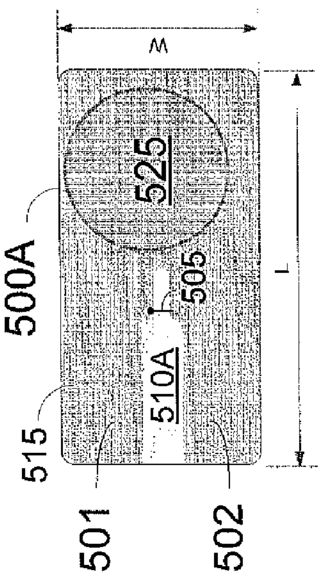


FIG. 5A

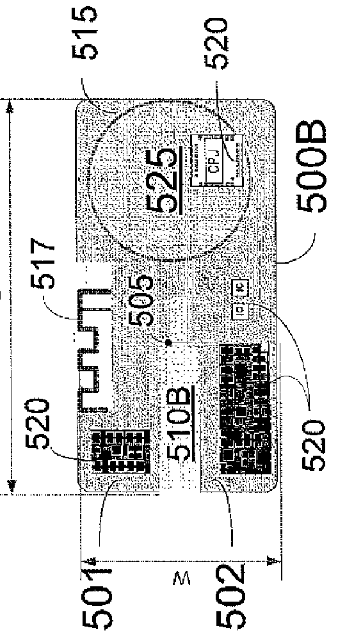


FIG. 5B

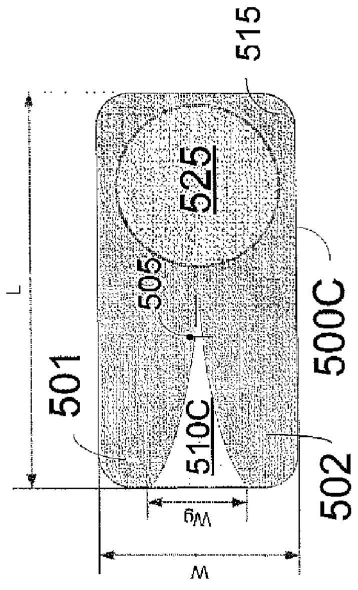


FIG. 5C

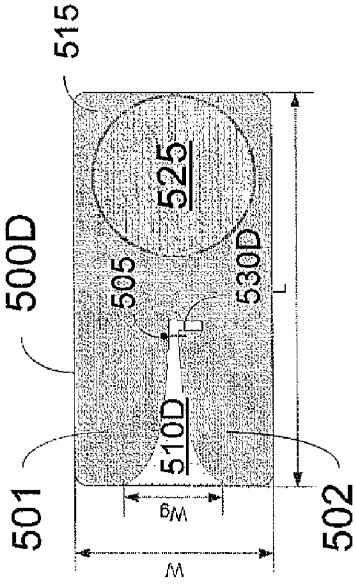
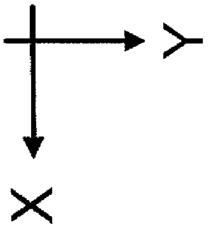


FIG. 5D



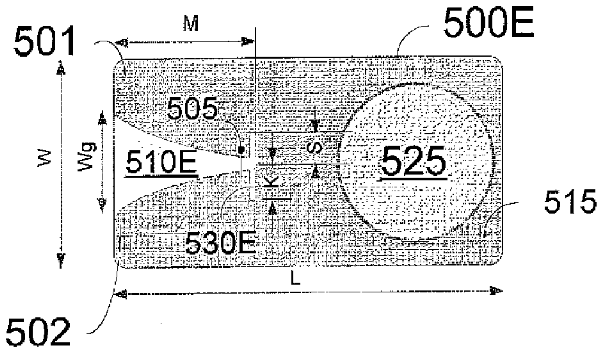


FIG. 5E

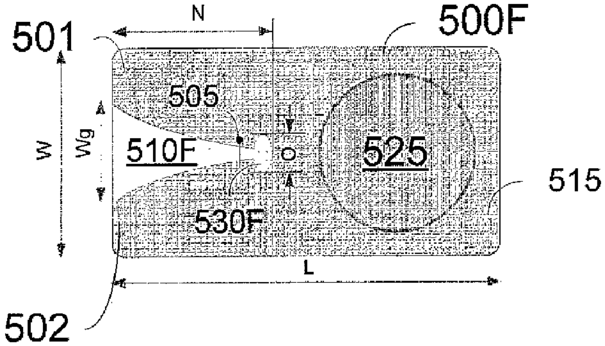
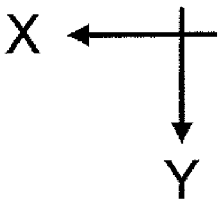


FIG. 5F



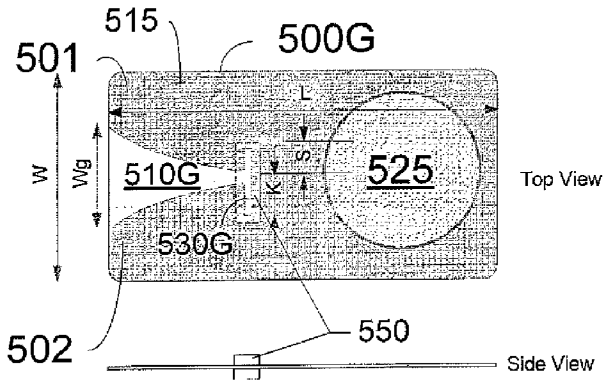


FIG. 5G

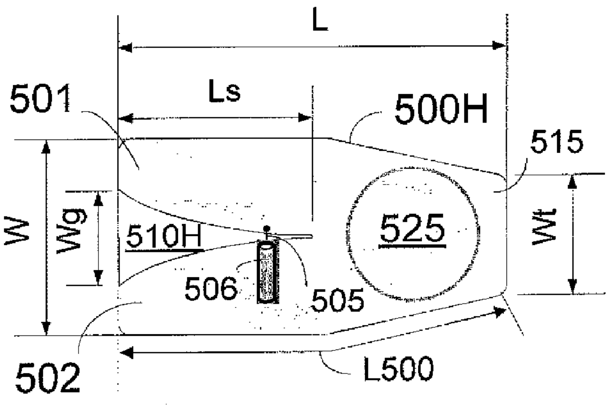


FIG. 5H

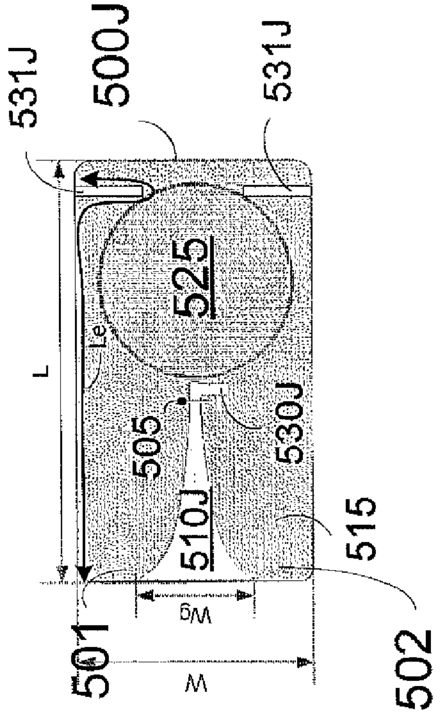
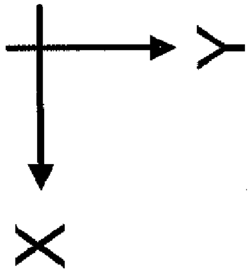

531J
500J
531J
525
L
Le
505
530J
510J
515
Wg
W
501
502

FIG. 5J


Y
X

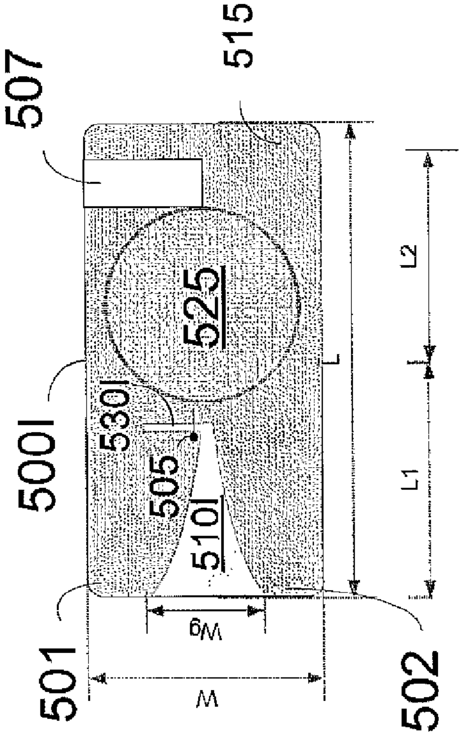

507
515
525
500I
530I
505
510I
L
L2
L1
Wg
W
501
502

FIG. 5I

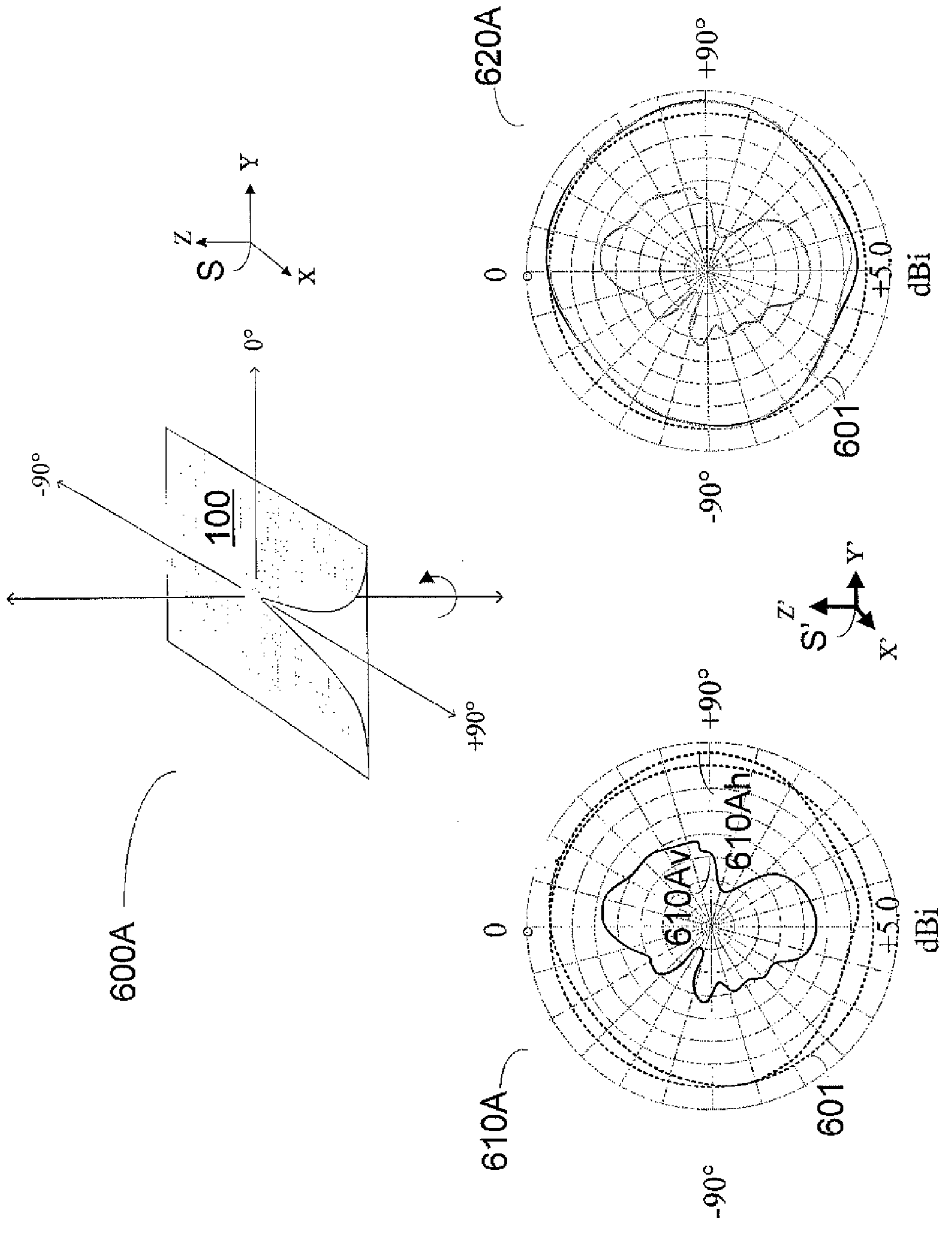

600A
100
-90°
0°
+90°
S
Z
Y
X
620A
+90°
0
-90°
+5.0
dBi
601
S'
Z'
Y'
X'
610A
610Av
610Ah
+90°
0
-90°
+5.0
dBi
601

FIG. 6A

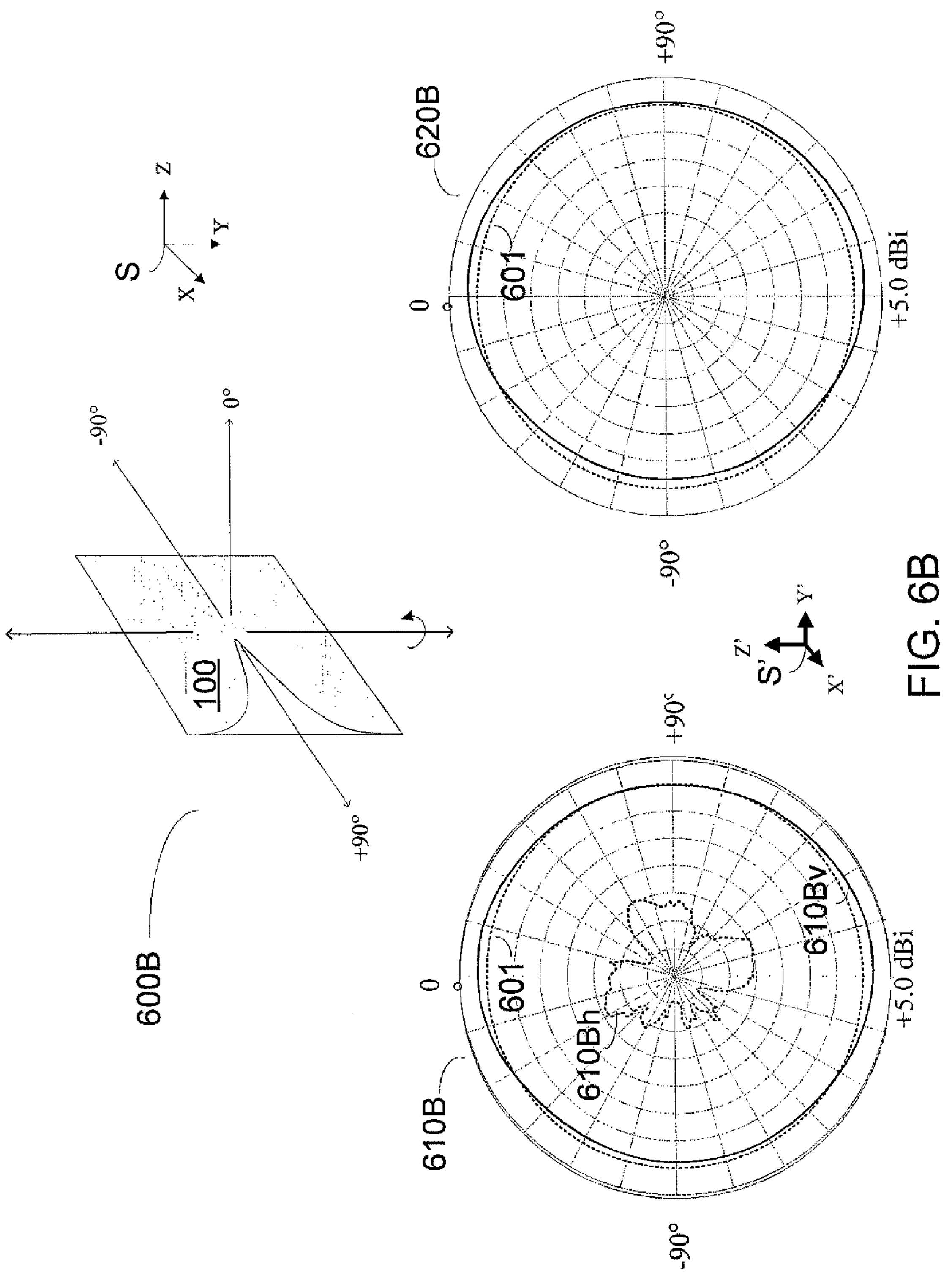

600B
100
-90°
0°
+90°
S
X
Y
Z
620B
601
0
+90°
-90°
+5.0 dBi
610B
601
0
610Bh
610Bv
+90°
-90°
+5.0 dBi
S'
X'
Y'
Z'

FIG. 6B

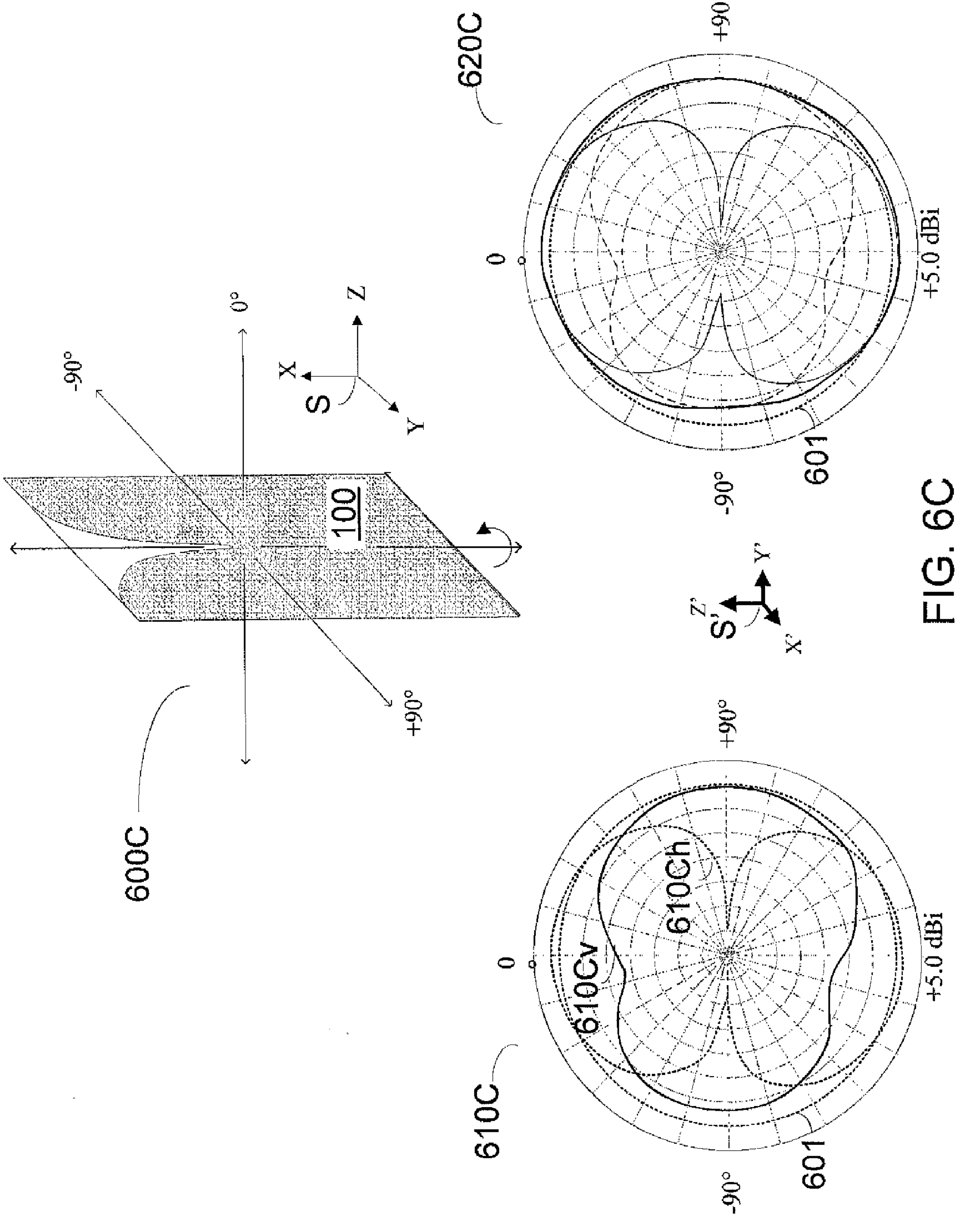

600C
0°
-90°
+90°
X
Y
Z
S
100
620C
+90°
0
+5.0 dBi
-90°
601
S'
Z'
Y'
X'
610C
610Cv
610Ch
+90°
0
+5.0 dBi
-90°
601

FIG. 6C

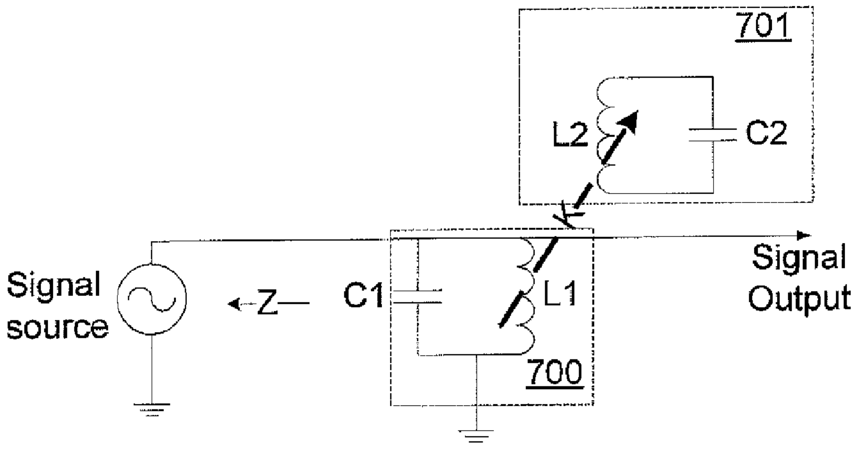

701
L2
C2
Signal source
Z
C1
L1
Signal Output
700

FIG. 7A

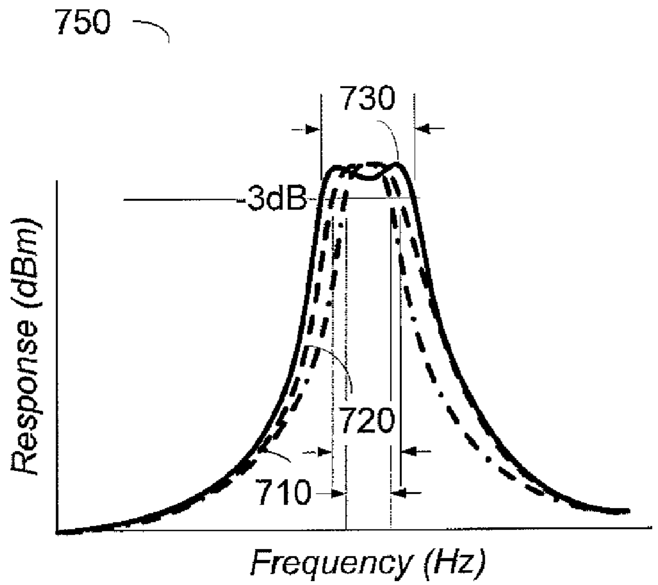

750
730
-3dB
Response (dBm)
720
710
Frequency (Hz)

FIG. 7B

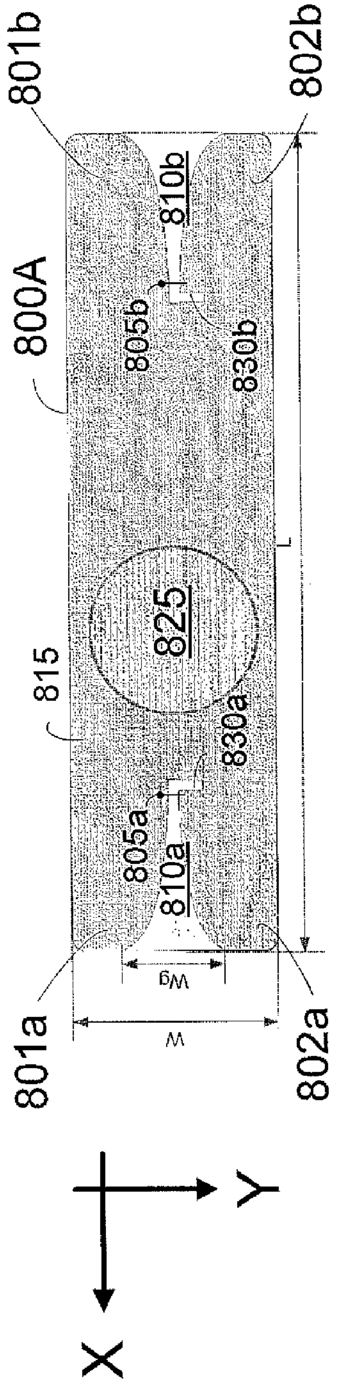


FIG. 8A

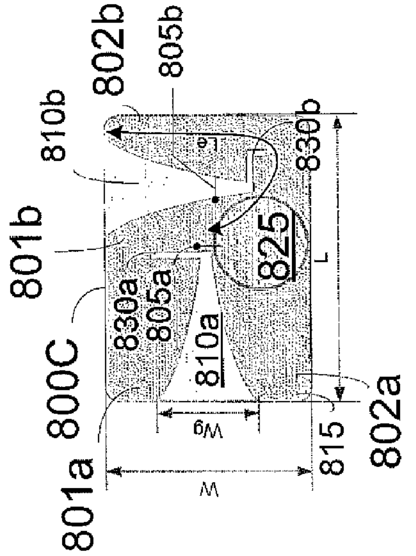


FIG. 8C

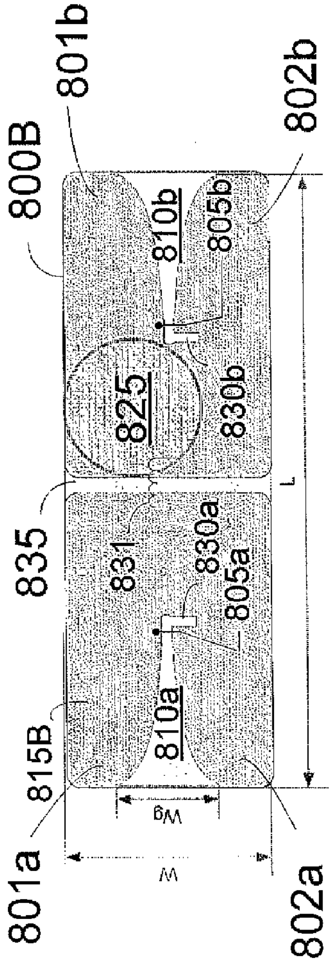


FIG. 8B

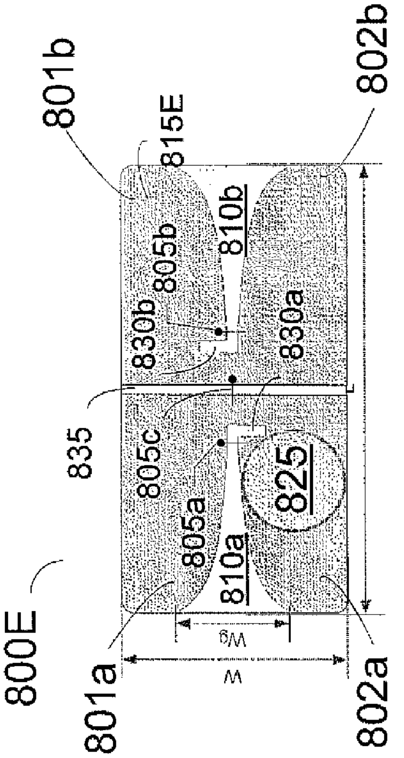


FIG. 8E

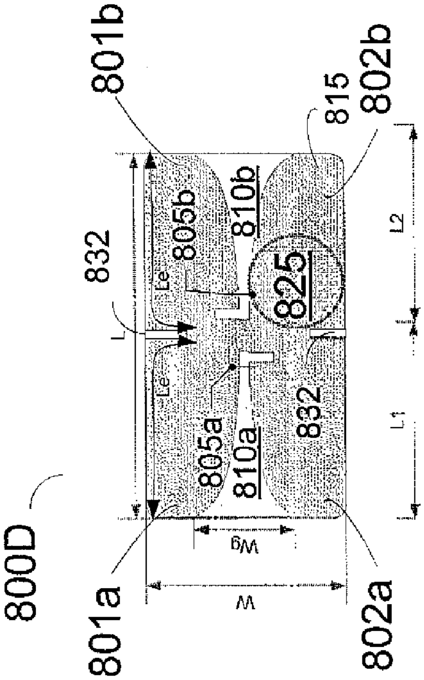


FIG. 8D

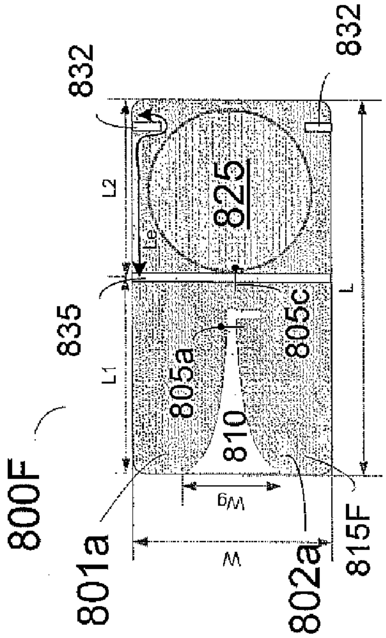
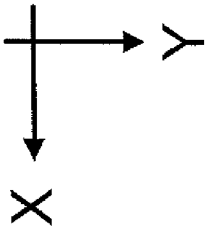


FIG. 8F



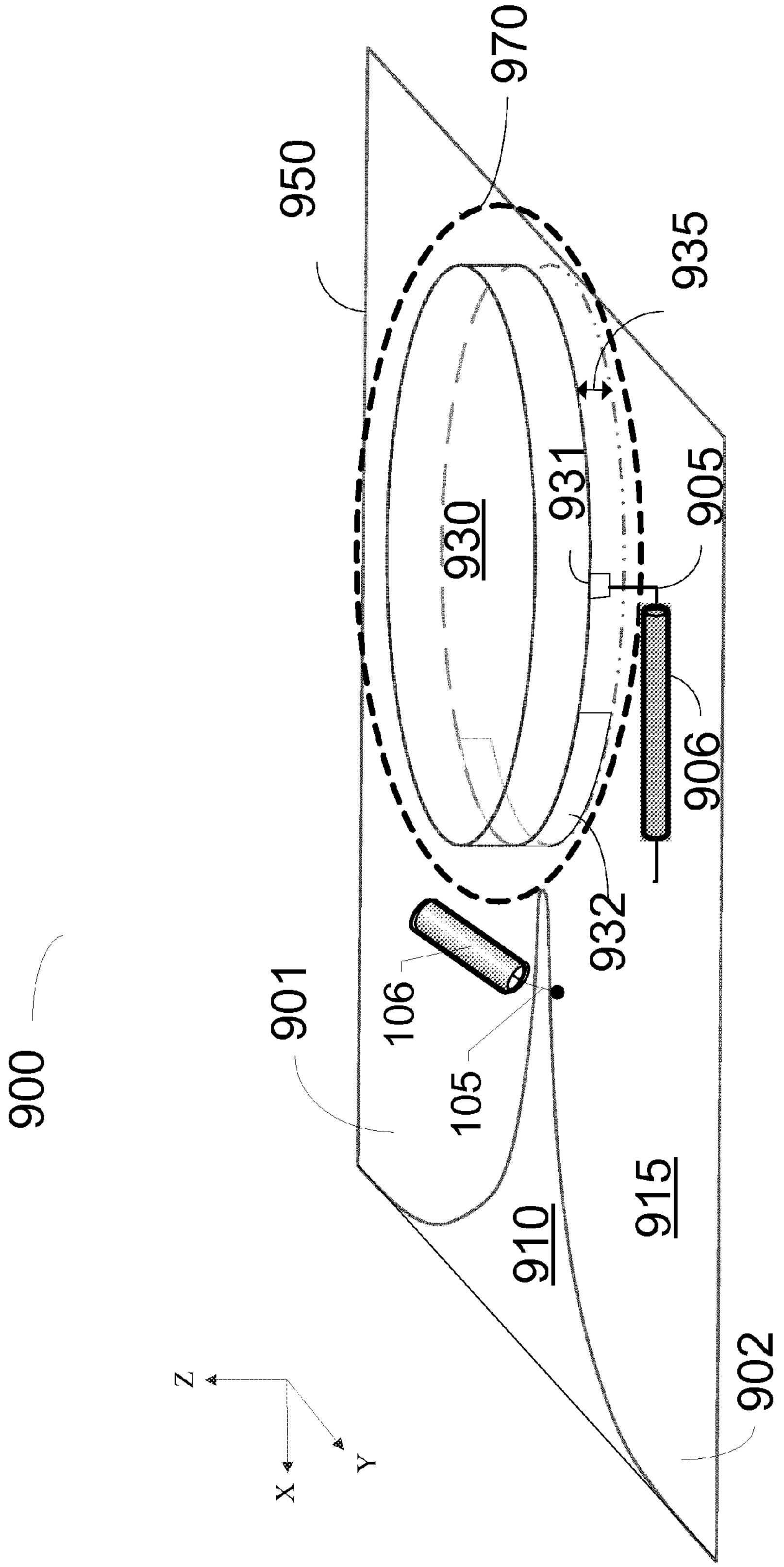


FIG. 9

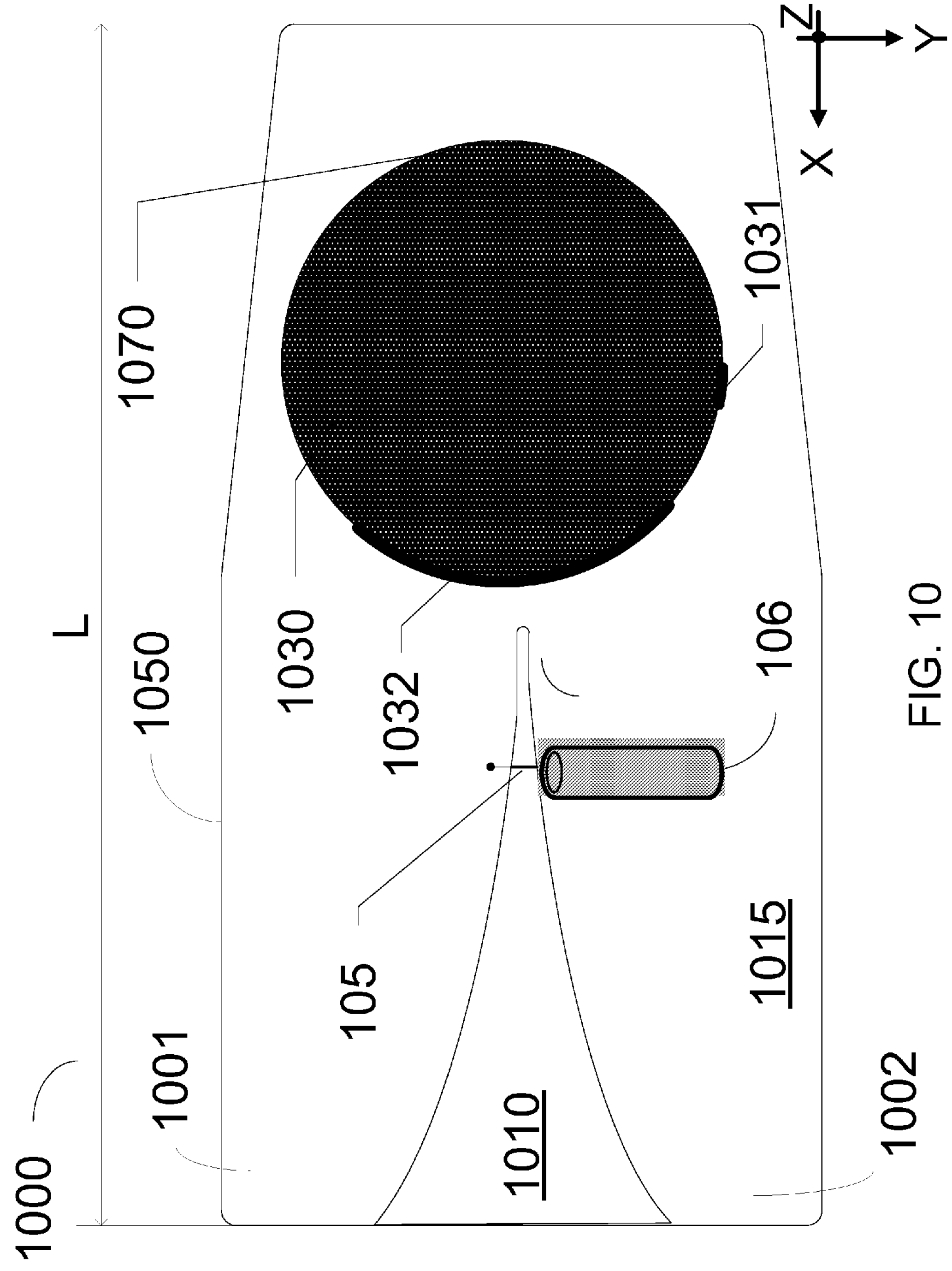

1000
1001
1002
1010
1015
105
106
1030
1031
1032
1050
1070
L
X
Y
Z

FIG. 10

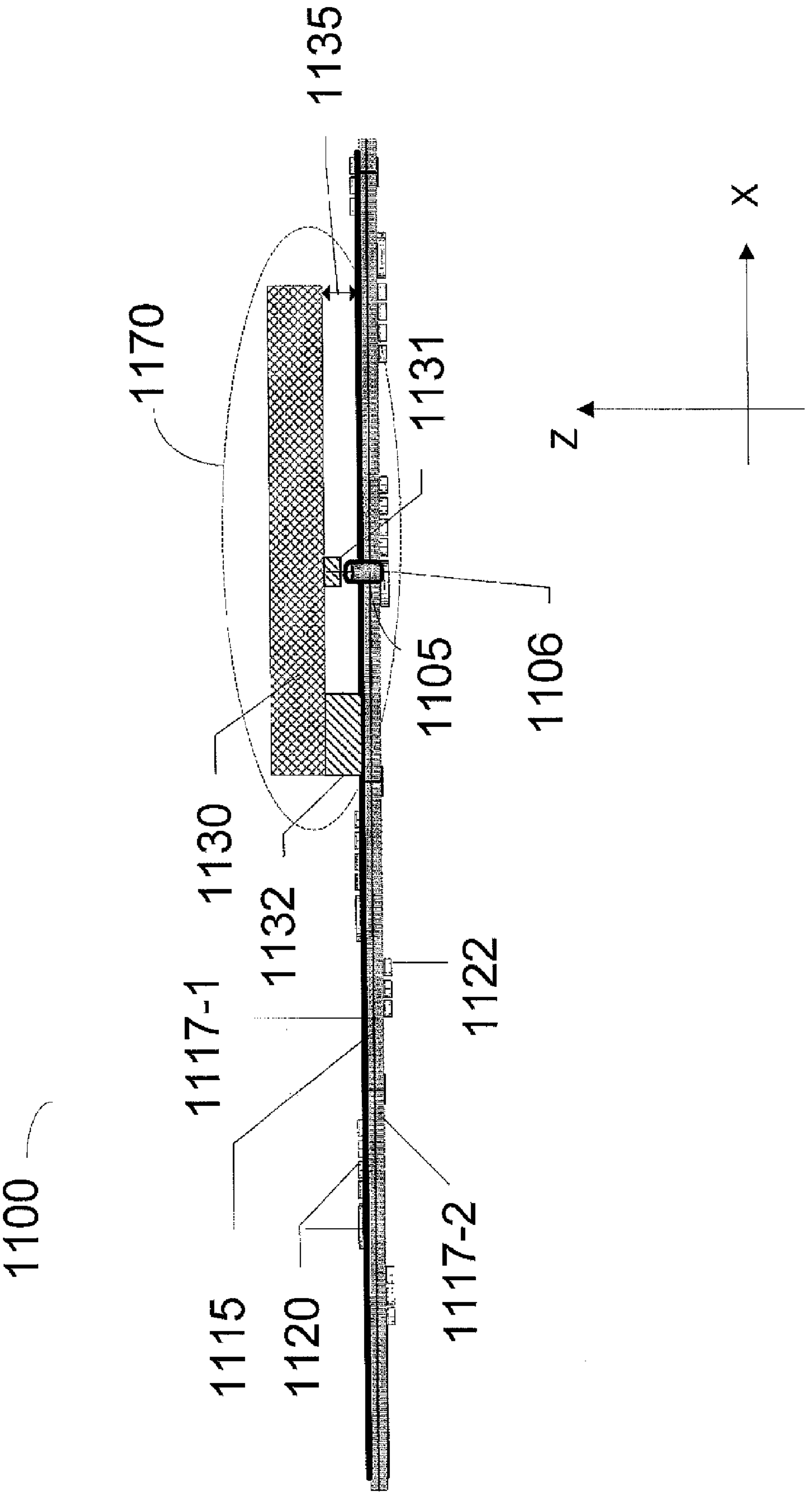

1100
1115
1120
1117-2
1117-1
1122
1132
1130
1105
1106
1170
1131
1135
z
x

FIG. 11

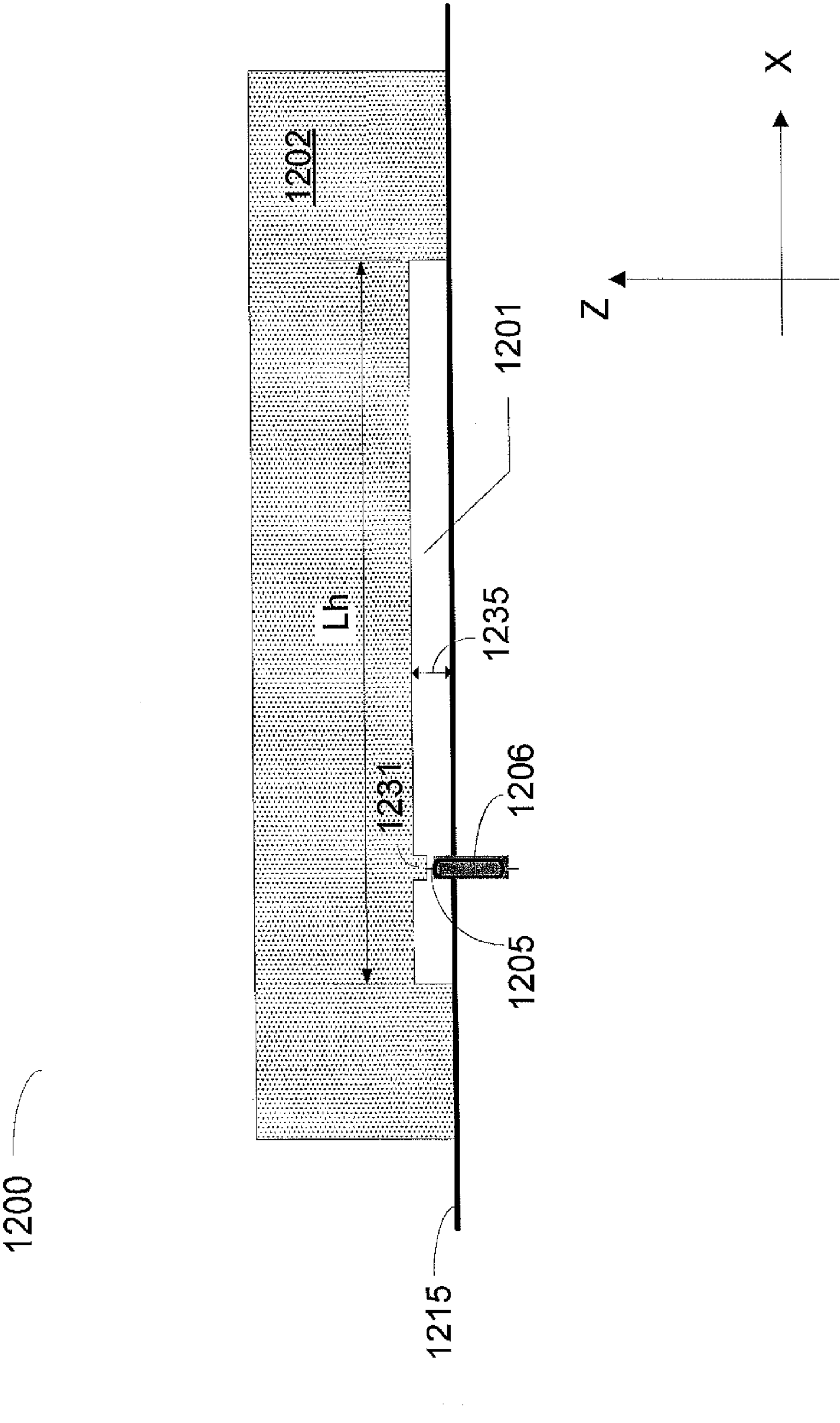


FIG. 12

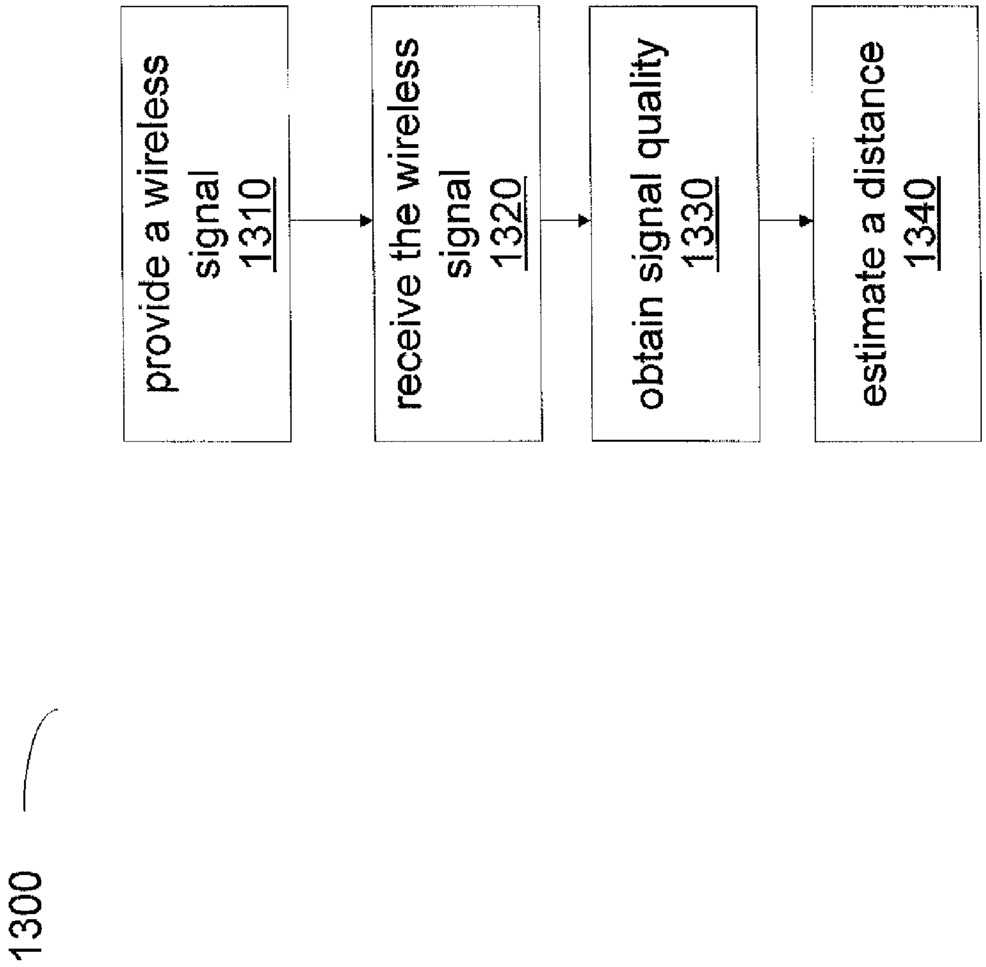

provide a wireless signal 1310
receive the wireless signal 1320
obtain signal quality 1330
estimate a distance 1340
1300

FIG. 13

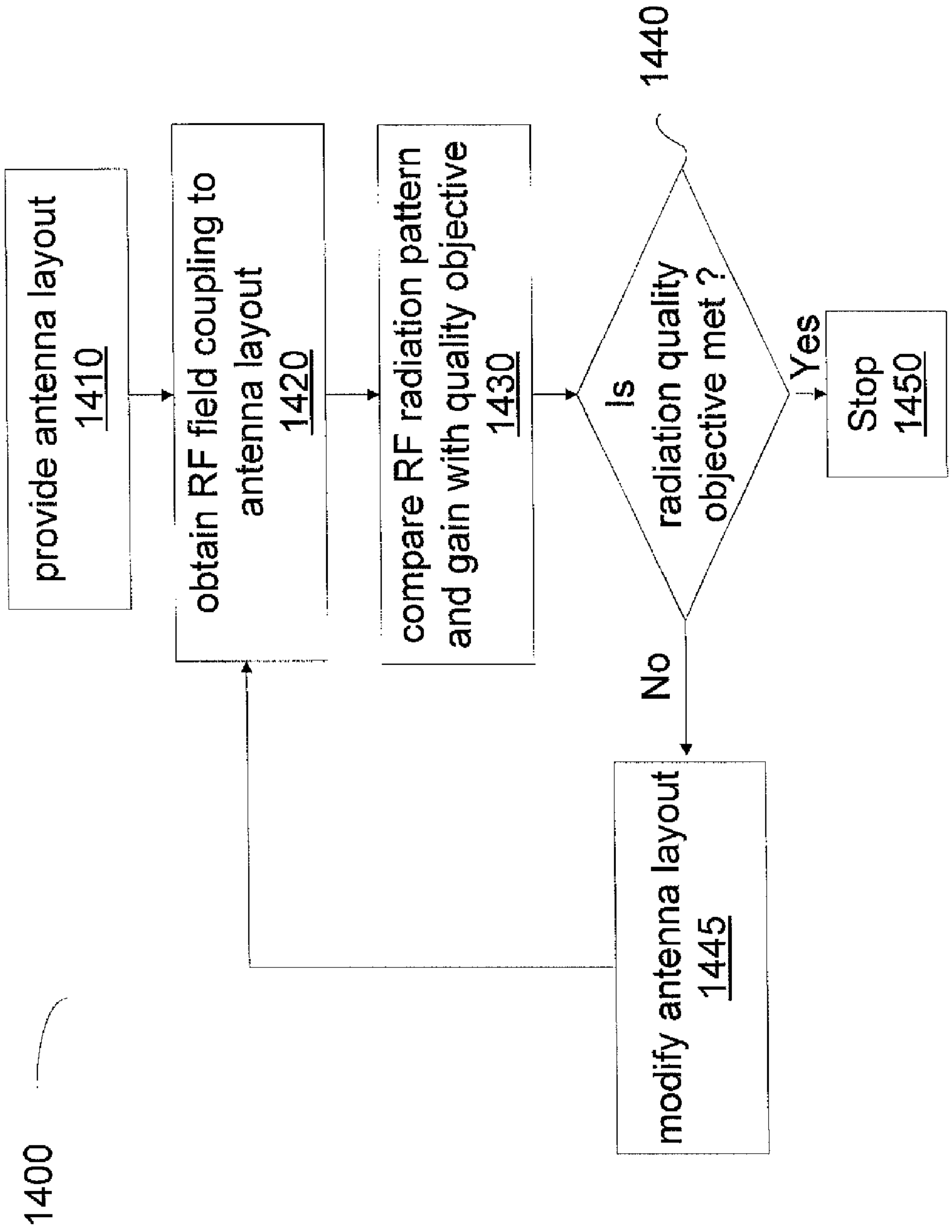

1400
provide antenna layout
1410
obtain RF field coupling to antenna layout
1420
compare RF radiation pattern and gain with quality objective
1430
1440
Is radiation quality objective met ?
Yes
Stop
1450
No
modify antenna layout
1445

FIG. 14

TRUE OMNI-DIRECTIONAL ANTENNA

CROSS-REFERENCE TO RELATED APPLICATIONS

The present application is related and claims priority to U.S. Provisional Patent Application No. 61/428,155, entitled "True Omni-directional Antenna," by Arun Kumar Sharma, David Arthur Candee, and Robert Hill filed on, Dec. 29, 2010, the contents of which are hereby incorporated by reference in their entirety, for all purposes.

BACKGROUND

1. Field of the Invention

Embodiments described herein relate to the field of wireless communication devices and systems. More particularly, embodiments described herein relate to the field of omni-directional antennas for emitters and receivers in wireless communication systems.

GLOSSARY

D_k: Dielectric Constant

PCB: Printed Circuit Board

λ or λ_0: Free space wavelength, for practical purposes same as wavelength in air.

λ_{Dk}: Wavelength in a material with Dk dielectric constant. Including end fringing effect.

λ_e: Wavelength in an environment that has a dielectric layer whose thickness is much smaller than λ_{Dk} (typically $<\frac{1}{4}\lambda_{Dk}$), thus includes effect of environment's Dk. Including end fringing effect.

LoS: Line of Sight

Link Budget:

For a line-of-sight radio system, a link budget equation might look like this:

$$P_{RX}=P_{TX}+G_{TX}-L_{TX}-L_{FS}-L_M+G_{RX}-L_{RX}$$

where:

P_{RX}=received power (dBm)

P_{TX}=transmitter output power (dBm)

G_{TX}=transmitter antenna gain (dBi)

L_{TX}=transmitter losses (coax, connectors . . .) (dB)

L_{FS}=free-space loss or path loss (dB)

L_{LM}=miscellaneous losses (fading margin, body loss, polarization mismatch, other losses . . .) (dB)

G_{RX}=receiver antenna gain (dBi)

L_{RX}=receiver losses (coax, connectors . . .) (dB)

Signal quality measurement: Signal measurements including but not limited to RSSI (Received signal strength indicator), LQI (Line quality indicator), BER (bit error rate) etc.

CAD: Computer Aided Design tool

VNA: Vector Network Analyzer equipment used to measure RF impedance and also two port transfer characteristic.

2. Description of Related Art

In the context of the present disclosure, a wireless appliance is understood as a device having a wireless communication capability. The device may be mobile or fixed to a station. In the field of wireless communications, wireless appliances are used to receive and transmit a signal to and from another wireless appliance. Either of a transmitter and a receiver may be moving, or in a fixed position. In order to receive and transmit radio-frequency (RF) signals, wireless appliances use antennas to couple freely propagating RF radiation and electrical signals in circuitry coupled to the antenna.

Typically, antennas are designed to have directional radiation patterns to preferentially emit or receive radiation into or from a desired direction. In many cases a design adapts a package to the antenna's limitation, adapting a device to radiate in a preferred direction. Most antennas exhibit different radiation patterns when coupled to vertical polarization and horizontal polarization, where a vertical and a horizontal direction are defined with respect to an antenna plane.

The RF propagation loss for line-of-sight (LoS) wireless communication between a transmitter and a receiver is a function of:

a. A distance between transmitter and receiver.

b. A transmitter's antenna gain in the direction of the receiver, relative to the orientation of the transmitter.

c. A receivers antenna gain in the direction of the transmitter, relative to the orientation of the receiver.

d. An operating frequency.

Due to b. above, it is difficult to estimate the distance between an arbitrarily oriented mobile wireless appliance and a fixed receiver using conventional antennas. Some strategies for estimating a transmitter-receiver distance use receiver signal strength indicator (RSSI) in their algorithms, or other 'signal quality measurement' parameters. Use of RSSI based algorithms is hampered by the high directional sensitivity of signal strength in state-of-the-art wireless systems and antennas. A person may carry a mobile wireless appliance in a varying orientation. Thus, the antenna gain of the mobile wireless appliance with respect to a fixed receiver will be unpredictable and highly variable. Typical antennas have radiation patterns with deep minima, and usually showing a high maxima-to-minima ratio. The difference between the peak antenna gain and the minimum antenna gain for various antenna orientations is generally more than 20 dB, and often as high as 50 dB. Thus, in state-of-the-art wireless communications the signal strength not only depends on the distance between the transmitter and the receiver, but also is highly dependent on relative antenna orientation.

In order to account for the aforementioned (maxima-to-minima) variance in antenna gain, low power mobile wireless appliances are often designed with far greater (pessimistic) link-budget compared to equivalent fixed wireless appliances communicating across the same distance. This adds complexity and expense to a wireless system with mobile wireless appliances, not to mention that it requires designing greater maximum transmitter power. High power usage is inconvenient due to frequently recharging or changing batteries. The additional expense is due to increased peak transmitter power, increased receiver sensitivity, increased battery capacity, increased size, increased material cost, and increased electromagnetic interference (EMI) effects.

Tapered slot antennas have been used extensively as linear polarized radiators. Linearly tapered slot antennas or exponentially tapered slot antennas, commonly known as notch antennas or Vivaldi antennas have been used. Terms like "tapered-notch," "flared-slot," and "tapered-slot" antennas have been used interchangeably with Vivaldi antennas in the literature. Linear slot antennas have been disclosed in U.S. Pat. No. 4,855,749 (DeFonzo); exponentially tapered slot antennas have been disclosed in U.S. Pat. No. 5,036,335 (Jairam), and U.S. Pat. No. 5,519,408 (Schnetzer). The conventional Vivaldi antenna is a directional antenna, having an end-fire radiation pattern with a high front-to-back gain ratio. Also, Vivaldi antennas are relatively large compared to the effective wavelength, λ_e, of the electromagnetic radiation that they are designed to detect. For example, some conventional Vivaldi antennas have a slot length that is many times $\lambda_e/4$.

Gain of exponentially tapered slot antennas with conventional designs and dimensions is not satisfactory in terms of directional gain uniformity.

Therefore, there is a need for antenna designs and systems in wireless communication providing high efficiency which is uniform and omni-directional.

SUMMARY

According to embodiments disclosed herein, an antenna for use in a wireless appliance may include a conducting surface having a length and a width; a dielectric slit having a slit length portion oriented along either the length or the width, the slit forming two lips on the conducting surface; the slit having an opening on one of the length and the width, the opening having a flare size; a feed-point element connecting the two lips; wherein the dimensions of the length, the width, the slit length portion, and the flare size are smaller than an effective propagation wavelength of the RF radiation in the antenna.

According to embodiments disclosed herein an antenna for use in a wireless appliance may include a conducting surface having a length and a width; a conductive plate having a plate area defined by a plate perimeter overlaying a portion of the conducting surface, the conductive plate having a contact portion and a feed point; a gap formed between the conductive surface and the conductive plate; a feed-point element connecting the conductive plate to the conductive surface; wherein a length dimension, a width dimension, a plate area dimension, the plate perimeter, and the gap are smaller than an effective propagation wavelength of the RF radiation.

According to embodiments disclosed herein an antenna for use in wireless appliances may include a conducting surface having a length and a width; a dielectric slit having a slit length portion oriented along either one of the length and the width, the slit forming two lips on the conducting surface; the slit having an opening on one of the length and the width, the opening having a flare size; a first feed-point element connecting the two lips; a conductive plate having a plate area defined by a plate perimeter overlaying a portion of the conducting surface, the conductive plate having a contact portion and a feed point; a gap formed between the conductive surface and the conductive plate; a second feed-point element connecting the conductive plate to the conductive surface; wherein a length dimension, a width dimension, the slit length portion, the flare size, a plate area dimension, the plate perimeter, and the gap are smaller than an effective propagation wavelength of the RF radiation.

According to embodiments disclosed herein, a method for estimating a distance using a wireless signal may include providing a wireless signal from a first communication partner having a wireless appliance including an emitter device; receiving the wireless signal at a second communication partner having a wireless appliance including a receiver device; obtaining a signal quality of the received wireless signal; estimating a distance separating the first communication partner from the second communication partner; wherein the signal quality of the received wireless signal is independent of the relative orientation of the emitter device and the receiver device; and the signal quality of the received wireless signal is independent of the polarization of an RF radiation carrying the wireless signal.

According to embodiments disclosed herein a method to provide an antenna in a wireless appliance may include providing an antenna layout, the layout including a length dimension, a width dimension, a slit length portion dimension, a flare size, and a feed-through distance; obtaining an RF field coupling to the antenna layout; comparing the RF field coupling to the antenna layout to a quality standard; modifying the antenna layout when the RE field coupling to the antenna fails to satisfy the quality standard; wherein the length dimension, the width dimension, the slit length portion dimension, the flare size, and the feed through distance are smaller than an effective propagation wavelength of the RF field in the antenna.

These and other embodiments of the present invention will be described in further detail below with reference to the following drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** illustrates a partial plan view of an omnidirectional antenna, according to embodiments disclosed herein.

FIG. **2**A illustrates an orientation-independent communication configuration between two wireless appliances, according to embodiments disclosed herein.

FIG. **2**B illustrates an orientation-independent communication configuration between two wireless appliances, according to embodiments disclosed herein.

FIG. **3**A illustrates a partial plan view of an omni-directional antenna, according to embodiments disclosed herein.

FIG. **3**B illustrates a partial plan view of an omni-directional antenna, according to embodiments disclosed herein.

FIG. **4**A illustrates a partial plan view of a multilayer PCB including a layer with an omni-directional antenna, according to embodiments disclosed herein.

FIG. **4**B illustrates a partial plan view of a multilayer PCB including a layer with an omni-directional antenna, according to embodiments disclosed herein.

FIG. **4**C illustrates a partial side view of a multilayer PCB including a layer with an omni-directional antenna, according to embodiments disclosed herein.

FIG. **4**D illustrates a partial side view of a multilayer PCB including a layer with an omni-directional antenna, according to embodiments disclosed herein

FIG. **5**A illustrates a partial plan view of an omni-directional antenna, according to embodiments disclosed herein.

FIG. **5**B illustrates a partial plan view of an omni-directional antenna including a second antenna and electronic circuits, according to embodiments disclosed herein.

FIG. **5**C illustrates a partial plan view of an omni-directional antenna including a slit having exponential-shaped sides, according to embodiments disclosed herein.

FIG. **5**D illustrates a partial plan view of an omni-directional antenna including a slit having tangential-shaped sides and a bent tip, according to embodiments disclosed herein.

FIG. **5**E illustrates a partial plan view of an omni-directional antenna including a doubly extended tip, according to embodiments disclosed herein.

FIG. **5**F illustrates a partial plan view of an omni-directional antenna including a round tip, according to embodiments disclosed herein.

FIG. **5**G illustrates a partial plan view and a side view of an omni-directional antenna including a doubly extended tip and a dielectric layer, according to embodiments disclosed herein.

FIG. **5**H illustrates a partial plan view of an omni-directional antenna, according to embodiments disclosed herein.

FIG. **5**I illustrates a partial plan view of an omni-directional antenna including a slit having tangential-shaped sides and a gap, according to some embodiments disclosed herein.

FIG. **5**J illustrates a partial plan view of an omni-directional antenna including gaps, according to embodiments disclosed herein.

FIG. **6**A illustrates a configuration of an omni-directional antenna receiving a signal from a radio emitter, and corresponding response plots.

FIG. **6**B illustrates a configuration of an omni-directional antenna receiving a signal from a radio emitter, and corresponding response plots.

FIG. **6**C illustrates a configuration of an omni-directional antenna receiving a signal from a radio emitter, and corresponding response plots.

FIG. **7**A illustrates a schematic view of resonance structures coupled to one another, according to embodiments disclosed herein.

FIG. **7**B illustrates a signal response spectrum for resonance structures coupled to one another under different configurations, according to embodiments disclosed herein.

FIG. **8**A illustrates a partial plan view of a dual omni-directional antenna including two slits, according to embodiments disclosed herein.

FIG. **8**B illustrates a partial plan view of a dual omni-directional antenna including two slits and a reactive component, according to embodiments disclosed herein.

FIG. **8**C illustrates a partial plan view of a dual omni-directional antenna including two slits, according to embodiments disclosed herein.

FIG. **8**D illustrates a partial plan view of a dual omni-directional antenna including two slits, according to embodiments disclosed herein.

FIG. **8**E illustrates a partial plan view of a triple omni-directional antenna including two slits, according to embodiments disclosed herein.

FIG. **8**F illustrates a partial plan view of a dual omni-directional antenna including on slit, according to embodiments disclosed herein.

FIG. **9** illustrates a partial perspective view of a dual omni-directional antenna including a Y-shaped antenna and an F-slot antenna, according to embodiments disclosed herein.

FIG. **10** illustrates a partial plan view of a dual omni-directional antenna including a Y-shaped antenna and an F-slot antenna, according to embodiments disclosed herein.

FIG. **11** illustrates a partial side view of a PCB antenna circuit including an F-slot antenna, according to embodiments disclosed herein.

FIG. **12** illustrates a partial plan view of an F-slot antenna according to embodiments disclosed herein.

FIG. **13** illustrates a flow chart in a method for estimating a distance using a wireless signal, according to embodiments disclosed herein.

FIG. **14** illustrates a flow chart in a method for providing an antenna in a wireless appliance, according to embodiments disclosed herein.

In the figures, like elements are assigned like reference numbers.

DETAILED DESCRIPTION

Wireless appliances as disclosed herein may be a cell phone, Bluetooth headset or a palm device having internet connectivity. In some embodiments, a wireless appliance as disclosed herein may be a hands-free key carried by a user in order to have access to doors in buildings and vehicles. An omni-directional antenna according to embodiments disclosed herein has a lower link budget as compared to conventional antennas having a high directivity and high maxima-to-minima directional gain. This is because the inherent minimum directional gain is higher for an omni-directional antenna than for a conventional antenna, according to embodiments disclosed herein. Thus, embodiments consistent with the present disclosure have a simple design that reduces costs and possibly consumes less power. This results in a simpler, more compact, and more economic product with a longer battery life.

Embodiments disclosed herein include a portable antenna device with near omni-directional characteristics. In some configurations, an omni-directional antenna may be used to ensure effective range estimation based on signal quality, regardless of antenna orientation with respect to a partner RF communication device. In some embodiments one of the partners may be a wireless appliance including an RF communication device using a circularly polarized antenna or a pair of orthogonal linearly polarized antennas.

According to some embodiments, a Printed Circuit Board (PCB) area includes an omni-directional antenna and electronic circuit components mounted on the board. Such embodiments allow lower manufacturing costs and provide a compact design suitable for small RF appliances.

An omni-directional antenna that is compact, has an appropriate bandwidth, and has high efficiency is desirable for use in mobile wireless appliances. In some embodiments, an appropriate bandwidth is a frequency bandwidth tuned to a center frequency and allowing for about 3-20% bandwidth detuning from the center frequency with good efficiency.

The antenna bandwidth obtained in embodiments consistent with the present disclosure is broader than a classical dipole antenna. While a 3-20% of center frequency bandwidth allows for certain amount of detuning, this bandwidth is not as broad as the wideband characteristics of a classical Vivaldi antenna. Thus, some embodiments do not pick up interference from out-of-band broadcasting devices, as Vivaldi antennas do.

An omni-directional antenna according to embodiments disclosed herein may be less sensitive to detuning, which is desirable for mobile wireless appliances. Detuning in mobile wireless appliances may be caused by proximity to body tissue or other materials, as the wireless appliance is carried by a person in a pocket, briefcase, or bag.

The realization of robust communication with mobile wireless appliances in an environment that can cause antenna detuning is desirable for range estimation and related applications. In range estimation, RSSI based algorithms are used to find the distance between a transmitter and a receiver in a LoS configuration. Having an omni-directional antenna is highly desirable to avoid the need to estimate relative spatial orientation in mobile configurations.

Some embodiments disclosed herein have a layout that lends itself to implementing two (or more) antennas on a common PCB. The two or more antennas may be tuned to the same resonance frequency or to somewhat different resonance frequencies. Thus, some embodiments disclosed herein allow for multiband antenna operation in a single PCB circuit. Such embodiments may be desirable in wireless appliances using multiple antennas.

FIG. **1** illustrates a partial plan view of an omni-directional antenna **100**, according to embodiments disclosed herein. Omni-directional antenna **100** includes a conductive layer **115** having a dielectric slit **110** cut out on one side. The dielectric slit **110** forms lips **101** and **102** in layer **115**. Antenna feed-element **105** joins lip **101** to pickup antenna RF signal and couples it to a transmission line (coaxial cable) **106**. In some embodiments consistent with the present disclosure, antenna **100** has a rectangular profile with length ‘L’ and width ‘W’. In some embodiments, length L is greater than width W. Dielectric slit **110** has a depth ‘Ls’ along length L of antenna **100**, and a flare width ‘Wg’ along width W. Antenna feed point **105** may be appropriately placed across slit **110** at a distance 'Fp' from the tip of slit **110** to match desired transmission line impedance.

According to some embodiments, the RF signal having a wavelength λ**0** propagates freely through the environment and is coupled into omni-directional antenna **100** through lips **101** and **102**. Wavelength λ**0** is the free space wavelength of the RF signal. In some embodiments, λ**0** is the wavelength of a desired RF signal in air. Conductive layer **115** is made of copper, according to some embodiments. Dielectric slit **110** is made of a material having a dielectric constant, Dk. According to some embodiments, Dk is greater than the dielectric constant of air at wavelength λ**0**. In some embodiments, conductive layer **115** may be embedded in a PCB having a substrate made of the material forming dielectric slit **110**. According to some embodiments, feed-through **105** includes a galvanic connection to lips **101** and **102**. In some embodiments, feed-point **105** is capacitively connected to lips **101** and **102**, yet in some embodiments lips **101** and **102** may be connected by an open ended transmission line whose electrical length is quarter-wave or less. Antenna **100** may be formed on an insulating substrate including slit **110**, and having a conductive surface forming layer **115**.

An RF signal propagating through the environment at wavelength λ**0** has a wavelength λDk when propagating in a material with dielectric constant Dk. Furthermore, when the RF signal having free space wavelength λ**0** is coupled into a thin layer of material having dielectric constant Dk and a thickness much smaller than λDk, the signal propagates with an effective wavelength, λe. Wavelength λe is the wavelength of RF signals in a dielectric layer whose thickness is typically smaller than ¼λDk. Thus, λe includes boundary effects resulting from the shape and size of the dielectric layer, such as end-fringing effects.

In some embodiments, antenna **100** is implemented in a thin planar shape having length L approximately equal to ½λe, and width W approximately equal to ¼λe. In some embodiments width W is comparable to ¼λe, but not exactly equal to ¼λe. Further, some embodiments may have a slit length Ls approximately equal to ¼λe. The position of feed point, Fp, may vary according to a desired impedance matching to transmission line **106**. In some embodiments, a 50 ohm match is found when Fp is approximately λe/15. According to embodiments consistent with the present disclosure, flare width Wg may be approximately equal to λe/8.

In some embodiments consistent with the present disclosure, a length 'L', width 'W', slit depth, 'Ls', flare width 'Wg', and distance 'Fp' may be selected for an RF wavelength λ**0** corresponding to frequencies in a range between about 100 MHz (mega-Hertz, 10^6 Hz) and about 20 GHz (Giga-Hertz, 10^9 Hz). Thus, in some embodiments antenna dimensions as described above may range from about a meter or so (for 100 MHz applications), down to a few millimeters (for 20 GHz applications). One of regular skill in the art would realize that antenna dimensions scale with inverse of frequency.

A planar, Y shaped antenna such as antenna **100** having a feed point Fp between lips **101** and **102** responds with uniform sensitivity to radiation emanating from multiple directions. In some configurations where a freely propagating RF signal includes two orthogonal polarizations, lack of sensitivity of antenna **100** in one polarization is compensated by good sensitivity of antenna **100** in the orthogonal polarization. Thus, irrespective of its own orientation, antenna **100** communicates with uniform sensitivity with a wireless appliance that has two orthogonally linearly polarized antennas. This will be described in more detail with reference to FIGS. **2**A and **2**B, below.

In embodiments consistent with the present disclosure, radio devices disclosed in FIGS. **2**A and **2**B may interchange emitter role and receiver role in a communication process. One of regular skill in the art would recognize that embodiments disclosed herein are not limiting as to whether an antenna is emitting RF radiation or receiving RF radiation. A radio device as disclosed herein may include a radio receiver and a radio transmitter, or a radio receiver, or a radio transmitter.

FIG. **2**A illustrates an orientation-independent communication configuration between a wireless appliance **150** and a wireless appliance **200**A, according to embodiments disclosed herein. Wireless appliance **150** includes a radio **160**, a controller **163** having a processor chip **161** and a memory chip **162**. Controller **163** may be a computer or an Application Specific Integrated Chip (ASIC) to control radio **170**, which in turn uses the omni-directional antenna **100**. Wireless appliance **200**A includes a controller **263** having a processor chip **261** and a memory chip **262**. In some embodiments, wireless appliance **200**A includes two linear antennas **251** and **252** that are orthogonally oriented. Controller **263** controls a radio **250**, according to some embodiments. Radio **250** is coupled to a switch **253** that can be controlled to connect the radio with either vertically polarized antenna **251** or horizontally polarized antenna **252**.

In some embodiments appliances **200**A and **150** can communicate with each other bi-directionally or uni-directionally. Communication in one direction requires a radio in one appliance to transmit while the radio in other appliance must receive, communication in other direction requires vice versa.

For the RF radiation emitted from or received by wireless appliance **200**A the definition of 'vertical' and 'horizontal' is not limiting, in reference to an arbitrarily oriented, right-handed Cartesian frame S' (X', Y', Z'). Thus, the direction may be the 'vertical' orientation, and a 'horizontal' direction may be any direction in the X',Y' plane, such as the X' direction. While the selection of frame S' is arbitrary, it is understood hereinafter that frame S' remains fixed relative to wireless appliance **200**A. In some embodiments, wireless appliance **200**A may be a fixed transmitter station, receiver station, a transceiver station, or a mobile device.

According to some embodiments, the signal from radio emitter **250** may be simultaneously broadcasted by vertical antenna **251** and horizontal antenna **252**. Thus, in some embodiments switch **253** operates as a signal splitter or a multiplexer rather than a switch. Wireless appliance **200**A generates an RF signal **230**A having a free space wavelength λ**0**. Note that dimensions in FIGS. **2**A and **2**B are not necessarily drawn up to scale. RF signal **230**A travels freely through the environment and reaches antenna **100**, which has an arbitrary orientation according to a right-handed Cartesian frame S (X,Y,Z), relative to wireless appliance **150**. The specific choice of axes (X,Y,Z) and handedness in Cartesian system S is not limiting. Hereinafter, the Z-axis will be chosen as the axis perpendicular to the plane formed by the length L and the width W of antenna **100**. The X-axis is shown as the axis along length L, and the Y-axis is shown as the axis along width W, of antenna **100**.

FIG. **2**B illustrates an orientation-independent communication configuration between wireless appliance **150** and wireless appliance **200**B, according to embodiments disclosed herein. Wireless appliance **200**B includes circularly polarized antenna **254** coupled to radio emitter **250**. Thus, radiation **230**B includes circularly polarized radiation, which may be envisioned as a vertically polarized signal and a horizontally polarized signal, phase-shifted by a quarter wavelength (¼λ**0**). In some embodiments, radio device **250** may be a receiver of a signal emitted by wireless appliance **150**.

FIGS. **2**A-**2**B illustrates an antenna design and communication system that allows an appliance to robustly communicate with another appliance even if the relative orientation of each appliance is subject to independent and uncontrollable change. The antenna utilizes a novel design that exhibits true omni-directional radiation when partnered with an appliance that uses a circularly polarized antenna, or a set of orthogonal linearly polarized antennas for radio communication. The antenna design can be made to exhibit wide bandwidth to make it robust in an environment that can induce antenna detuning.

For an LoS radio system, a link budget equation might include the following terms:

$$P_{RX}=P_{TX}+G_{TX}-L_{TX}-L_{FS}-L_M+G_{RX}-L_{RX} \qquad (1)$$

where: P_{RX} is the received power (dBm); P_{TX} is the transmitter output power (dBm); G_{TX} is the transmitter antenna gain (dBi); L_{TX} represents transmitter losses (coaxial cables, connectors, and other elements) (dB); L_{FS} is the free space loss or path loss (dB); L_M are miscellaneous losses (fading margin, body loss, polarization mismatch, other losses) (dB); G_{RX} is the receiver antenna gain (dBi); L_{RX} represents receiver losses (coaxial cables, connectors, and other elements) (dB). L_{FS} is determined by following terms:

$$L_{FS}=32.4\text{ dB}+20\times\log(f/1\text{ GHz})+10\times n\times\log(d/1\text{ meter}) \qquad (2)$$

Whereby:

f—frequency (GHz), d—distance (m)

n=2 for LoS (Line of sight)

where L_{FS} includes a $1/R^2$ loss term, with R an absolute distance between emitter and receiver.

When RF radiation **230**A or **230**B is received by antenna **100**, an appliance including antenna **100** may perform a signal quality measurement. In some embodiments, a signal quality measurement may include RSSI, Line quality indicator (LQI), or bit error rate (BER), among others.

A signal quality measurement may be used to optimize the design and performance of omni-directional antenna **100**, according to some embodiments. For example, a Computer Aided Design (CAD) tool may be used to simulate the propagation and coupling of RF signal **200**A to antenna **100**. In some embodiments, a prototype of antenna **100** may be tested using Vector Network Analyzer (VNA) equipment to measure RF impedance and also two-port transfer characteristic. Different variations of antenna parameters such as length L, width W, slit length Ls, flare width Wg, and feed-point distance Fp may be optimized according to embodiments described herein. Furthermore, a CAD tool and VNA equipment may be used to optimize the specific shape of slit **110** and lips **101** and **102**, feed-point Fp as well as width of the side opposite to the slit in antenna **100**.

An omni-directional antenna consistent with embodiments described herein can be used in flight termination systems for rockets and missiles. In addition, the design can be used for command, telemetry and tracking systems in flight vehicles (e.g. remotely piloted aircraft, robot or spacecraft) due to its omni-directional feature. This results in compact and versatile systems in the above applications.

FIG. **3**A illustrates an omni-directional antenna **300**A, according to embodiments disclosed herein. Antenna **300**A includes layer **315**, slit **310**A, lips **301** and **302**, and feed-point **305**. Layer **315** and feed-point **305** may be as described in detail above with respect to layer **115**, slit **110**, and feed-point **105** in antenna **100** (cf. FIG. **1**). Slit **310** forming lips **301**A and **302**A may have a shape including sides L**301** and L**302**. According to embodiments disclosed herein, the length of sides L**301** and L**302** may be approximately equal to ¼λe.

In some embodiments, the bandwidth of antenna **300**A may be increased by making sides L**301** and L**302** of slightly different length relative to one another. This is similar to coupling two circuits that are tuned to slightly different frequencies. A wideband performance may be desirable to overcome antenna detuning effects introduced by proximity to human body or other objects having dielectric and/or conductive properties.

FIG. **3**B illustrates an omni-directional antenna **300**B, according to embodiments disclosed herein. In some embodiments, slit **310**B in antenna **300**B may have a curved shape, as illustrated in FIG. **3**B. Sides L**301** and L**302** may be as described in detail above with respect to FIG. **3**A. In some embodiments, sides L**301** and L**302** have a total length of approximately λe/4. Furthermore, sides L**301** and L**302** may have slightly different lengths and shapes, as discussed in detail above with respect to FIG. **3**A.

Sides L**301** and L**302** in FIG. **3**B show a continuously tapered separation. In some embodiments, the tapered shape has an exponential profile. In some embodiments, the tapered shape of sides L**301** and L**302** in slit **310**B has a partially tangential (Tan (θ)) or a partially hyperbolic tangential (Tan h(θ)) profile. A smoothly varying taper as shown in slit **310**B results in near uniform E field in the slit tip, and thus a better coupling efficiency for omni-directional antenna **300**B. In some embodiments consistent with the present disclosure the shape and size of slit **300**B may be used to determine the bandwidth of an omni-directional antenna. For example, a smoothly curved slit such as **310**B may provide a broader RF bandwidth compared to a slit having straight edges, such as **310**A.

FIGS. **3**A and **3**B illustrate RF signals **330**A and **330**B impinging on antennas **300**A and **300**B, according to some embodiments. RF signals **330**A and **3308** may include an electric field polarized in the XY plane. For example, RF signal **330**A may have an electric field polarized along the X-axis, and a wave traveling along the Y-axis. RF signal **330**B may have an electric field polarized along the Y-axis and a wave traveling along the X-axis. According to embodiments consistent with the present disclosure, the response of antennas **300**A and **3008** to RF signal **330**A is enhanced by greater separation of lips **301**A,B and **302**A,B along the Y-axis (W). This is due to the greater phase delay of **330**A signal impinging on **301**A compared to signal impinging on **302**A. Thus, when the separation of lips **301**A,B and **302**A,B (W) is comparable to λe/4, the antenna response is observed to be enhanced for RF signal **330**A. In the case of RF signal **3308**, the response of antennas **300**A and **300**B is governed by the projection of lengths L**301** and L**302** along the Y-axis, which is comparable to λe/4, according to embodiments disclosed herein. Thus, embodiments of antennas as disclosed herein provide enhanced coupling efficiency to radiation coming from multiple directions.

In embodiments of an omni-directional antenna as disclosed herein an electronic circuit may be laid on top of conductive layer **115** (cf. FIG. **1**). Thus, a compact package may be obtained having space used for both antenna operation and the electric circuit operations.

In some embodiments, conductive layer **115** hosts electronic circuitry in a PCB assembly. Furthermore, antenna **100** may be provided on a multilayer PCB assembly according to some embodiments. Thus, appliance electronic circuitry may be placed above or below conductive layer **115**. This will be described in detail below with reference to FIGS. **4**A-4D.

FIG. **4**A illustrates a partial plan view of a multilayer PCB **470** including a layer with an omni-directional antenna **400**, according to embodiments disclosed herein. Omni-directional antenna **400** in FIG. **4**A includes a conductive layer **415** and a slit **410**. Conductive layer **415** and slit **410** may be as described in detail above in relation to conductive layer **115** and slit **110** in antenna **100** (cf. FIG. **1**). Omni-directional antenna **400** may be an inner layer of multilayer PCB **470**.

FIG. **4**B illustrates a partial plan view of multilayer PCB **470** including a layer with omni-directional antenna **400**, according to embodiments disclosed herein. FIG. **4**B illustrates an electronic circuit layer **420** laid on the PCB surface. In some embodiments, circuit layer **420** may be placed above omni-directional antenna **400**. In some embodiments, circuit layer **420** may be placed below omni-directional antenna **400**. Further, in some embodiments a first circuit layer **420** is placed above antenna layer **400**, and a second circuit layer **420** is placed below antenna **400**.

FIG. **4**C illustrates a partial side view of a multilayer PCB **470** including a layer with omni-directional antenna **400**, according to embodiments disclosed herein. When omni-directional antenna **400** is fabricated using a technique similar to that used for PCB, a metallic laminate used to realize conductive layer **415**, **425** and **426** is surrounded by PCB substrate layers **417-1** and **417-2**. According to some embodiments, substrate layers **417-1** and **417-2** are formed of a material with high dielectric constant (Dk). Slit **410** in omni-directional antenna **400** is formed of the same dielectric material Dk as substrate layers **417-1** and **417-2**. This results in reduced velocity of wave propagation (compared to that in free space) by a factor of $1/\sqrt{D_K}$. However, since the dielectric material layer is thin compared to λDk, the net reduction of speed may not be so dramatic. The effective reduction in speed can be computed by CAD tools, to determine the actual size of copper laminate to construct the antenna. Thus the actual length L of omni-directional antenna **400** tends to be somewhat smaller than $\frac{1}{2}\lambda\mathbf{0}$. And the actual width W of omni-directional antenna **400** tends to be somewhat smaller than $\frac{1}{4}\lambda\mathbf{0}$. For example, in embodiments consistent with the present disclosure, the actual length of omni-directional antenna **400** tends to be approximately equal to $\frac{1}{2}\lambda$e. And the actual width of omni-directional antenna **400** tends to be approximately equal to $\frac{1}{4}\lambda$e. Having a material with a large value of Dk, it is typically found that $\lambda e < \lambda \mathbf{0}$. For example for use in 2.4 GHz Industrial, scientific and medical (ISM) band $\lambda\mathbf{0} = 122.5$ mm where as λe is approximately 119 mm.

FIG. **4**D illustrates a partial side view of multilayer PCB **470** including a layer with omni-directional antenna **400**, according to embodiments disclosed herein. Layers **415** and **420** in FIG. **4**D are as described in detail above with respect to FIGS. **4**A-**4**C. Embodiments consistent with the present disclosure may further include dielectric filler **450** in multilayer PCB **470**. Dielectric filler layer **450** is a layer including a high dielectric constant (Dk) material. Thus, λe of an RF signal propagating through multilayer PCB **470** including dielectric layer **450**, is reduced. A reduced λe allows for some embodiments of omni-directional antenna **400** to have a smaller profile, reducing length L and width W of multilayer PCB **470** (cf. FIG. **1**).

In some embodiments, dielectric layer **450** includes a high Dk material in a middle section along the length L of multilayer PCB **470**. Further, some embodiments consistent with the present disclosure may use a high Dk material for at least one of substrate layers **417-1** and **417-2** in multilayer PCB **470**. Some embodiments may include a high dielectric material in a thicker dielectric layer **450** in addition to having high Dk material in substrate layers **417-1** and **417-2** and in slit **410**. Material in layer **450** may be different from the material in substrate layers **417-1** and **417-2**.

Some embodiments such as illustrated in FIG. **4**D show dielectric layer **450** covering only a portion of the width W of multilayer PCB **470**. Other embodiments may use dielectric layer **450** overlaying the entire length L and width W of multilayer PCB **470**. Further, some embodiments may use more than one dielectric layer **450**, with at least one of the layers overlaying the entire length L and width W of multilayer PCB **470**, and at least one of the layers partially covering the area defined by length L and width W. Further according to some embodiments, layer **450** may include a thick enclosure surrounding the entire multilayer PCB **470**, made of a high dielectric material.

Instead of planar antenna arrangement as shown in FIGS. **1**-**4**D, some embodiments may include a three-dimensional (3D) antenna structure consistent with the present disclosure. For example, more than two lips **101** and **102** arranged in a 3D configuration may be used to receive an RF signal.

Embodiments using a multilayer PCB consistent with the present disclosure may be included in appliances using RF communication for more complex tasks. This includes for example RFID applications, RF sensor systems, security devices and locking devices such as used in door locking systems, phone, walkie-talkie, and others. Other appliances that may use omni-directional antennas embedded in a multilayer PCB configuration as disclosed here may include home automation devices, electronic locks, automatic billing and debiting system, and 'pay as you use' appliances. In the above examples, and in other configurations, an omni-directional antenna embedded in a multilayer PCB circuit is implemented for a system including a communication between two partners using an RE signal. The two partners may have wireless appliances including a transmitter and a receiver moving relative to one another. In some embodiments, one of the communication partners may be at a fixed position. Further in some embodiments one or both wireless appliances included in the communication partners acts as a transmitter and a receiver.

FIGS. **5**A-**5**J illustrate a battery **525** placed within the layout of omni-directional antennas **500**A-**500**J. Omni-directional antennas **500**A-**500**J are Y-shaped antennas. Other common elements between omni-directional antennas **500**A-**500**J in FIGS. **5**A-**5**J are a conductive layer **515** having lips **501** and **502** formed by slits **510**A-**510**J. A feed-point element **505** is also included in omni-directional antennas **500**A-**500**J to couple an RF signal into an electrical circuit, for processing. Conductive layer **515**, lips **501** and **502**, and feed-point element **505** are as described in detail above with respect to conductive layer **115**, lips **101** and **102**, and feed-point element **105** (cf. FIG. **1**).

Omni-directional antennas **500**A-**500**H in FIGS. **5**A-**5**H have a generally rectangular layout, with a length L and a width W as described in detail above (cf. FIG. **1**). Thus, some embodiments of an omni-directional antenna consistent with the present disclosure have a length L approximately equal to $\lambda e/2$, and a width W approximately equal to $\lambda e/4$.

FIG. **5**A illustrates a partial plan view of an omni-directional antenna **500**A, according to embodiments disclosed herein. Omni-directional antenna **500**A includes slit **510**A made of linear segments. The linear segments of slit **510**A are such that a wider portion is closer to the edge of omni-directional antenna **500**A, and a narrower portion points to an inner point in omni-directional antenna **500**A.

FIG. **5**B illustrates a partial plan view of an omni-directional antenna **500**B including a second antenna **517** and a plurality of electronic circuits **520**, according to embodiments disclosed herein. Antenna **500**B may be implemented on a multilayer PCB structure such as multilayer PCB **470** (cf. FIG. **4**B above). Thus, electronic circuits **520** may be included in a circuit layer such as layer **420**. Circuits **520** may include a CPU, processor chips such as **161** and **261** (cf. FIGS. **2**A-**2**B), memory chips such as **162** and **262** (cf. FIGS. **2**A-**2**B), and other ASICs. Circuits **520** may be configured to perform processing of the RF signal received by omni-directional antenna **500**B. Processing of the RF signal received by omni-directional antenna **500**B may include analogue and digital operations, according to embodiments consistent with the present disclosure. Furthermore, some embodiments may include in circuits **520** a radio circuitry configured to perform a multi-tiered signal processing for reducing power usage from battery **525**. Circuits **520** in omni-directional antenna **500**B may be configured to perform a multi-tiered signal processing circuit and method such as described in U.S. patent application Ser. No. 12/500,587, entitled "Low Power Radio Communication System," by Arun Kumar Sharma, filed on Jul. 9, 2009, the contents of which are hereby incorporated by reference in their entirety, for all purposes.

Omni-directional antenna **500**B may also include a second antenna circuit **517**. Antenna **517** may be configured to couple a different RE frequency than omni-directional antenna **500**B, so that the two antennas do not interfere with each other. In further embodiments antenna **517** may be configured to couple an RF signal at a different polarization than the RF signal coupled by omni-directional antenna **500**B.

FIG. **5**C illustrates a partial plan view of an omni-directional antenna **500**C including a slit **510**C having exponential-shaped sides, according to embodiments disclosed herein. FIGS. **5**C-**5**J illustrate omni-directional antennas **500**C-**500**J having smoothly tapered slits **510**C-**510**J that may show an exponential profile or a tangential or hyperbolic tangential profile. Slits **510**C-**510**J terminate in a mouth on a side of antennas **500**C-**500**J. The mouth has a flare width Wg similar to that described in detail in relation to omni-directional antenna **100**, above (cf. FIG. **1**). Thus, slits **510**C-**510**J may have Wg approximately equal to λe/8 according to some embodiments. In some embodiments, a non-linear tapered slit resembling slits **510**C-**510**J is realized by a plurality of linear sections of varying length and width. The plurality of linear sections is selected to approximately describe a nonlinear-shaped taper.

In some embodiments, an omni-directional antenna having a smoothly tapered slit such as antennas **500**C-**500**J may include a tapered shape that follows an exponential curve, a geometric ratio curve, a partial Tan (θ) curve, or a partial Tan h(θ) curve. A smoothly tapered slit resembling slits **510**C-**510**J may follow any other monotonically increasing mathematical functions, including the above and combinations thereof.

An appliance including an omni-directional antenna as disclosed herein has a reduced size, as shown above. The area for circuitry that can be implemented on layers above and below the antenna in a multi-layer PCB can be further increased by reducing the slit length. A significantly greater circuit area can be realized for larger bulkier circuit components in an omni-directional antenna consistent with embodiments herein by different configurations such as described in more detail below with reference to FIGS. **5**D-**5**G.

FIG. **5**D illustrates a partial plan view of an omni-directional antenna **500**D including a slit **510**D having tangential-shaped sides and a bent tip **530**D, according to embodiments disclosed herein. Meandering the tip opposite to the mouth having flare width Wg in slit **510**D allows for extra space in the printed circuit board layout. The extra space may be used to place electrical components such as battery **525** overlaying conductive layer **515**, as shown in FIG. **5**D. Other elements that may be placed in the extra space created by meandering the tip in slit **510**D may be another antenna, and circuits **520** (cf. FIG. **5**B).

FIG. **5**E illustrates a partial plan view of an omni-directional antenna **500**E including a doubly extended tip **530**E, according to embodiments disclosed herein. According to some embodiments, tip **530**E forms a T junction, thus extending the depth of slit **510**E without reaching further along length L into the layout of omni-directional antenna **500**E.

In FIG. **5**E, slit **510**E has a size Ls equal to M (cf. FIG. **1**), where M<¼λe. Tip **530**E forms a slot that extends the net electrical length of slit **510**E. Tip **530**E has a T shape with a first feature extending laterally by a distance K and a second feature extending laterally in the opposite direction by a distance S. According to some embodiments, M+(K+S)≈¼λe. Distances K and S may be the same, in some embodiments consistent with the present disclosure. In some embodiments also consistent with the above description, distances K and S may be different. In embodiments of omni-directional antenna **500**E using a multilayer PCB circuit (cf. FIGS. **4**A-**4**D) tip **530**E frees a large portion of PCB space for placing large objects such as battery **525** or circuits **520**.

FIG. **5**F illustrates a partial plan view of an omni-directional antenna **500**F including a round tip **530**F, according to embodiments disclosed herein. According to some embodiments, tip **530**F may have an elliptical profile.

In FIG. **5**F the length Ls of slit **510**F is equal to N, where N<¼λe. The perimeter of tip **530**F extends the net electrical length of slit **510**F. In some embodiments, the perimeter of round tip **530**F is chosen such that N (perimeter of tip **530**F)/2 is approximately equal to ¼λe. In embodiments where tip **530**F is an ellipse, the ellipse can be of any eccentricity. In embodiments of omni-directional antenna **500**F using a PCB circuit (cf. FIGS. **4**A-**4**D) tip **530**F allows large objects such as battery **525** or circuits **520** to be placed in portions of the PCB.

FIG. **5**G illustrates a partial plan view and a side view of an omni-directional antenna **500**G including a doubly extended tip **530**G and a dielectric layer **550**, according to embodiments disclosed herein. According to some embodiments, tip **530**G can be dielectric loaded by a dielectric layer **550**, to further increase electrical length of slit **510**G. In some embodiments a dielectric layer **550** is placed on top and on the bottom of tip **530**G. The electrical length of slit **510**G is increased by distances K and **5**, and also by the high dielectric constant of the material in layer **550**. Thus, slit **510**G frees space in embodiments using a PCB circuit. In the freed space not covered by slit **510**G, large objects such as battery **525** or circuits **520** may be placed.

FIG. **5**H shows an embodiment that reduces the size of an omni-directional antenna **500**H. According to embodiments consistent with the present disclosure, omni-directional antenna **500**H maintains electrical propagation length along its length to be approximately ½λe. As a result, the profile of omni-directional antenna **500**H has a reduced width Wt on the side opposite to the mouth of slit **510**H. In embodiments consistent with the present disclosure slit **510**H in omni-directional antenna **500**H has a smooth shape similar to slits in **510**C-**510**G. Further, according to some embodiments slit **510**H may have an approximately curved shape formed by linear edge sections, consistent with the present disclosure.

FIG. **5**I illustrates a partial plan view of an omni-directional antenna **500**I including a slit **510**I having tangential-shaped sides and a bent tip **530**I, according to some embodiments disclosed herein. Omni-directional antenna **500**I may also include a gap **507** in conductive layer **515**. In some embodiments conductive layer **515** may have a shape folding on itself in the XY plane. This enables reduction of length L of omni-directional antenna **500**I, while maintaining an electrical length approximately equal to $\lambda_e/2$ through conductive layer **515**.

FIG. **5**J illustrates a partial plan view of an omni-directional antenna **500**I including gaps **531**J, according to embodiments disclosed herein. According to embodiments consistent with the present disclosure gaps **531**J reduce the length L of omni-directional antenna **500**J. Gaps **531**, cut out on conductive layer **515**, maintain the electrical length Le of omni-directional antenna **500**J by symmetrically extending (or meandering) conductive layer **515**. In some embodiments conductive layer **515** may be folded on itself in the XY plane (cf. FIG. **5**I).

Thus, embodiments consistent with the present disclosure include an omni-directional antenna having a length L significantly shorter than $\frac{1}{2}\lambda_e$ and a width W on one side significantly shorter than $\frac{1}{4}\lambda_e$. Some embodiments having a reduced omni-directional antenna size include one or more of the following features: a meandering of a conductive layer at the side opposite to a side having two lips separated by a dielectric slit; a high Dk material in a middle section of the conductive layer, along the length L of the conductive layer; a high Dk material forming the substrate of a multilayer PCB that includes the conductive layer; and a different high Dk material on the top and the bottom of the conducting layer.

Embodiments of an omni-directional antenna as disclosed herein exhibit distinctive radiation patterns. For an omni-directional antenna according to embodiments disclosed herein the combined signal strength from vertical polarization and horizontal polarization is nearly uniform in all directions. According to some embodiments, RF signals in vertical and horizontal polarization may be received and transmitted independently of one another. In some embodiments, the contribution of vertically polarized and horizontally polarized RF signals is added in **200**A by the antennas **251** and **252**, controlled by radio **250** and controller **263**, while in other embodiment it is done in wireless appliance **150** by radio **170** and controller **163** with the help suitable communication protocol. This will be described in detail with reference to FIGS. **6**A-**6**C, below.

FIGS. **6**A-**6**C illustrate configurations **600**A-**600**C of an omni-directional antenna **100** receiving a signal from a radio emitter, and corresponding response plots **610**A-**610**C and **620**A-**620**C. Configurations **600**A-**600**C may be as illustrated in FIG. **2**A using omni-directional antenna **100** and radio emitter **250** in wireless appliance **200**A. As in FIG. **2**A, reference frame S (XYZ) is fixed to antenna **100**, and reference frame S' (X'Y'Z') is fixed to the radio emitter in wireless appliance **200**A. Also as in FIG. **2**A, the radio emitter produces a vertically polarized radiation and a horizontally polarized radiation. Hereinafter, vertically polarized radiation and horizontally polarized radiation are defined with reference to frame S'. While the radio emitter remains fixed at a certain position in space, omni-directional antenna **100** is rotated by 360° about its Z-axis (configuration **600**A), about its Y-axis (configuration **600**B), and about its X-axis (configuration **600**C). According to embodiments consistent with FIGS. **6**A-**6**C, the distance between a center point of omni-directional antenna **100** and the radio emitter is fixed.

Refer to FIGS. **6**A, **6**B and **6**C. In configurations **600**A-**600**C, the amplitude of an RF signal received by omni-directional antenna **100** from the radio emitter is plotted for every angle of rotation. Polar plots **610**A-**610**C and **620**A-**620**C are obtained, showing RF signal power (dBi) in a radial direction and the angle of rotation of omni-directional antenna **100** about the rotation axis in the azymuthal direction. A circle **601** in plots **610**A-**610**C and **620**A-**620**C at 0 dBi represents an isotropic antenna receiver. This is the ideal embodiment of an omni-directional antenna as disclosed herein. Polar plots **610**A-**610**C include plots **610**Av-**610**Cv and **610**Ah-**610**Ch, respectively. Plots **610**Av-**610**Cv correspond to the power measured by omni-directional antenna **100** when the radiation from the radio emitter is vertically polarized. Plots **610**Ah-**610**Ch correspond to the power measured by omni-directional antenna **100** when the radiation from the radio emitter is horizontally polarized. Plots **620**A-**620**C are sum plots: **620**A=**610**Av+**610**Ah; **620**B=**610**Bv+**610**Bh; and **620**C=**610**Cv+**610**Ch; corresponding to sum of radiation from both horizontal polarization and vertical polarization.

In configuration **600**A the rotation of omni-directional antenna **100** leaves the Z-axis of the S-frame unchanged relative to the S' frame. In particular, in embodiments consistent with configuration **600**A the Z-axis of the rotating S-frame remains parallel to the Z-axis of the fixed S' frame.

According to plots **610**A and **620**A in configuration **600**A, embodiments of an omni-directional antenna consistent with the present disclosure have a negligible vertical polarization response (**610**Av) because there is no physical metal in Z direction to allow Z reception when the antenna lies flat on the XY plane. Also in configuration **600**A, a horizontal polarization response (**610**Ah) is close to ideal curve **601** for the +90° and −90° direction in omni-directional antennas according to embodiments disclosed herein. This is due to a bent dipole configuration of the two lips formed by a dielectric slit having a tip near the antenna feed-point point (cf. FIG. **1**). Along the 0° and 180° direction the horizontal polarization response (**610**Ah) is good due to the ½λe long virtual antenna elements separated by about ¼λe propagation phase difference (omni-directional antenna width, W, cf. FIG. **1**).

FIG. **6**B illustrates a configuration **600**B of an omni-directional antenna **100** receiving a signal from a radio emitter, and corresponding response plots **610**B and **620**B. In configuration **600**B the rotation of omni-directional antenna **100** leaves the Y-axis of the S-frame unchanged relative to the S' frame. In particular, in embodiments consistent with configuration **600**B the Y-axis of the rotating S-frame remains anti-parallel to the Z'-axis of the fixed S' frame.

According to plots **610**B and **620**B in configuration **600**B, embodiments of an omni-directional antenna consistent with the present disclosure have a uniform vertical polarization response (**610**Bv). The radiation pattern is similar to a bent dipole (cf. FIG. **3**A-**3**B) created by the two lips formed by the slit. Each lip of length approximately ¼λe converges near the feed-point point, creating a bent dipole of length ¼λe with vertex near the feed-point point. In such configurations, a half dipole at the desired RF frequency (λe) is formed with arms bent towards each other and a vertex near the feed-point point. This makes the antenna's directional response close to curve **601** in the XZ plane. This matches the supplementary antenna response from other orientations and polarizations, rendering a response close to curve **601**. Also in configuration **600**B a horizontal polarization response (**610**Bh) is negligible because the feed point is at an equi-potential surface even if the antenna resonates along its length L (approximately ½λe).

FIG. **6**C illustrates a configuration **600**C of an omni-directional antenna **100** receiving a signal from a radio emitter, and corresponding response plots **610**C and **620**C. In configuration **600**C the rotation of omni-directional antenna **100** leaves the X-axis of the S-frame unchanged relative to the S' frame. In particular, in embodiments consistent with configuration **600**C the X-axis of the rotating S-frame remains parallel to the Z-axis of the fixed S' frame.

According to plots **610**C and **620**C in configuration **600**C, embodiments of an omni-directional antenna consistent with the present disclosure have a horizontal polarization response similar to a figure '8' (**610**Ch). Thus, in the +0° and −180° directions antenna response is close to ideal curve **601** (0 dBi) for embodiments consistent with the present disclosure. In particular, omni-directional antennas as disclosed herein having a bent dipole formed by the two lips with a length approximately equal to ¼λe with the antenna feed-point point near the vertex. The bent dipole hence responds well when it faces the horizontal polarization emitter in 0° and 180° direction. Also in configuration **600**C a vertical polarization response (**610**Cv) is close to curve **601** in the +90° and −90° directions. In particular, in embodiments of an omni-directional antenna as disclosed herein curve **610**Cv is close to curve **601** at orientations where curve **610**Ch departs from curve **601** (i.e. it complements the Horizontal polarization radiation pattern). Along the +90° and −90° direction the vertical polarization response is close to curve **601** in embodiments with omni-directional antenna having a length L approximately equal to ½λe, with lips separated by a width W of about ¼λe. In such embodiments, the width W of the antenna is comparable to the propagation phase difference of an RF signal with effective wavelength λe; that results in good antenna response in end fire orientation. **620**C shows the combined radiation pattern response due to sum of both polarization, and it is close to deal curve **601**.

Irrespective of the different configurations **600**A-**600**C, the sum of the omni-directional antenna response for vertical and horizontal polarization is similar to ideal curve **601**. This is shown in curves **620**A-**620**C. An omni-directional antenna consistent with embodiments disclosed herein may include a partner emitting horizontally and vertically polarized radiation. In such configuration the antenna response is uniform regardless of the antenna orientation relative to a LoS between antenna and radio emitter. Curves **620**A-**620**C illustrate the omni-directional nature of an antenna and a wireless communication system consistent with embodiments disclosed herein.

FIG. **7**A illustrates a schematic view of resonance structures **700** and **701** coupled to one another, according to embodiments disclosed herein. Structures **700** and **701** are schematically represented as resonant LC circuits. According to embodiments disclosed herein, structure **700** may be coupled to a signal source and return a signal output, as shown. Structure **700** is tuned to a first resonance frequency determined by design factors such as the values for inductance L**1** and capacitance C**1**. The presence of resonance structure **701** tuned to a second resonant frequency may alter the frequency response obtained at the signal output from structure **700**. For example, the bandwidth of the first resonance frequency in the signal output may be altered. The second resonant frequency is determined by design factors such as the values for inductance L**2** and capacitance C**2**. The alteration of the frequency response in signal output is generally governed by a coupling factor K. The value of K depends on the geometric configuration of structures **700** and **701**, such as distance and relative orientation. The value of K also depends on the frequency response of each structure **700** and **701** taken independently of one another. For example, the relative values of the first resonance frequency and the second resonance frequency may determine the value of K. Also, the bandwidth of the first resonance response and the bandwidth of the second resonance response may affect the value of K. In general, the value of K is a function of the frequency selected to measure the signal output. In some embodiments consistent with the present disclosure at least one of resonant structures **700** and **701** may be an omni-directional antenna, or any other type of antenna configured to receive an RF signal.

FIG. **7**B illustrates a signal response spectrum graph **750** for resonance structures coupled to one another under different configurations, according to embodiments disclosed herein. Graph **750** includes an abscissa for Frequency (Hz) and an ordinate for Response amplitude (dBm). FIG. **7**B illustrates the broadening of a first antenna's bandwidth by having another resonant structure proximal to the first antenna, such as a second antenna. A coupling of the two antennas generally results in a broadening of the first antenna bandwidth. The specific amount of broadening depends on the value of the coupling factor K. For a low value of K, the signal response of a first antenna may be largely unaffected by the presence of the second antenna, showing a response curve **710** similar to that of a standalone first antenna. Two antennas tuned to the same resonance, in close proximity, may be critically coupled when the value of K reaches a critical value Kc. In some embodiments critical value Kc may be a coupling value such that the 3 dB bandwidth response of the first antenna is doubled compared to the 3 dB bandwidth of a stand alone antenna. In such scenario, the first antenna may show a broadened response curve **720**. Further according to some embodiments, the value of K may exceed the value of Kc, in which case a broadened response curve **730** may result.

The layout of omni-directional antennas as disclosed herein lends itself to implementing two (or more) antennas on a common PCB (antenna surface). The plurality of antennas may be tuned to the same resonance frequency or to different resonance frequencies. Thus, embodiments consistent with the present disclosure support applications and appliances configured for multiple antenna operation. This will be described in detail with reference to FIGS. **8**A-**8**F, below.

FIGS. **8**A-**8**D illustrate a partial plan view of dual omni-directional antennas **800**A-**800**D including two slits **810***a* and **810***b*, according to embodiments disclosed herein. In FIGS. **8**A-**8**D each one of slits **810***a* and **810***b* defines a first Y-shaped antenna (**810***a*) and a second Y-shaped antenna (**810***b*). Slits **810***a* and **810***b* include bent tips **830***a* and **830***b* to reduce Ls while accommodating for an effective electrical length Le. The first and second Y-shaped antennas in FIGS. **8**A & **8**D are implemented on a common conducting surface **815**. Feed-point elements **805***a* and **805***b* couple the RF signals from the first and second Y-shaped antennas, respectively. The specific shape of slits **810***a* and **810***b* may be a continuous taper following a nonlinear curve such as an exponential curve, a tangential curve, or a hyperbolic tangential curve (cf. FIG. **5**C-**5**H). Furthermore, at least one of slits **810***a* or **810***b* may include linear portions (cf. FIG. **5**A-**5**B). Dual omni-directional antennas **800**A-**800**D are spatially arranged so as to provide space for battery **825** overlaying conductive layer **815**. In some other embodiment the two Y-shaped antennas could operate at different frequencies.

FIG. **8**A shows an embodiment that has two tapered slits **810***a* and **810***b* symmetrically opposite each other. Dual omni-directional antenna **800**A has a length L allowing for slits **810***a* and **810***b* to be placed longitudinally. In some embodiments, the length L of omni-directional antenna **800**A is an integral multiple of ½λe.

FIG. **8**B illustrates a partial plan view of an omni-directional antenna **8008** including slits **810***a* and Blob, and a reactive component **831**, according to embodiments disclosed herein. Slits **810***a* and **810***b* in dual omni-directional antenna **8008** are symmetrically opposite each other. According to embodiments consistent with the present disclosure, the length L of dual omni-directional antenna **8008** allows for slits **810***a* and **810***b* to be placed longitudinally. The length L of dual omni-directional antenna may be greater than $\frac{1}{2}\lambda e$ and smaller than $\frac{3}{2}\lambda e$, according to some embodiments. Conductive layer **815**B is split in two via dielectric channel **835**, and additional phase shift provided by a reactive component **831**. In some embodiments, reactive component **831** may be a discrete or distributed inductor, or a transmission line.

FIG. **8**C illustrates a partial plan view of a dual omni-directional antenna **800**C including slits **810***a* and **810***b*, according to embodiments disclosed herein. Slits **810***a* and **810***b* in dual omni-directional antenna **800**C are oriented perpendicular to each other. Feed-point **805***b* of the second antenna in FIG. **8**C is meandered to provide an effective electrical length of approximately $\frac{1}{2}\lambda e$. Thus, slit **810***b* makes a dipole with lips **801***b* and **802***b*.

FIG. **8**D illustrates a partial plan view of a dual omni-directional antenna **800**D including slits **810***a* and **810***b*, according to embodiments disclosed herein. In FIG. **8**D slits **810***a* and **810***b* are symmetrically opposite to each other along the length L of dual omni-directional antenna **800**D. FIG. **8**D embodies a method to reduce the length L of dual omni-directional antenna **800**D using gaps or notch-cutouts **832**. Thus, embodiments consistent with the present disclosure maintain the effective electrical propagation length Le of the dipole by extending (meandering) the propagation path around notch cutouts **832**.

FIG. **8**E illustrates a partial plan view of a triple omni-directional antenna **800**E including slits **810***a* and **810***b*, according to embodiments disclosed herein. In triple omni-directional antenna **800**E slits **810***a* and **810***b* form two Y-shaped antennas symmetrically opposite each other. A third dipole antenna is created in the middle of the layout by splitting conductive layer **815**E in two, with dielectric channel **835**. Dielectric channel **835** may be formed of the same high Dk material as slits **810***a* and **810***b*. A feed-point **805***c* couples the RF signal captured by the dipole antenna into an electric circuit. Feed-point elements **805***a* and **805***b* couple the RF signals from the first and second omni-directional antennas, respectively. The third antenna is practically only a dipole antenna, and could be operated at a frequency that is different from the other two omni-antennas.

FIG. **8**F illustrates a partial plan view of a dual antenna **800**F formed by slits **810***a* and **835**, according to embodiments disclosed herein. Dual antenna **800**F includes a omni-directional formed by slit **810** on the left side and a dipole antenna in the middle. This is accomplished by splitting conductive layer **815**F with channel **835** and coupling the RF signal with feed-point element **805***c*. Some embodiments may include notch-cutout elements **832**. Thus, dual omni-directional antenna **800**F may have a reduced layout length L, maintaining electrical propagation length Le by symmetrically extending (meandering) the tail and folding on itself, around notch-cutouts **832**.

FIG. **9** illustrates a partial perspective view of a dual omni-directional antenna **900** including a Y-shaped antenna **950** and an F-slot antenna **970**, according to embodiments disclosed herein. For antenna diversity, compact vertical hybrid F-Slot antenna **970** formed by a metal disc **930** is located next to Y shaped antenna **950** having dielectric slit **910** forming lips **901** and **902** in conductive layer **915**. Y-shaped antenna **950** operates similarly to what has been described in detail above with respect to omni-directional antenna **100** (cf. FIG. **1**). In embodiments consistent with the present disclosure, no detuning or interference is introduced by F-slot antenna **970** due to close proximity with Y-shaped antenna **950**. F-slot antenna **970** provides coupling to vertically polarized RF signals (along the Z-axis in the S-frame) between disc plate **930** and conductive layer **915**. Plate **930** and conductive layer **915** are separated by gap **935**. The signal from F-slot antenna **970** is coupled to coaxial element **906** by feed-point element **905**, which makes electric contact with conducting plate **930** at feed point **931**.

In some embodiments, F-slot antenna **970** is realized by configuring a small dielectric space as gap **935**, and configuring a metallic part of the appliance (e.g. coin cell battery) as plate **930**. Thus, a conducting layer **915** becomes the antenna ground plane. According to embodiments disclosed herein, a portion **932** of the perimeter of conducting plate **930** is connected to a ground plane. In such embodiments, the perimeter of plate **930** facing gap **931** forms an aperture of size comparable to $\frac{1}{2}\lambda e$, acting as a slot antenna for vertically polarized radiation (along the Z-axis).

The precise location of feed point **931** is determined by suitably matching the impedance of the system. In some embodiments, a CAD tool is used to find a suitable location for feed point **931** in order to maximize coupling efficiency at a desired RF wavelength. In some embodiments, a VNA may be used to iteratively determine the position of feed point **931** using a physical prototype consistent with the present disclosure.

According to embodiments consistent with the present disclosure F-slot antenna **970** is not open on both sides. As a result, the resonance frequency is not same as in a classical slot antenna of comparable dimensions that is open on both sides of the slot. The antenna arrangement and feed structure as in F-slot antenna **970** shows a hybridized behavior of both a classical slot antenna and an inverted F antenna.

The resonant frequency of F-slot antenna **970** can be adjusted by changing the dielectric constant of the material forming gap **935**. In general, increasing the dielectric constant of the material reduces the resonance frequency of F-slot antenna **970**. In some embodiments, the resonance frequency of F-slot antenna **970** may be adjusted placing a shorting pin between conductive plate **930** and conductive layer **915** in the interior part of gap **935**. In some embodiments, the shorting pin could be the negative contact pin of the battery connector that connects the negative contact of a battery to conducting plate **915**. In such configurations, the resonance frequency of F-slot antenna **970** is increased. F-slot antenna **970** exhibits omni-directional response (on the XY plane) for vertically polarized radiation (along Z-axis).

Embodiments of an F-slot antenna consistent with the present disclosure may be used stand alone. In dual omni-directional antenna **900**, F-slot antenna **970** is placed such that negligible coupling results between Y-shaped antenna **950** and F-slot antenna **970**. F-slot antenna **970** excites current in conducting layer **915** such that it has little coupling with Y shaped antenna **950**. Thus, embodiments consistent with the present disclosure include a Y-shaped antenna **950** and an F-slot antenna **970** that co-exist without mutual detuning or interference.

FIG. **10** illustrates a partial plan view of a dual omni-directional antenna **1000** including a Y-shaped antenna **1050** and an F-slot antenna **1070**, according to embodiments disclosed herein. Y-shaped antenna **1050** and F-slot antenna **1070** operate in a manner similar to Y-shaped antenna **950** and F-slot antenna **970** described in detail in FIG. **9**. Thus, F-slot antenna **1070** includes conductive plate **1030** separated from conductive layer **1015**. F-slot antenna **1070** also includes portion **1032** connecting conductive plate **1030** to conductive layer **1015**. F-slot antenna **1070** includes feed point **1031**. Dual omni-directional antenna **1000** includes a profile with a reduced total length L by adding a bend to the side of conductive layer **1015** (cf. antenna **500**H in FIG. **5**H).

According to embodiments consistent with the present disclosure, Y-shaped antenna **1050** and F-Slot Antenna **1070** may be included in a single PCB.

In some embodiments, a dual omni-directional antenna as disclosed herein may be formed by an F-slot antenna directly overlaying a Y-shaped antenna. In such configurations, detuning of the Y-shaped antenna and the F-slot antenna due to close proximity will be negligible for the reasons given above in relation to FIG. **9**. Detuning between a Y-shaped antenna and an F-slot antenna is negligible.

As described in relation to FIG. **9**, F-slot antenna **1070** exhibits omni-directional responsivity along the XY plane for vertically polarized radiation. Vertically polarized radiation points along the Z-axis, out of the plane in FIG. **10**.

FIG. **11** illustrates a partial side view of PCB antenna circuit **1100** including an F-slot antenna **1170**, according to embodiments disclosed herein. Features of F-slot antenna **1170** shown in FIG. **11** include conductive plate **1130**, gap **1135**, side wall contact **1132**, feed point **1131**, and conductive layer **1115**. Analogous features have been described in detail above with reference to F-slot antenna **1070** in FIG. **10**. According to some embodiments, an F-slot antenna such as illustrated in FIG. **11** may include a multilayer PCB including PCB substrate layers **1117-1** and **1117-2** surrounding conductive layer **1115**. Substrate layers **1117-1** and **1117-2** may be as described in detail above with respect to layers **417-1** and **417-2** (cf. FIG. **4**C). Circuit layer **1120** includes circuit elements as described in detail above in relation to circuit layer **420** (cf. FIG. **4**B-**4**D). PCB antenna circuit **1100** may further include circuit elements **1122** placed on the bottom of the multilayer PCB device.

FIG. **12** illustrates a conceptual view of an F-slot antenna **1200** according to embodiments disclosed herein, of the slot formed by flattening out the curved slot in a flat 2D plane like a conventional slot antenna that is open on both sides. F-slot antenna **1200** includes slot **1201** formed on a conductive plate **1202** on one side of slot **1201** and a ground element **1215** on another side of slot **1201**. One can understand a simplified behavior of the antenna by accounting for capacitive loading of parallel plates forms by **930** and **915** that is shorted on one end by shunting wall **932**. Slot **1201** has a profile given by a gap size **1235** and a length Lh along the perimeter of **930**. An RF signal impinging on F-slot antenna **1200** resonates with the slot structure and creates an electric field that is coupled into coaxial cable **1206** via feed-point element **1205** from feed point **1231**. The precise location of feed point **1231** for an efficient RF signal coupling may be found using a CAD tool for simulating the RF electric field coupled into slot **1201**. According to embodiments consistent with the present disclosure an F-slot antenna may be realized by folding plate **1202** on itself so that the left hand side joins the right hand side. Furthermore, in order to increase the wavelength of the RF signal coupled to the folded F-slot antenna, a conductive plate may be placed in the top, thus resulting in a structure similar to F-slot antennas **970**, **1070**, and **1170** (cf. FIGS. **9-11**).

FIG. **13** illustrates a flow chart in a method **1300** for estimating a distance using a wireless signal, according to embodiments disclosed herein. The distance in method **1300** may be the distance separating two communication partners, according to some embodiments. A first communication partner may be a user carrying a wireless appliance with a Radio device including an omni-directional antenna as disclosed herein. The second communication partner may have a wireless appliance with an Radio device providing an RF signal. The user may be moving within reach of the RF signal emitted by a second communication partner. The method may be performed by either one of the first communication partner or the second communication partner. Furthermore, in embodiments of method **1300** some steps may be performed by the first communication partner and some steps may be performed by the second communication partner. Method **1300** may be performed by a system monitoring the two communication partners. The system may be controlled by a computer or by an operator. Either one of the communication partners may be a person carrying a wireless appliance. Either one of the communication partners may be a mobile unit or a fixed unit having attached a wireless appliance. A wireless appliance in each of the communication partners includes at least a receiver device or a transmitter device having an omni-directional antenna according to embodiments disclosed herein.

According to some embodiments, in step **1310** an emitter device provides a calibrated wireless signal output to a receiver device the wireless signal may carry information about the RF output level that was emitted, along with the emitter's antenna gain. In some embodiments of step **1310** the emitter device provides an RF signal having vertical polarization and horizontal polarization. In some embodiments of step **1310** the emitter device provides an RF signal having circular polarization. Further according to some embodiments of step **1310** the emitter device provides a combination of RF signals having vertical polarization, horizontal polarization, and circular polarization.

In step **1320** the wireless signal provided in step **1310** is received by a receiver device in one of the communication partners. Step **1320** may be performed by a user or a mobile unit having a wireless appliance including a receiver device with an omni-directional antenna as disclosed herein. The receiver radio in addition to receiving the signal measures signal quality.

Step **1330** obtains a signal quality of the signal received in step **1320** for both polarization. Step **1330** may be performed by a controller in the wireless appliance including the receiver device (e.g. **163** in FIGS. **2**A-**2**B). Step **1330** may be performed by a controller in the wireless appliance including the emitter device (e.g. **263** in FIGS. **2**A-**2**B). In some embodiments, step **1330** may be performed by a computer in the system controlling the two wireless appliances. According to some embodiments, step **1330** includes performing digital and analogical operations. In some embodiments of step **1330** the digital and analogical operations may include return-signal-strength-indicator (RSSI) algorithms, LQI algorithms, and BER algorithms. In some embodiments, step **1330** includes a combination of one or more of the above algorithms.

In step **1340** a distance separating the two communication partners is estimated using the signal quality measured in step **1330**. For example, in some embodiments of step **1340** a signal strength as measured by the receiver device is compared to a function or a table listing signal strength as a function of distance. The table may be stored in a memory circuit, and the function may be computed using a processor circuit. Knowing signal quality, the receiver antenna gain, the transmitter's calibrated output signal level and the transmitter antenna gain, one can use Eq. (1) to estimate Path Loss L_{FS}. For a given operating frequency and LoS communication

Path loss is a known function of distance, thus distance between transmitter and receiver can be estimated using Eq. (2). The memory circuit and the processor circuit may be included in either one of the wireless appliances including the receiver device or the emitter device. For example, memory circuits **162** and **262**, and processors **161** and **261** may be used (cf. FIGS. **2A-2B**).

In some embodiments step **1340** is performed sequentially for each one of two orthogonal polarizations included in the RF radiation. For example, step **1340** may be performed when appliance **200**A emits vertically polarized RF signals (cf. FIG. **2**A). Furthermore, step **1340** may be performed when appliance **200**A emits horizontally polarized RF signals (cf. FIG. **2**A). Further, in some embodiments a receiver device may include two orthogonally oriented antennas, such as described in FIGS. **9-10**. In such embodiments, step **1310**, **1320** and **1330** may be performed sequentially for the RF signals detected by each of the two orthogonally oriented antennas. In some embodiments step **1340** is performed at the same time for the two or more orthogonal antennas included in the receiver device.

FIG. **14** illustrates a flow chart for a method **1400** to provide an antenna in a wireless appliance, according to embodiments disclosed herein. Method **1400** may be performed by a machine or a computer. Machines used to perform method **14** may include RF spectrum analyzers, a VNA, oscilloscopes, BER testers, and the like. Method **1400** may also be performed by a prototype assembler. Further embodiments include some steps in method **1400** performed by a machine or a computer, and some steps performed by a prototype assembler. A prototype assembler may be a person or an automatic machine.

In step **1410** an antenna layout is provided. Step **1410** may include providing parameters and diagrams as input to a CAD tool to be performed by a computer. Step **1410** may also include providing a physical prototype of the antenna by a prototype assembler. The parameters provided in step **1410** may be chosen according to a desired radiation pattern.

A desired radiation pattern may include an RF signal having a selected frequency, which determines the wavelength $\lambda 0$ of the RF signal. Having a desired $\lambda 0$, some embodiments of step **1410** find the effective wavelength λe of the desired signal. This may be obtained using a CAD simulation tool or an electromagnetic field solver. In some embodiments of step **1410** the material dielectric constants Dk, the length L, the width W, and the thickness of the antenna are used to find an approximate value of λe corresponding to the desired $\lambda 0$. Having an approximate value for λe, further details of the antenna layout may be provided, according to embodiments of method **1400** consistent with the present disclosure.

For example, the radiation field in the X-direction of the antenna structure (cf. FIG. **1**) may be selected by choosing design parameters such as the length Ls of slit **110** (Ls, cf. FIG. **1**). According to some embodiments of step **1410**, Ls may be chosen to be an integer factor of ¼λe. In some embodiments step **1410** provides a width for the antenna layout (W, cf. FIG. **1**). For example, a width of about ¼λe may be provided. Further embodiments may provide an initial value of W slightly lower than ¼λe by a factor of 0.1 to 0.7. Further embodiments of step **1410** may provide a flare width (Wg, cf. FIG. **1**). For example, in some embodiments a value of Wg approximately equal to ⅛λe may be provided in step **1410** to realize higher antenna efficiency and near omni-directional radiation response.

In some embodiments of method **1400**, it is desired that the resulting antenna has omni-directional response properties, as disclosed herein. To obtain an omni-directional antenna, step **1410** provides parameters such that the radiation field polarized along the ‘Y’ direction matches the radiation field polarized in the ‘X’ direction (cf. FIG. **1**). In some embodiments step **1410** provides a length for the antenna layout (L, cf. FIG. **1**). For example, a value of L may be provided as an integer multiple of ½λe.

Some parameters provided in step **1410** produce desired characteristic impedance for the antenna. In some embodiments it is desired to enhance the coupling efficiency for the freely propagating RF signal into an electric circuit. The optimal efficiency is obtained when the antenna impedance matches the impedance of a coaxial cable or a detector element included in an electric circuit. Thus, step **1410** may provide the location of feed-point point Fp (cf. FIG. **1**) chosen to match a desired characteristic impedance.

In step **1420** the RF field coupling to the antenna layout provided in step **1410** is obtained. Some embodiments of step **1420** include simulating RF signals using a CAD tool. A CAD tool may be used to calculate a radiation pattern and antenna gain.

The feed point of the antenna Fp can be iteratively computed by an automation script using a RF Field solver included in a CAD tool. Fp can also be experimentally determined by iterative perturbation and measurement using a CAD tool or a VNA.

Some embodiments of step **1420** include placing an antenna prototype inside a chamber having an RF emitter inside. For example, the chamber may be an anechoic chamber. The antenna prototype may be coupled to a VNA tool while inside the chamber. A VNA tool is used to measure prototype antenna’s radiation pattern and gain.

In some applications the antenna surface has a dielectric material around it (e.g. PCB or other supporting structure), the capacitive effect of the dielectric can be computed using field solving techniques. The capacitive effect of the dielectric can also be experimentally determined by iterative perturbation and measurement.

The fringe effects of the edge of the metallic surface can be computed using field solver computing techniques to optimize the dimensions of the antenna. Fringe effects can also be determined by iterative perturbation and measurement using CAD tools and a VNA.

In step **1430** the RF field coupling is compared to a quality standard. In some embodiments step **1430** includes measuring a signal quality using digital and analogical operations from the electrical signal. Signal quality may include RSSI data, LQI data, or BER data. In some embodiments step **1430** may include measuring a spectral response of the omni-directional antenna and comparing it to a quality standard. The quality standard may include parameters such as center frequency, 3 dB bandwidth, and maximum amplitude.

Step **1440** includes determining whether or not the antenna satisfies the quality standard used for comparison in step **1430**. If it does, method **400** is stopped in step **1450**.

If the antenna fails to satisfy the quality standards in step **1430**, step **1445** includes modifying the antenna layout. In some embodiments, step **1445** includes tuning the antenna by adjusting layout parameters. Some of the layout parameters that may be adjusted are the length of one or both lips (e.g. L**301** and L**302** in FIG. **3**). The antenna can be tuned by the addition or removal of dielectric material between the two lips (e.g. **101** and **102** in FIG. **1**).

In some embodiments, step **1445** includes fine tuning the antenna resonance frequency by cutting a slot in the dielectric material in the slit separating the two conducting lip (e.g. **110** in FIG. **1**). This increases the resonance frequency. In some embodiments step **1445** includes fine tuning the antenna resonance frequency by adding a high Dk material in the slit separating the two conducting lips. This reduces the resonance frequency. In some embodiments step **1445** includes fine tuning the antenna resonance frequency by adding a high Dk material on the extremities of the two conducting lips. This reduces the resonance frequency.

After modifying the antenna layout in step **1445**, method **1400** is repeated from step **1420**, until the antenna satisfies the radiation quality standard in step **1430**.

Embodiments of method **1400** may be used to design a first prototype of an antenna. The first prototype is fed into a RF CAD system to iteratively adjust the antenna design for desired radiation, electronic and mechanical characteristics. The prototype is verified experimentally and if necessary iterative perturbation and measured till optimum behavior is realized.

Embodiments of devices and methods as disclosed above allow making a compact appliance where both the antenna and circuitry are provided in the same package (e.g. a PCB package). In some embodiments a method for providing a wireless appliance on a PCB integrated circuit having an omni-directional antenna is disclosed. According to such embodiments, the wireless appliance may have a reduced physical size shorter than ½λe in length and ¼λe in width.

Embodiments consistent with the present disclosure may be utilized in applications including Radio communication antennas, RFID devices and systems, RF heating, RF stealth, Radar Cross Section (RCS) uniformity, RF absorbing/anechoic application, Passive antenna in a larger antenna array, RF direction finding, Proximity sensing, Flight termination systems in rockets and missiles, Telemetry, and tracking and control systems for flight vehicles or munitions.

Embodiments described above are exemplary only. One skilled in the art may recognize various alternative embodiments from those specifically disclosed. Those alternative embodiments are also intended to be within the scope of this disclosure. As such, the invention is limited only by the following claims.

What is claimed is:

1. An antenna for use in a wireless appliance, comprising:

a conducting surface having a length and a width, wherein the length is greater than the width and the width is less than a quarter of a first wavelength which is an operating wavelength of the antenna;

a dielectric slit having a slit length portion oriented along the length, the slit forming two lips on the conducting surface;

the slit length portion extending along the length to provide mouth that opens out of the conducting surface;

a feed-point element connecting the two lips.

2. The antenna as in claim **1** wherein the two lips form respectively a first side and a second side of the slit, each side having a shape;

wherein the first side and the second side have different lengths and different shapes.

3. The antenna as in claim **1** wherein the two lips form respectively a first side and a second side of the slit, each side having a shape;

wherein each side has either an exponential function shape or a shape formed of linear segments.

4. The antenna as in claim **1** wherein the two lips form respectively a first side and a second side of the slit, each side having a shape;

wherein each side has a tangent function shape.

5. The antenna as in claim **1** wherein the slit forms a tip at a junction point of the two lips;

wherein the tip is bent in the plane of the conducting surface.

6. The antenna as in claim **1** wherein the dielectric slit is formed of a dielectric material having a dielectric constant greater than 3, at the first wavelength.

7. The antenna as in claim **1** wherein the length is approximately equal to one half of the effective wavelength and the width is approximately equal to one quarter of the effective propagation wavelength.

8. The antenna as in claim **1** wherein the length is approximately equal to an integer multiple of one half of the effective wavelength and the width is approximately equal to one quarter of the effective propagation wavelength.

9. A method for estimating a distance between a first wireless appliance and a second wireless appliance, the method comprising the second wireless appliance performing operations of:

receiving a wireless signal from the first wireless appliance by a receiver device of the second wireless appliance, the receiver device comprising the antenna of claim **1**, wherein the wireless signal is received at the antenna;

obtaining a signal quality of the received wireless signal;

estimating a distance separating the first wireless appliance from the second wireless appliance, the distance being estimated from the received wireless signal.

10. The antenna of claim **1** wherein for at least one antenna position relative to a source of two linearly polarized electromagnetic waves one of which is polarized along a first polarization axis and the other one of which is polarized along a second polarization axis perpendicular to the first polarization axis, and

for at least one predefined axis passing through the antenna and parallel to the first polarization axis, a condition holds that a sum of the antenna's response to the two linearly polarized electromagnetic waves varies by no more than a first value not exceeding 15 dB as the antenna is rotated around the first predefined axis.

11. The antenna of claim **10** wherein the first value does not exceed 10 dB.

12. The antenna of claim **10** wherein said condition holds for at least one of positional relationships (A), (B), and (C):

(A) the first predefined axis extends along the length;

(B) the first predefined axis extends along the width;

(C) the first predefined axis is perpendicular to the length and the width.

13. The antenna of claim **12** wherein the first value does not exceed 10 dB.

14. The antenna of **12** wherein the said condition holds for each of (A), (B) and (C).

15. The antenna of claim **14** wherein the first value does not exceed 10 dB.

16. A method for estimating a distance between a first wireless appliance and a second wireless appliance, the method comprising:

the second wireless appliance receiving a first wireless signal from the first wireless appliance by a receiver device of the second wireless appliance, the receiver device comprising the antenna of claim **10**, wherein the first wireless signal is received at the antenna and is polarized along the first polarization axis;

the second wireless appliance obtaining a signal quality of the received first wireless signal;

the second wireless appliance receiving a second wireless signal from the first wireless appliance by the receiver device of the second wireless appliance, wherein the second wireless signal is received at the antenna and is polarized along the second polarization axis;

the second wireless appliance obtaining a signal quality of the received second wireless signal; and

the second wireless appliance estimating the distance between the first and second wireless appliances based on the signal qualities of the received first and second wireless signals, and/or sending information on the signal qualities to the first wireless appliance to enable the first wireless appliance to estimate the distance between the first and second wireless appliances based on the signal qualities.

17. The method of claim **16** wherein estimating the distance is based on a Free Space Loss parameter.

18. The method of claim **16** wherein the second wireless appliance estimates the distance.

19. The method of claim **16** wherein the second wireless appliance sends said information to the first wireless appliance, the method further comprising estimating said distance by the first wireless appliance.

20. The antenna of claim **1** wherein the slit length portion is tapered to flare out towards the mouth.

21. The antenna of claim **20** wherein the slit's flare width is no greater than one eighth of the first wavelength.

22. An antenna structure for use in a wireless appliance, comprising:

a first antenna for providing a gain with respect to electromagnetic ("EM") radiation polarized in an XY plane of a Cartesian XYZ frame; and

a second antenna for providing a gain with respect to EM radiation polarized along the Z axis of the Cartesian XYZ frame;

wherein the first and second antennas share a conductive surface extending in the XY plane, wherein the conductive surface is for providing coupling to EM radiation polarized in the XY plane;

wherein the second antenna comprises a conductive plate spaced from the conductive surface along the Z axis, the conductive plate having a contact portion connected to the conductive surface;

wherein:

in a projection onto the XY plane along the Z axis, the conductive plate lies entirely within the conductive surface;

the second antenna structure comprises a gap between the conductive surface and the conductive plate, the gap having a width along the Z axis to provide a gain with respect to EM radiation polarized along the Z axis in the gap;

the second antenna is operable to provide coupling to EM radiation polarized along the Z axis in the gap;

the antenna structure comprises one or more feed-point elements connected to the conductive plate and to the conductive surface.

23. The antenna structure of claim **22**, wherein the first antenna comprises a dielectric slit forming two lips on the conductive surface and extending to provide a mouth that opens out of the conductive surface;

wherein the one or more feed-point elements comprise a first feed-point element connecting the two lips.

24. The antenna structure of claim **22** wherein the first and second antennas provide antenna diversity.

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