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(54) **CHASSIS-EXCITED ANTENNA APPARATUS AND METHODS**

(71) Applicant: **Pulse Finland OY**, Oulunsalo (FI)

(72) Inventors: **Prasadh Ramachandran**, Kempele (FI); **Petteri Annamaa**, Oulunsalo (FI)

(73) Assignee: **Pulse Finland OY**, Oulunsalo (FI)

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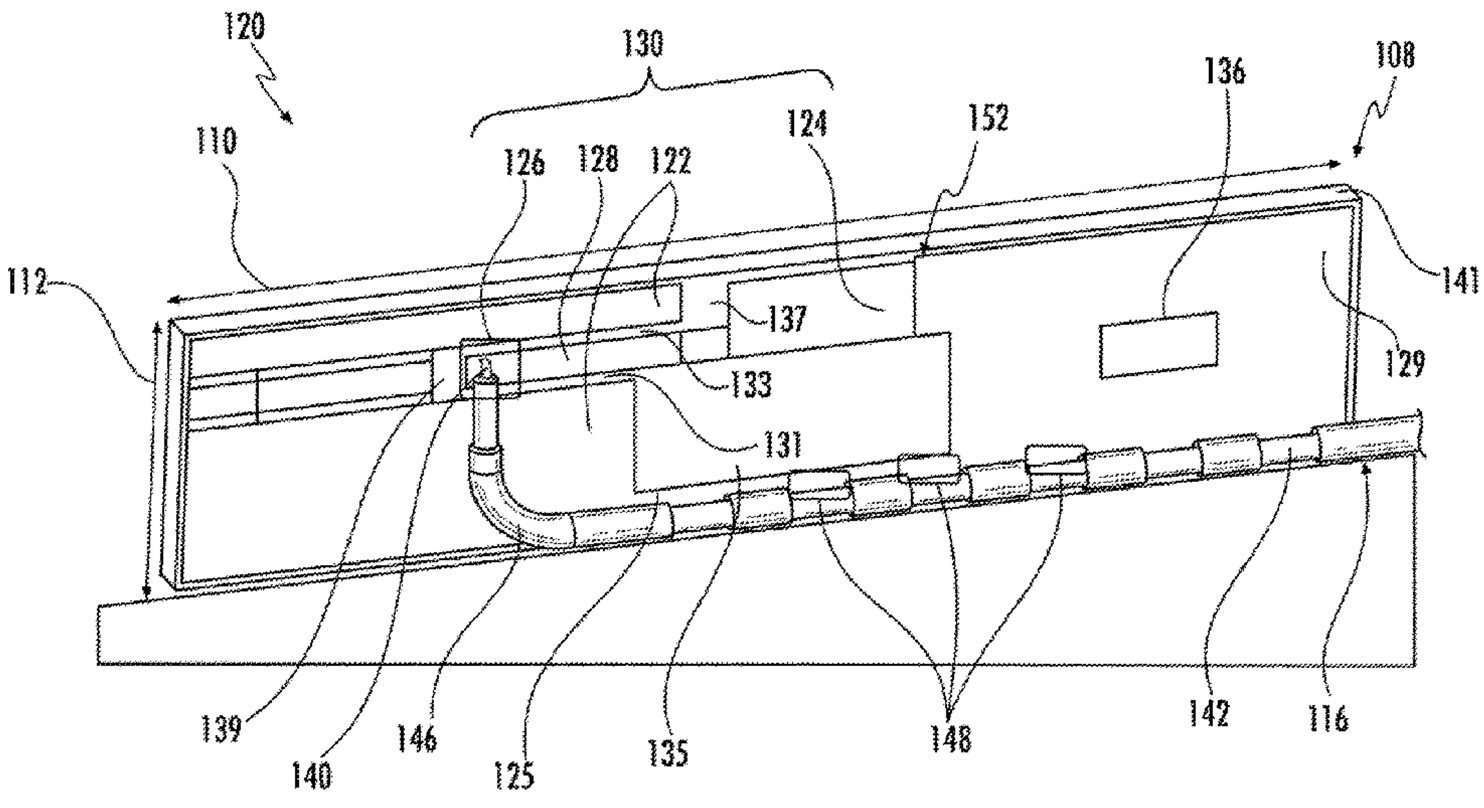
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Primary Examiner — Jessica Han
Assistant Examiner — Bamidele A Jegede
(74) *Attorney, Agent, or Firm* — Gazdzinski & Associates PC

(57) **ABSTRACT**

A chassis-excited antenna apparatus, and methods of tuning and utilizing the same. In one embodiment, a distributed loop antenna configuration is used within a handheld mobile device (e.g., cellular telephone). The antenna comprises two radiating elements: one configured to operate in a high-frequency band, and the other in a low-frequency band. The two antenna elements are disposed on different side surfaces of the metal chassis of the portable device; e.g., on the opposing sides of the device enclosure. Each antenna component comprises a radiator and an insulating cover. The radiator is coupled to a device feed via a feed conductor and a ground point. A portion of the feed conductor is disposed with the radiator to facilitate forming of the coupled loop resonator structure.

33 Claims, 10 Drawing Sheets



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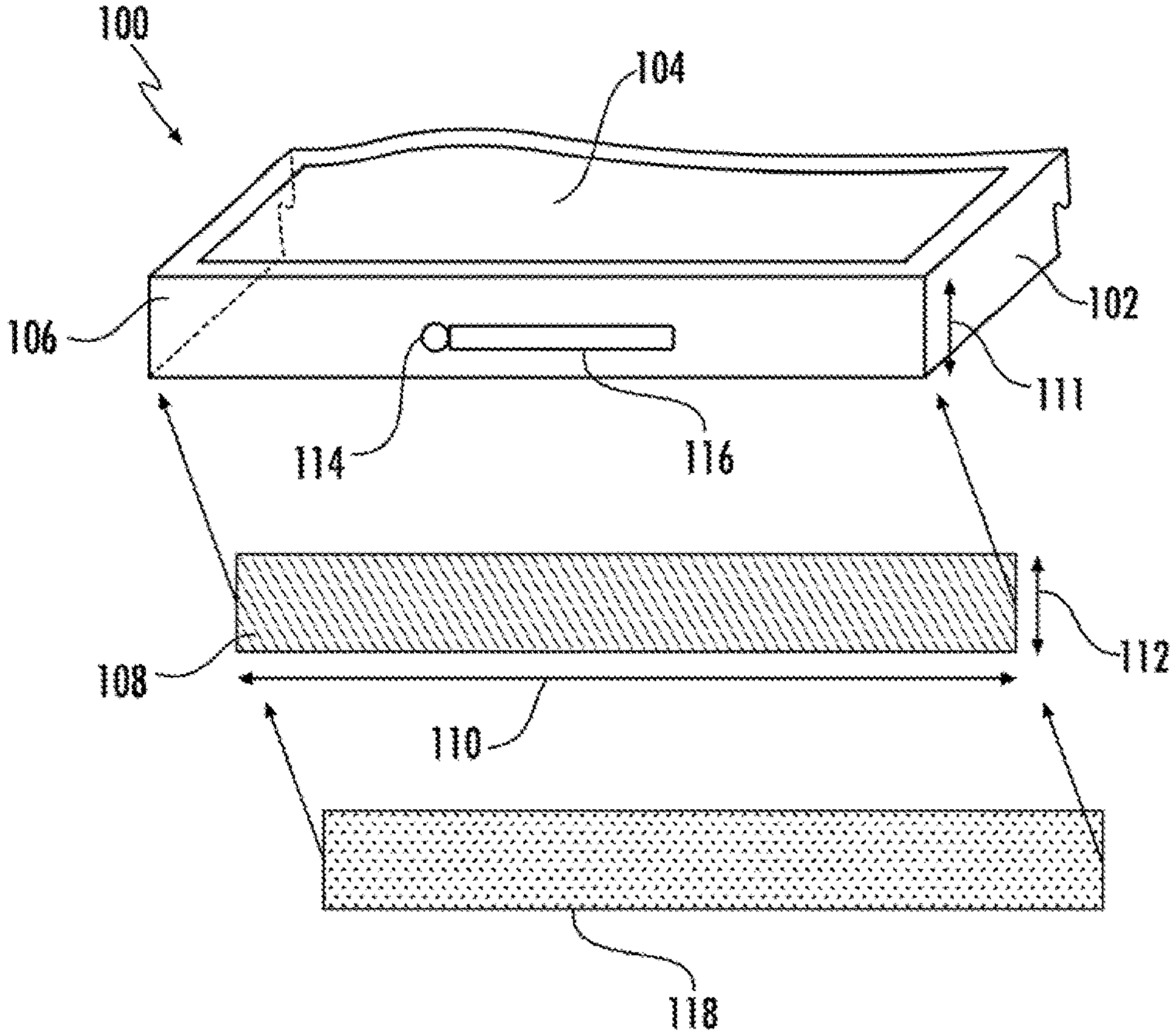


FIG. 1

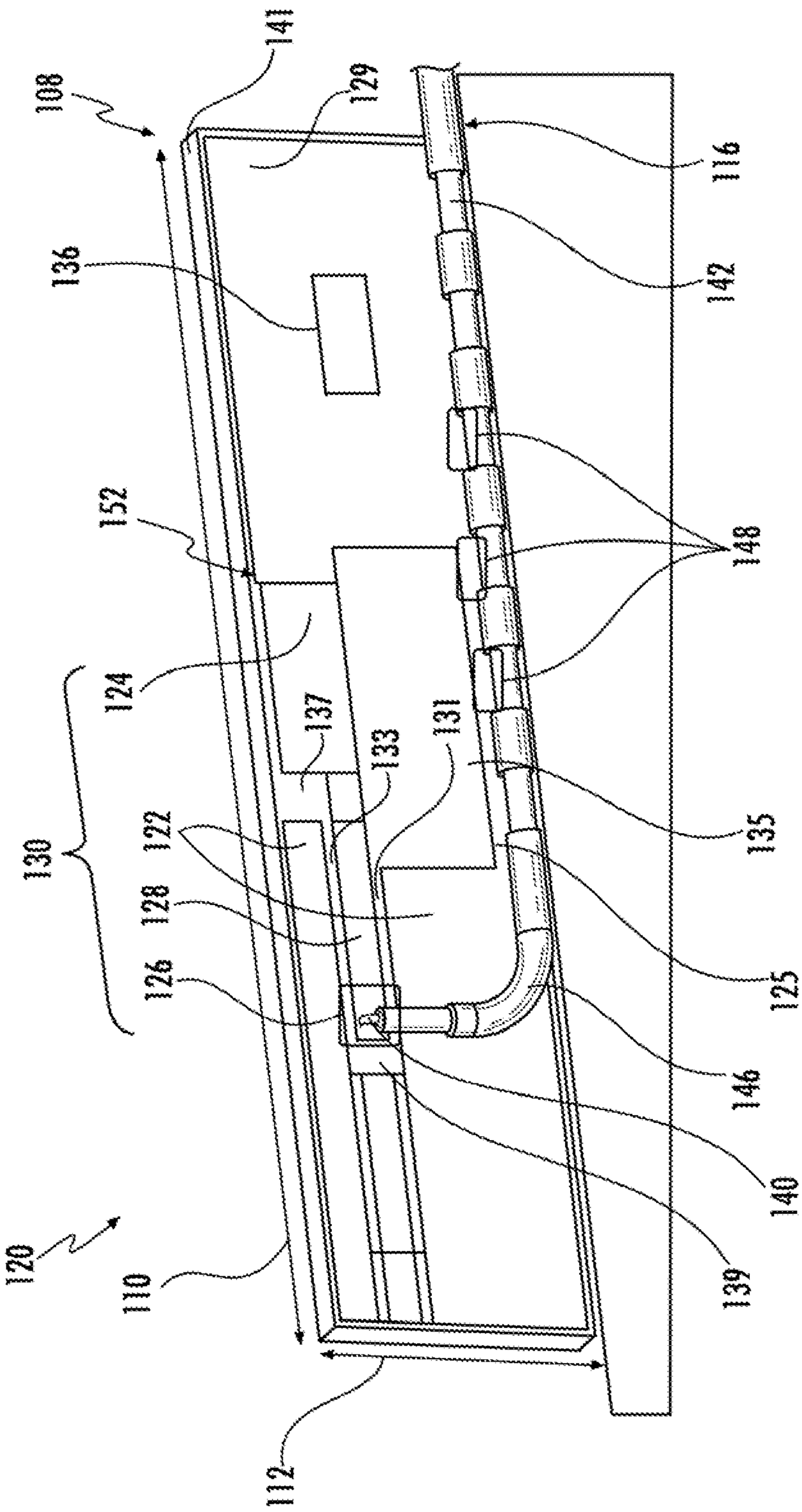

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FIG. 1A

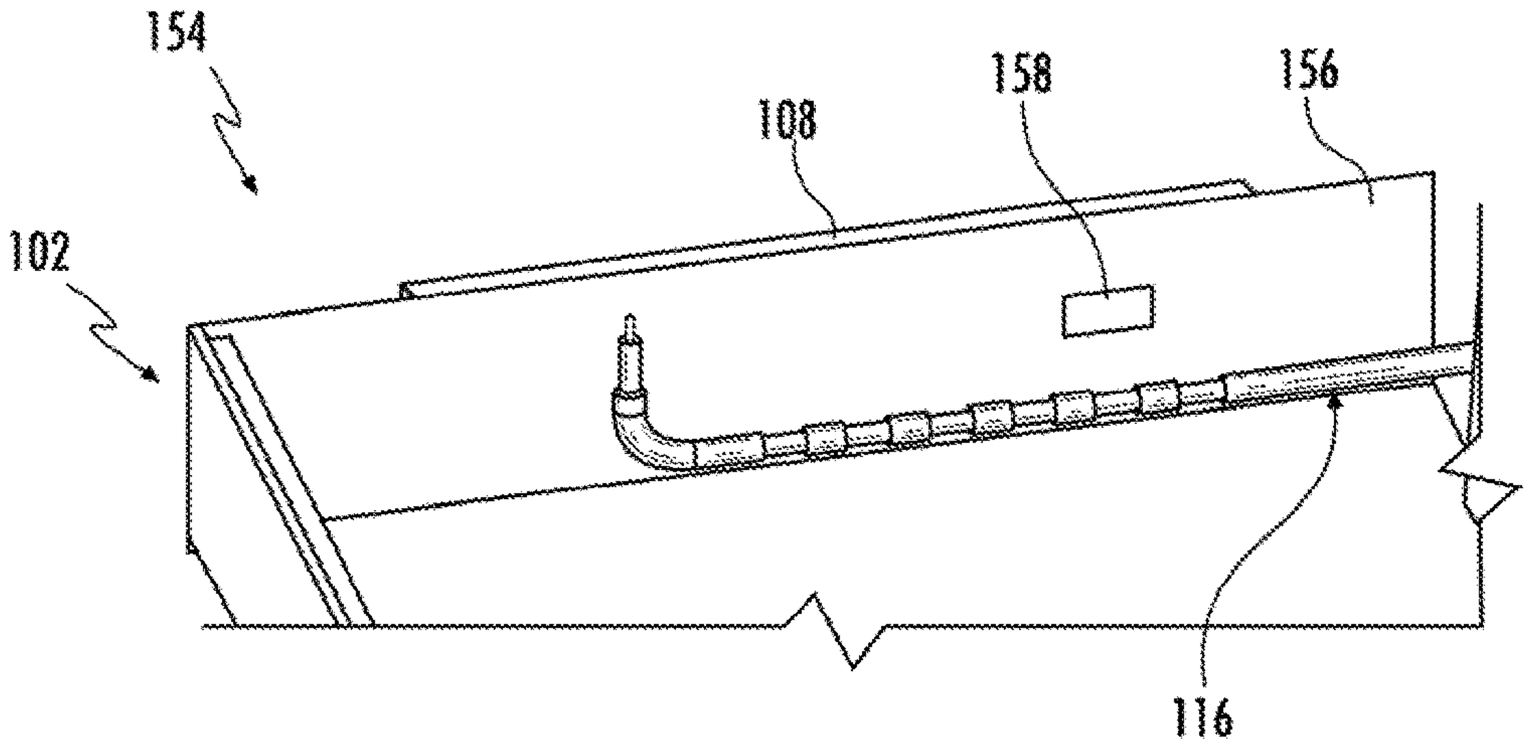


FIG. 1B

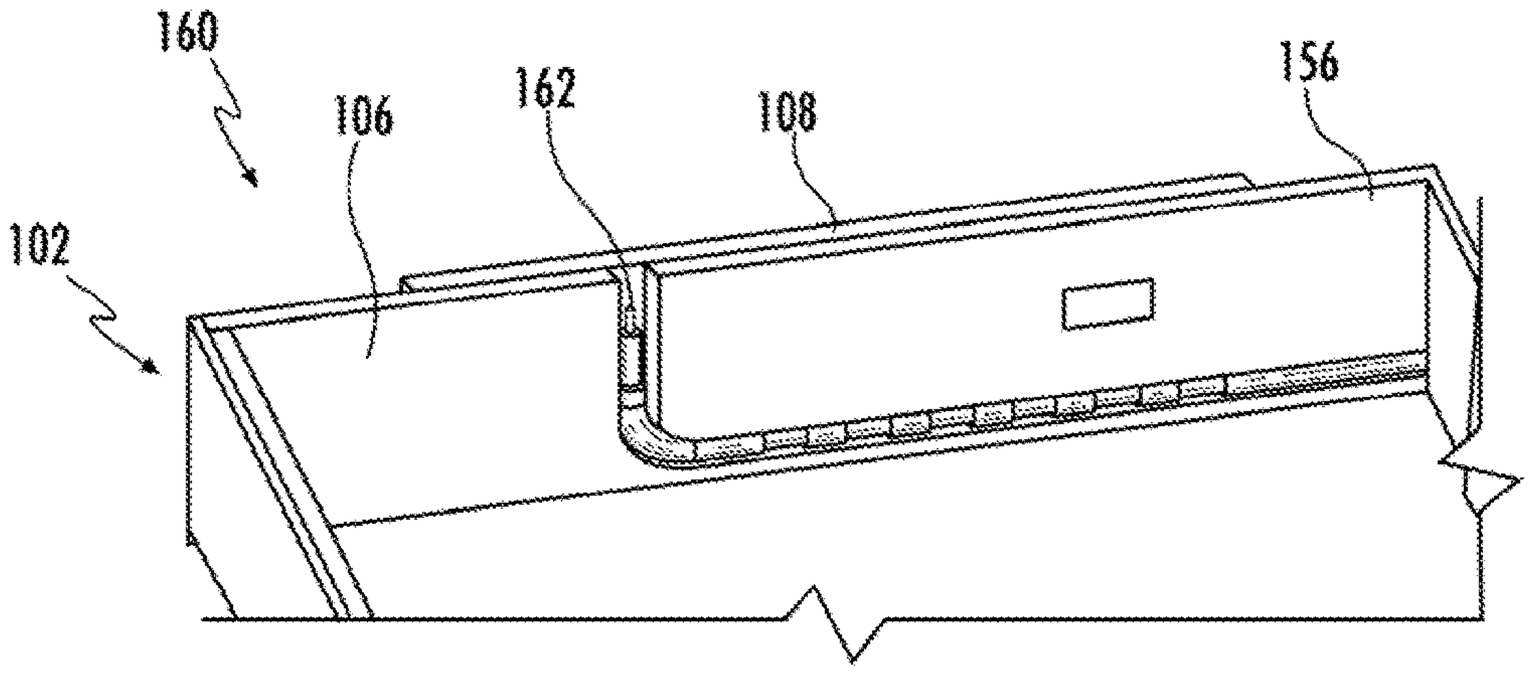


FIG. 1C

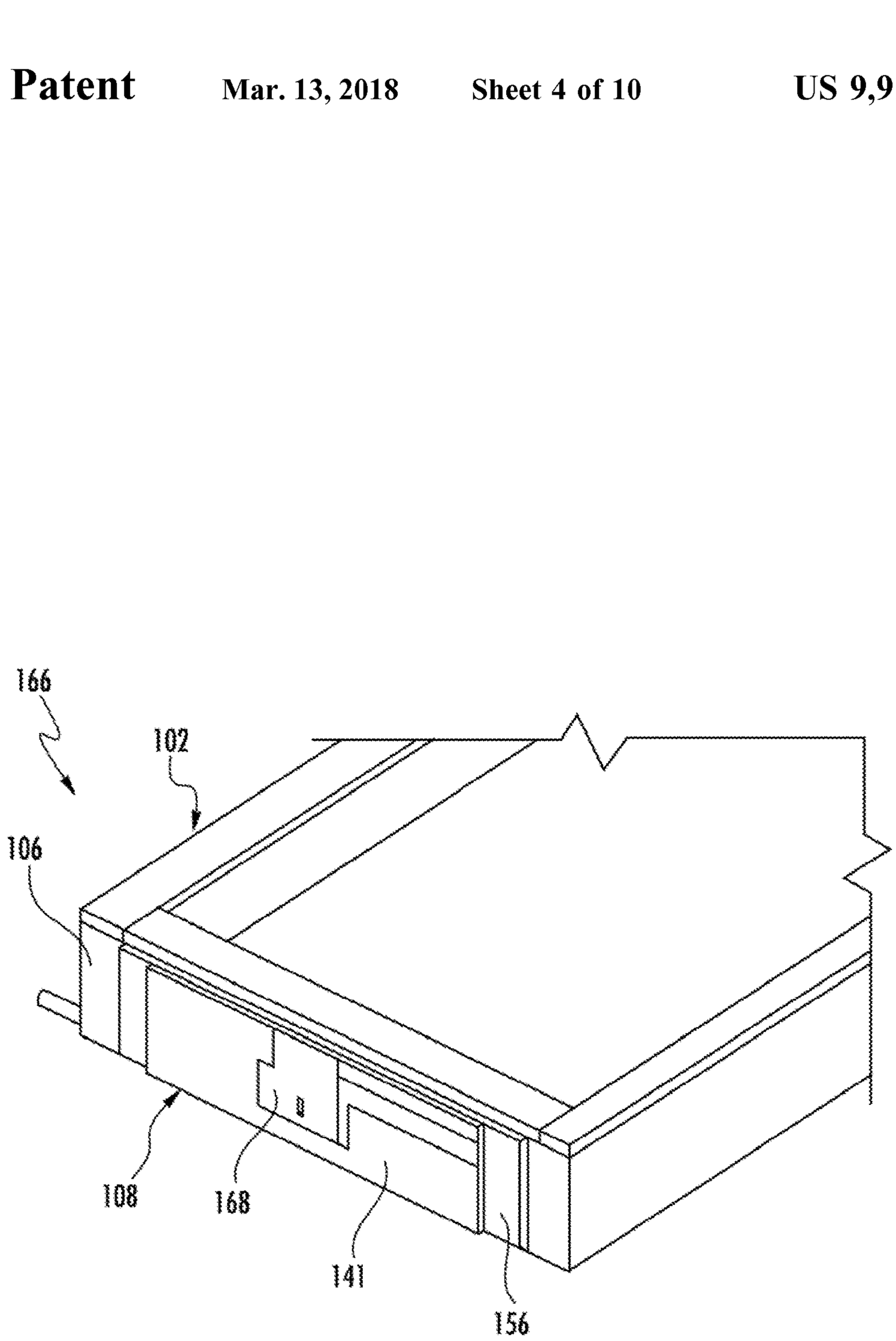


FIG. 1D

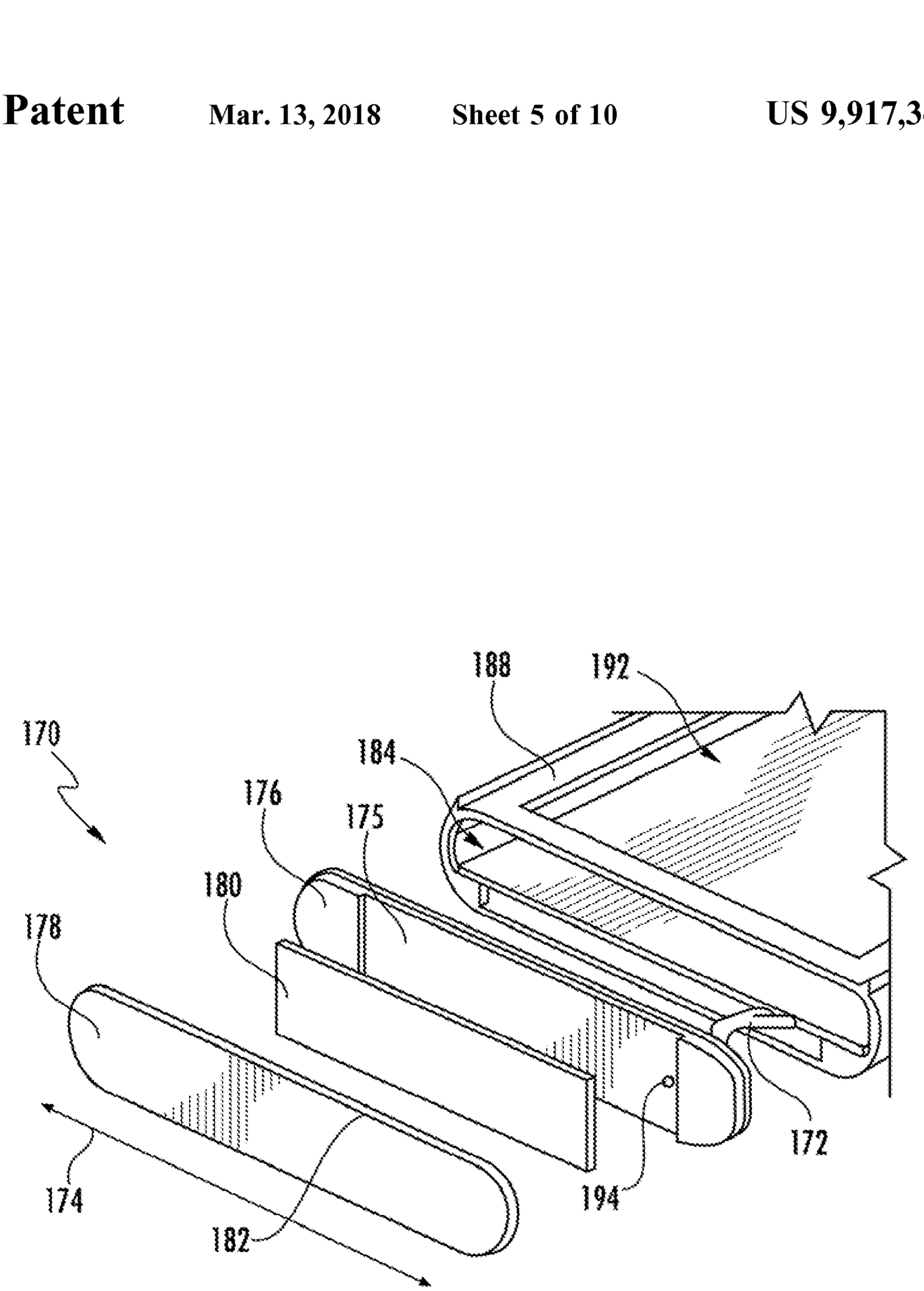


FIG. 1E

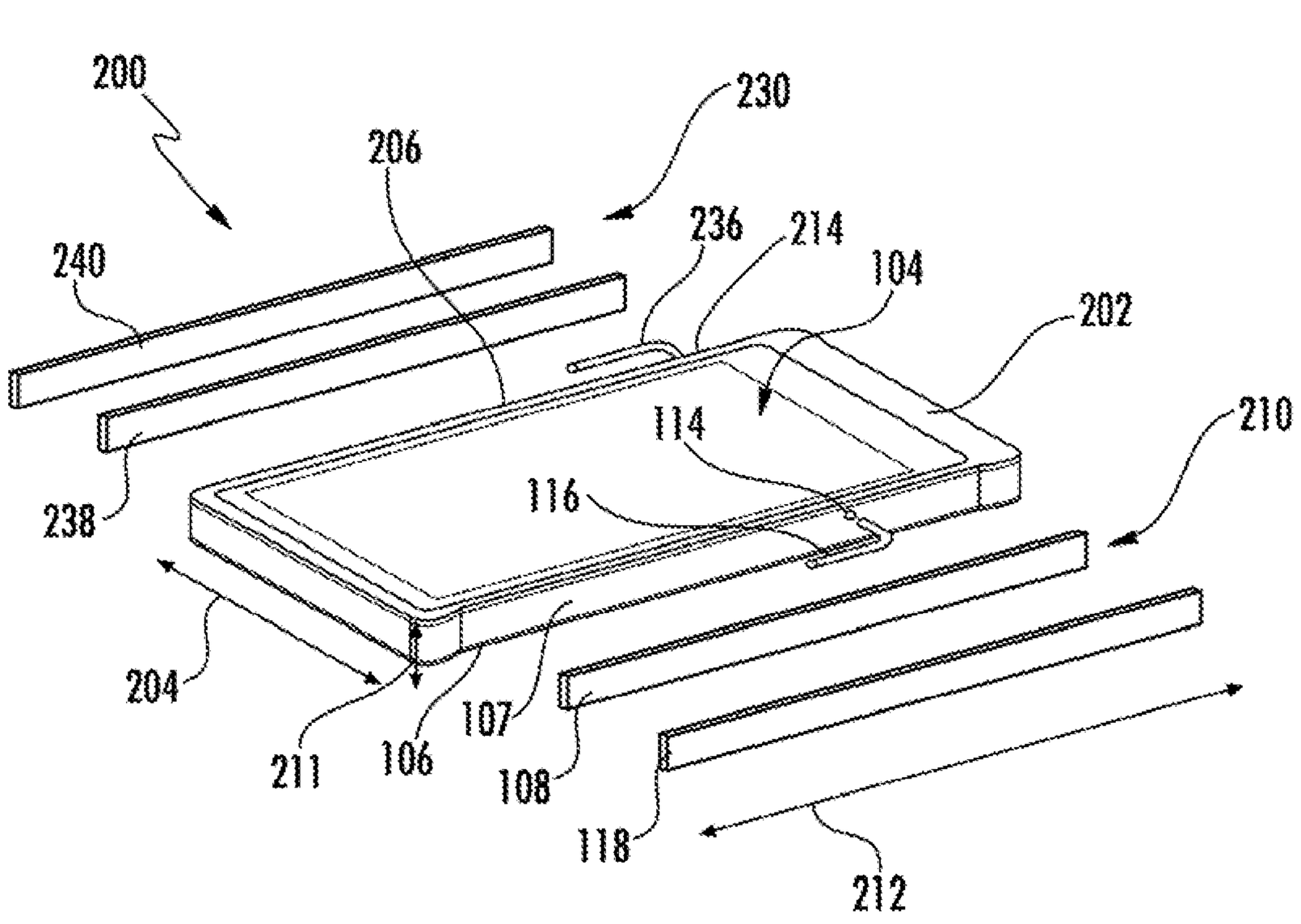

200
230
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FIG. 2A

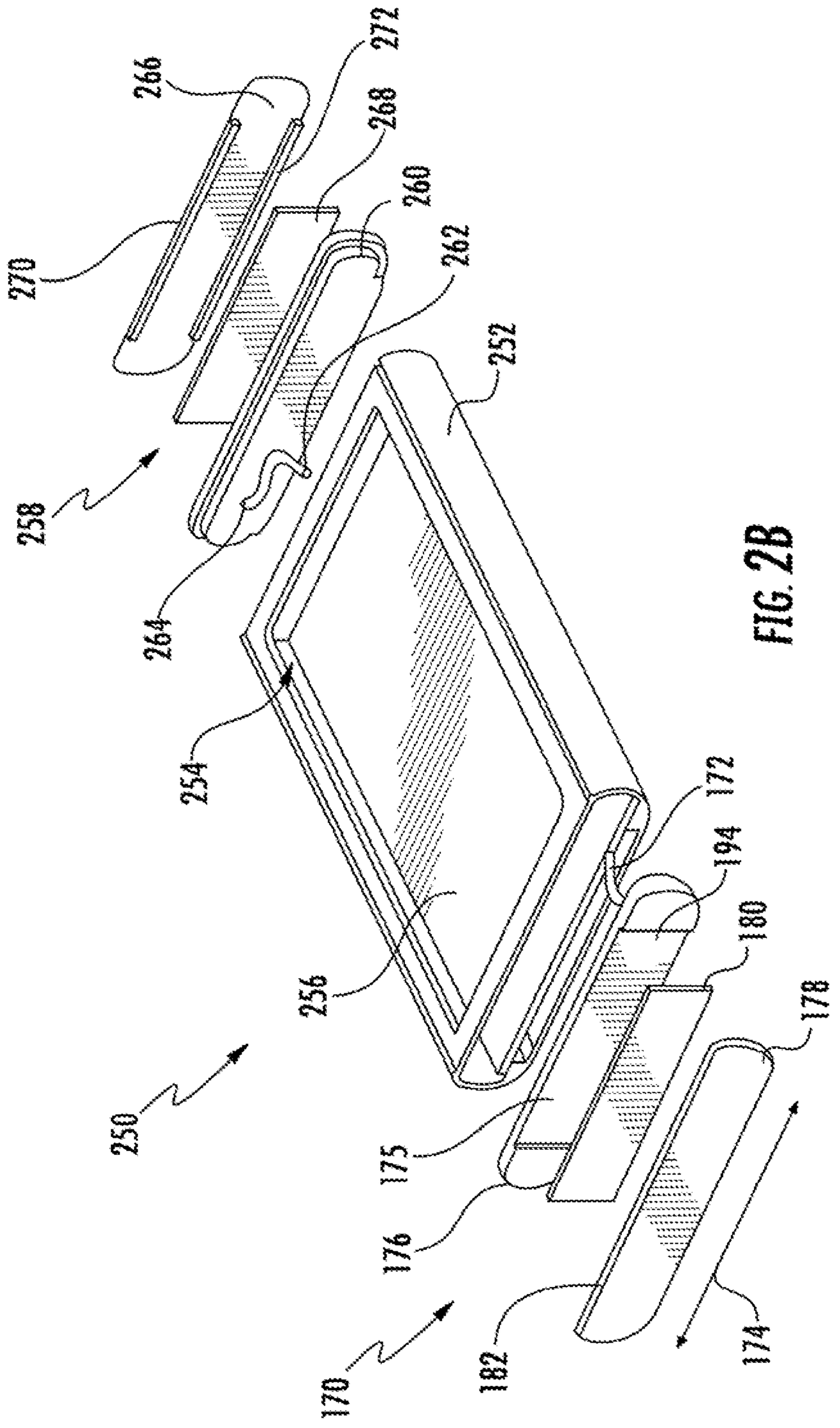

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FIG. 2B

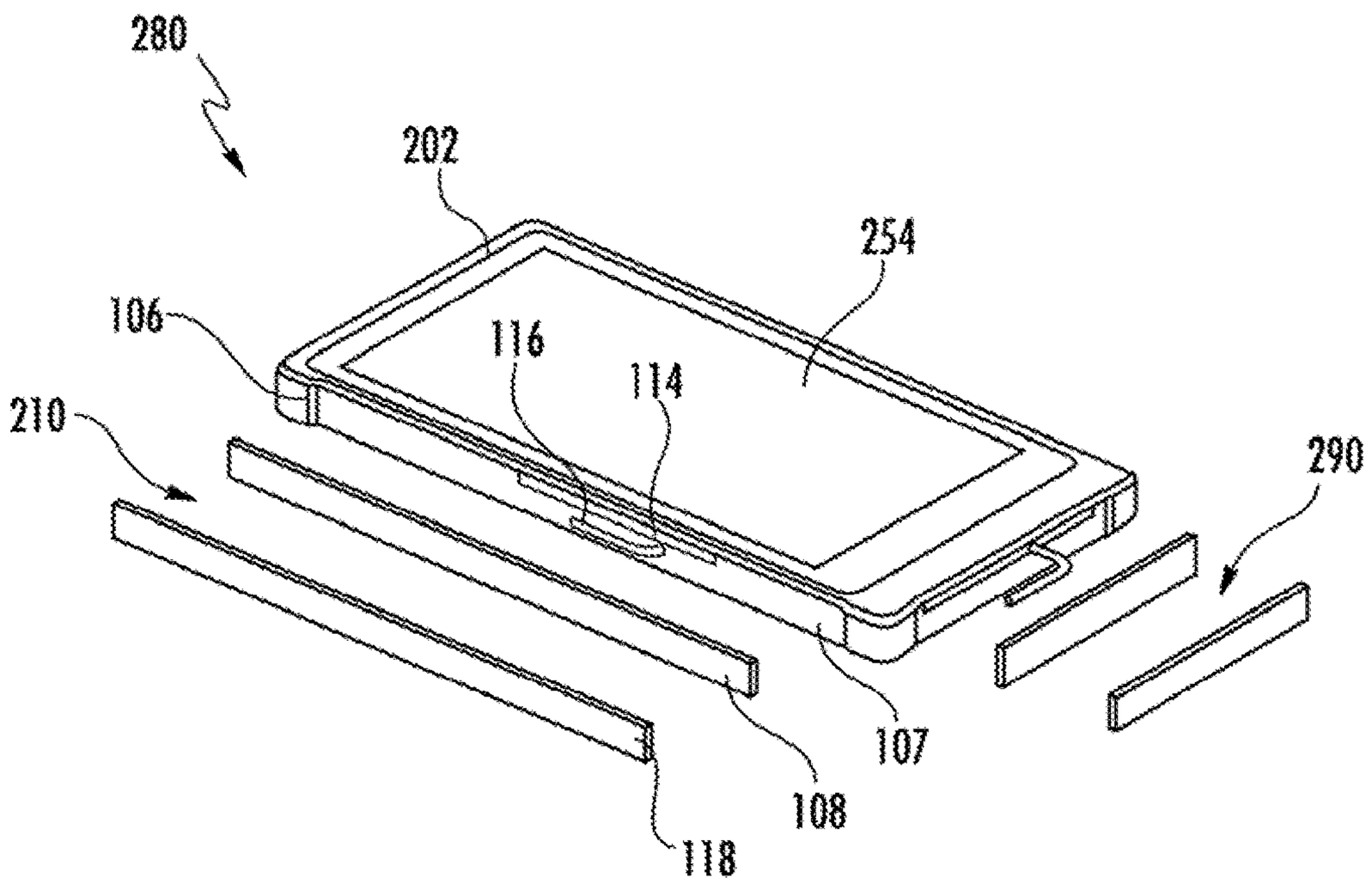


FIG. 2C

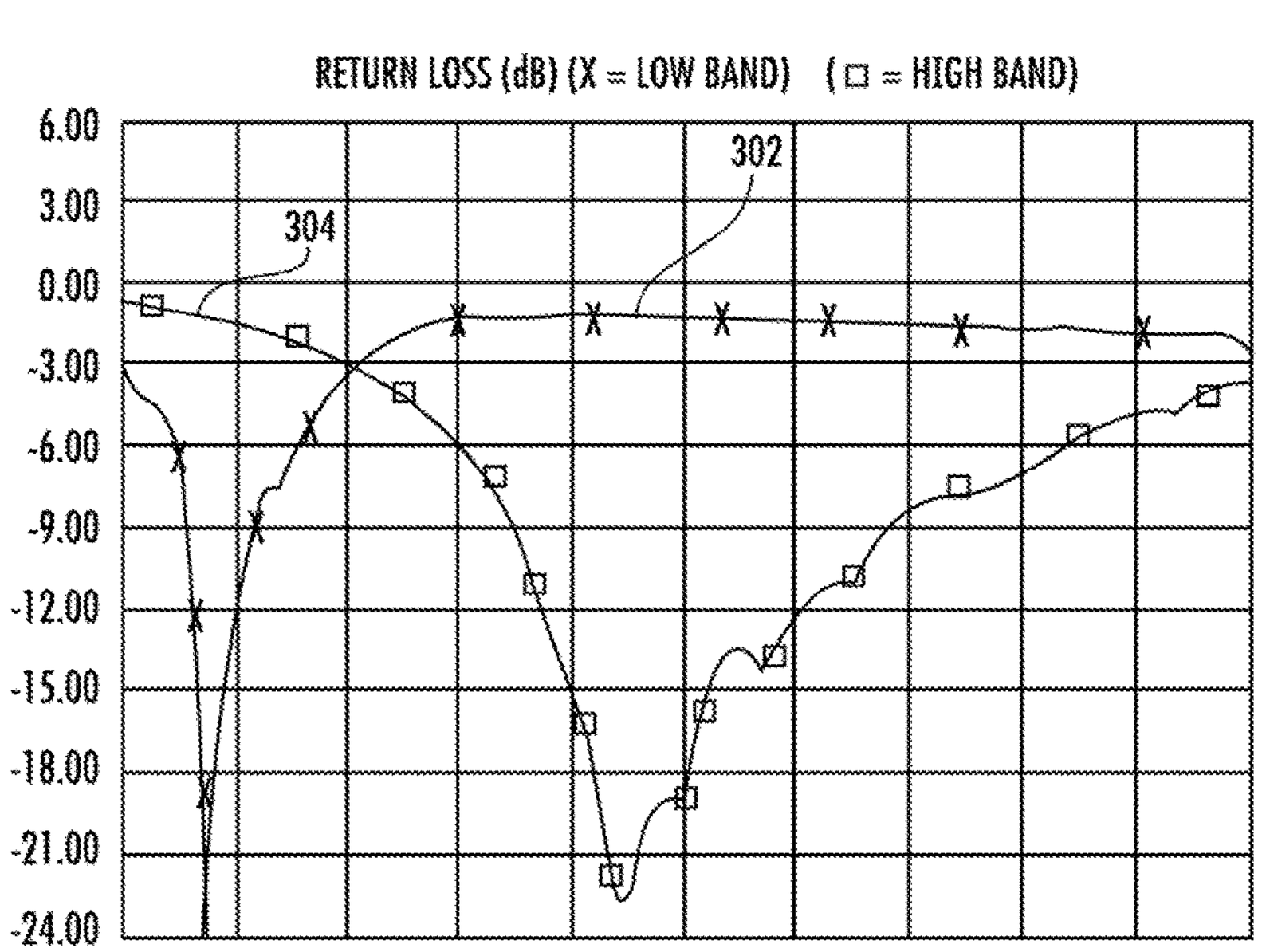

RETURN LOSS (dB) (X = LOW BAND) (□ = HIGH BAND)
6.00
3.00
0.00
-3.00
-6.00
-9.00
-12.00
-15.00
-18.00
-21.00
-24.00
302
304
700MHz
3GHz

FIG. 3

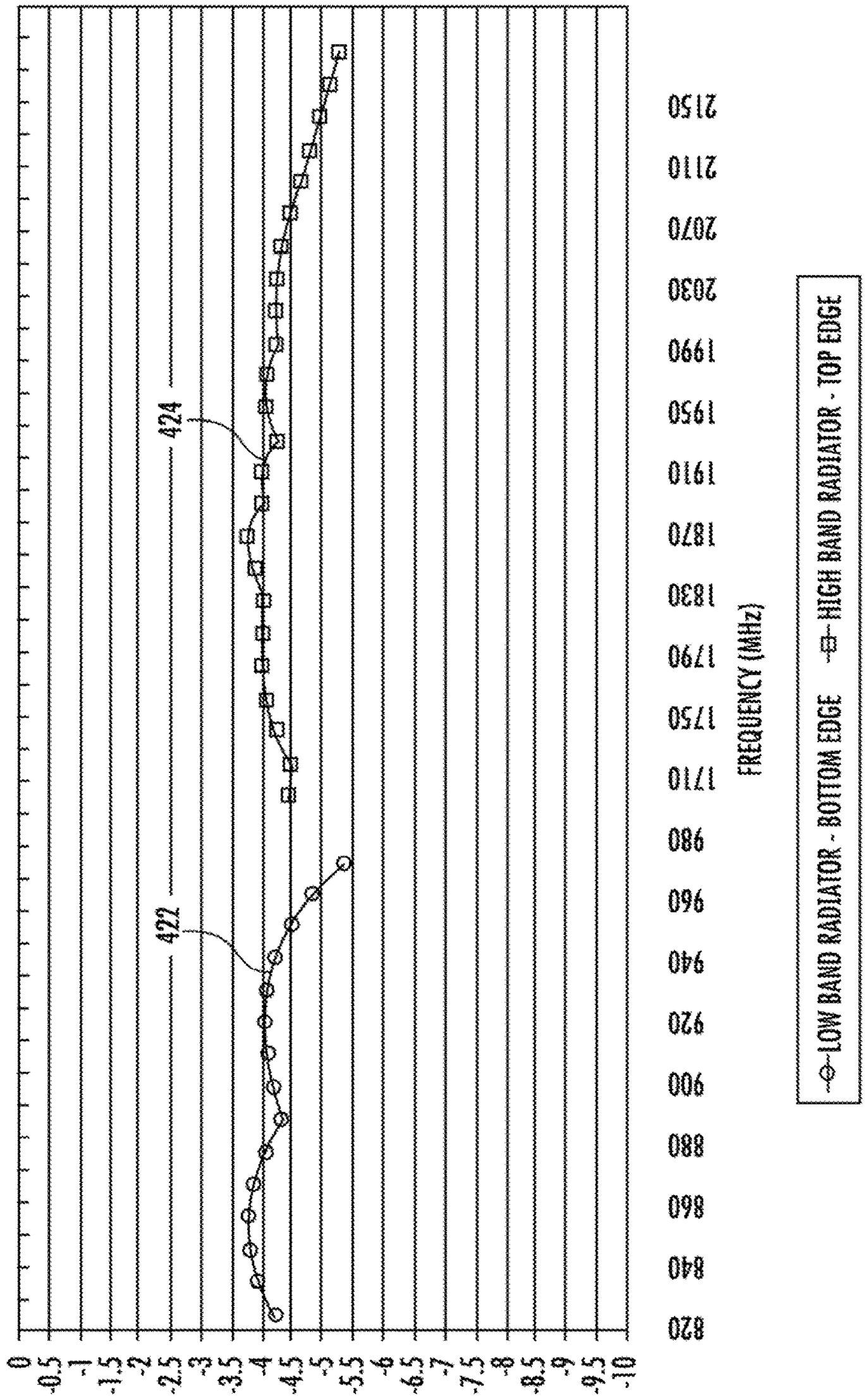

424
422
TOTAL EFFICIENCY (dB)
0
-0.5
-1
-1.5
-2
-2.5
-3
-3.5
-4
-4.5
-5
-5.5
-6
-6.5
-7
-7.5
-8
-8.5
-9
-9.5
-10
820
840
860
880
900
920
940
960
980
1710
1750
1790
1830
1870
1910
1950
1990
2030
2070
2110
2150
FREQUENCY (MHz)
LOW BAND RADIATOR - BOTTOM EDGE
LOW BAND RADIATOR - TOP EDGE
HIGH BAND RADIATOR - BOTTOM EDGE
HIGH BAND RADIATOR - TOP EDGE

FIG. 4

CHASSIS-EXCITED ANTENNA APPARATUS AND METHODS

PRIORITY CLAIM

This application is a continuation of and claims priority to co-owned U.S. patent application Ser. No. 13/026,078 of the same title, filed Feb. 11, 2011, and issuing as U.S. Pat. No. 8,648,752, the contents of which is being incorporated herein by reference in its entirety.

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FIELD OF THE INVENTION

The present invention relates generally to antenna apparatus for use in electronic devices such as wireless or portable radio devices, and more particularly in one exemplary aspect to a chassis-excited antenna, and methods of tuning and utilizing the same.

DESCRIPTION OF RELATED TECHNOLOGY

Internal antennas are commonly found in most modern radio devices, such as mobile computers, mobile phones, Blackberry® devices, smartphones, personal digital assistants (PDAs), or other personal communication devices (PCD). Typically, these antennas comprise a planar radiating plane and a ground plane parallel thereto, which are connected to each other by a short-circuit conductor in order to achieve the matching of the antenna. The structure is configured so that it functions as a resonator at the desired operating frequency. It is also a common requirement that the antenna operate in more than one frequency band (such as dual-band, tri-band, or quad-band mobile phones), in which case two or more resonators are used. Typically, these internal antennas are located on a printed circuit board (PCB) of the radio device, inside a plastic enclosure that permits propagation of radio frequency waves to and from the antenna(s).

Recent advances in the development of affordable and power-efficient display technologies for mobile applications (such as liquid crystal displays (LCD), light-emitting diodes (LED) displays, organic light emitting diodes (OLED), thin film transistors (TFT), etc.) have resulted in a proliferation of mobile devices featuring large displays, with screen sizes of up to 180 mm (7 in) in some tablet computers and up to 500 mm (20 inches) in some laptop computers.

Furthermore, current trends increase demands for thinner mobile communications devices with large displays that are often used for user input (touch screen). This in turn requires a rigid structure to support the display assembly, particularly during the touch-screen operation, so as to make the interface robust and durable, and mitigate movement or deflection of the display. A metal body or a metal frame is often utilized in order to provide a better support for the display in the mobile communication device.

The use of metal enclosures/chassis and smaller thickness of the device enclosure create new challenges for radio

frequency (RF) antenna implementations. Typical antenna solutions (such as monopole, PIFA antennas) require ground clearance area and sufficient height from ground plane in order to operate efficiently in multiple frequency bands. These antenna solutions are often inadequate for the aforementioned thin devices with metal housings and/or chassis, as the vertical distance required to separate the radiator from the ground plane is no longer available. Additionally, the metal body of the mobile device acts as an RF shield and degrades antenna performance, particularly when the antenna is required to operate in several frequency bands

Various methods are presently employed to attempt to improve antenna operation in thin communication devices that utilize metal housings and/or chassis, such as a slot antenna described in EP1858112B1. This implementation requires fabrication of a slot within the printed wired board (PWB) in proximity to the feed point, as well as along the entire height of the device. For a device having a larger display, slot location, that is required for an optimal antenna operation, often interferes with device user interface functionality (e.g. buttons, scroll wheel, etc), therefore limiting device layout implementation flexibility

Additionally, metal housing must have openings in close proximity to the slot on both sides of the PCB. To prevent generation of cavity modes within the device, the openings are typically connected using metal walls. All of these steps increase device complexity and cost, and impede antenna matching to the desired frequency bands.

Accordingly, there is a salient need for a wireless antenna solution for e.g., a portable radio device with a small form factor metal body and/or chassis that offers a lower cost and complexity and provides for improved control of antenna resonance, and methods of tuning and utilizing the same.

SUMMARY OF THE INVENTION

The present invention satisfies the foregoing needs by providing, inter alia, a space-efficient multiband antenna apparatus and methods of tuning and use.

In a first aspect of the invention, an antenna component for use in a portable communications device is disclosed. In one embodiment, the antenna component comprises: a radiator having a first dimension and a second dimension, a first and second surface, the radiator configured to be proximate to a first side of said plurality of sides; a dielectric substrate having a third dimension and a fourth dimension, and configured to be disposed proximate the second surface; and a feed conductor configured to couple to the radiator element at a feed point.

In one variant, the dielectric substrate is configured such that its normal projection is equal or larger than a normal projection of the radiator element. The radiator element is further electrically coupled to the ground at a ground point. At least a portion of the feed conductor is further arranged along the first side substantially parallel to the first dimension; and the radiator element, the at least a portion of the feed conductor, and at least a portion of the first side form a coupled loop antenna operable in a first frequency band.

In another variant, the antenna component further comprises a dielectric element disposed between the radiator element and the first side and configured to electrically isolate at least a portion of the first side from the radiator element; e.g., a dielectric substrate and a conductive coating disposed thereon, or a flex circuit.

In another variant, the radiator element of the antenna component comprises a conductive structure having a first portion and a second portion. The second portion is coupled

to the feed point via a reactive circuit. The antenna component further comprises a dielectric element disposed between the radiator element and the first side and configured to electrically isolate at least a portion of the first side from the radiator element. The reactive circuit of the antenna component comprises e.g., a planar transmission line.

In yet another variant, the radiator element comprises a dielectric substrate, and a conductive coating disposed thereon; and the conductive structure comprises the conductive coating.

In another embodiment, the antenna component comprises: a dielectric substrate having a plurality of surfaces; a conductive coating disposed on at least one surface of the substrate, the conductive coating configured to form at least a portion of a ground plane, the ground plane having a ground point; and a radiator structure. In one variant, the radiator structure comprises: a feed; a first portion, a second portion, a stripline coupled from said second portion to said feed point; and a plurality of non conductive slots isolating substantially separating the strip line from the first portion; and at least one ground clearance area disposed substantially within perimeter of the surface. The ground point is further configured to couple the at least a portion of the ground plane to a ground of a host device. The second portion is coupled to the first portion via a conductive element.

In another variant, the second portion of the antenna component is further coupled to the first portion via a reactive circuit. The reactive circuit comprises e.g., at least one of (i) an inductive element, and/or (ii) a capacitive element.

In a second aspect of the invention, an antenna apparatus for use in a portable communications device is disclosed. In one embodiment, the antenna apparatus comprises: a first antenna assembly configured to operate in a first frequency band, and a second antenna assembly configured to operate in a second frequency band. The first antenna assembly comprises a first radiator element comprising a first ground point and a first feed point, and is disposed along a first of the plurality of sides of the device enclosure, a first feed conductor coupled to the first feed point and to the at least one feed port of the device, and a first non-conductive cover disposed proximate the first radiator so as to substantially cover the first radiator. The second antenna assembly comprises a second radiator element comprising a second ground point and a second feed point, and is disposed along a second of the plurality of sides the device enclosure; a second feed conductor coupled to the second feed point and to a feed port of the device, and a second non-conductive cover disposed proximate the second radiator so as to substantially cover the second radiator.

In one variant, the metal enclosure of the device is electrically coupled to device ground, to the first ground point, and to the second ground point. At least a portion of the first feed cable is disposed along the first side thereby forming a first coupled loop antenna structure between at least a portion of the enclosure, the first radiator element, and the at least a portion of the first feed cable. At least a portion of the second feed cable is disposed along the second side thereby forming a second coupled loop antenna structure between at least a portion of the enclosure, the second radiator element, and the at least a portion of the second feed cable.

In another variant, the first and second radiator elements are disposed substantially between the first and second covers, respectively, and the metal enclosure.

In yet another variant, the antenna apparatus further comprises a dielectric element disposed between the radiator element and the first side and configured to electrically isolate at least a portion of the first side from the radiator element.

In another variant the first and the second radiator elements of the antenna are disposed substantially between the first and second covers, respectively, and the metal enclosure.

In yet another variant, the first and the second antenna elements are disposed on opposing surfaces of the device enclosure. In another variant, the first and the second antenna elements are disposed on adjacent sizes of the device enclosure.

In another embodiment of the antenna apparatus, the first frequency band of the antenna comprises a frequency band between 700 and 960 MHz, and the second frequency band comprised an upper frequency band.

In one variant, the upper frequency band comprises frequency band between 1710 and 2150 MHz. In another variant, the upper frequency band comprises a global positioning system (GPS) frequency band.

In another variant, the portable device comprises a single feed port.

In yet another variant, the device enclosure is fabricated to form a sleeve like shape having a first cavity and a second cavity. A first metal support structure is disposed within the first cavity and configured to receive the first radiator element. A second metal support structure is disposed within the second cavity and configured to receive the second radiator element.

In a third aspect of the invention, a mobile communications device is disclosed. In one embodiment, the mobile communications device comprises: a substantially metallic exterior housing comprising a plurality of sides; an electronics assembly contained substantially therein and comprising a ground and at least one feed port; and a first antenna assembly configured to operate in a first frequency band. In one variant, the first assembly comprises: (i) a first radiator element comprising a first ground point and a first feed point, and disposed along a first of the plurality of sides; a first feed conductor coupled to the first feed point and to the at least one feed port; and a first non-conductive cover disposed proximate the first radiator so as to substantially cover the first radiator; and (ii) a second antenna assembly configured to operate in a second frequency band, the second assembly comprising: a second radiator element comprising a second ground point and a second feed point, disposed along a second of the plurality of sides; a second feed conductor coupled to the second feed point and to a feed port; and a second non-conductive cover disposed proximate the second radiator so as to substantially cover the second radiator. The first ground point and the second ground point are electrically coupled to the metal housing. A first coupled loop resonance structure is formed between at least a portion of the housing, the first radiator, and at least a portion of the first feed cable. A second coupled loop resonance structure is formed between at least a portion of the housing, the second radiator, and at least a portion of the second feed cable.

In a fourth aspect of the invention, a method of operating an antenna apparatus is disclosed.

In a fifth aspect of the invention, a method of tuning an antenna apparatus is disclosed.

In a sixth aspect of the invention, a method of testing an antenna apparatus is disclosed.

In a seventh aspect of the invention, a method of operating a mobile device is disclosed.

In an eighth aspect, a mobile communications device is disclosed. In one embodiment, the mobile communications device includes an exterior housing having a plurality of sides; an electronics assembly having a ground and at least one feed port, and which is further configured to be substantially contained within the exterior housing; and an antenna component.

In one variant, the antenna component includes a radiator element having first and second surfaces, and is further configured to be disposed proximate to a first side of the housing. A feed conductor is coupled to the at least one feed port, and configured to couple to the radiator element at a feed point. A dielectric element is disposed between the first surface of the radiator element and the first side of the housing, the dielectric element configured to electrically isolate at least a portion of the first surface of the radiator element from the first side of the housing.

In a ninth aspect, an antenna apparatus for use in a portable communications device is disclosed. In one embodiment, the portable communications device includes a metal enclosure having a plurality of sides, and that substantially houses an electronics assembly having a ground and a feed port.

In one variant, the antenna apparatus includes: a first antenna assembly configured to operate in a first frequency band and having a first radiator element and a first feed conductor disposed along a first side of the metal enclosure; and a second antenna assembly configured to operate in a second frequency band and having a second radiator element and a second feed conductor disposed along a second side of the metal enclosure. A first coupled loop antenna structure is formed between at least a portion of the first side of the metal enclosure, the first radiator element, and at least a portion of the first feed conductor disposed along the first side of the metal enclosure. A second coupled loop antenna structure is formed between at least a portion of the second side of the metal enclosure, the second radiator element, and at least a portion of the second feed conductor disposed along the second side of the metal enclosure.

In a tenth aspect, an antenna component for use in a mobile communications device is disclosed. In one embodiment, the mobile communication device includes a metal chassis having a plurality of sides that substantially houses an electronics assembly that includes a ground and at least one feed port. In a first variant, the antenna component includes a dielectric substrate having a first surface disposed proximate a first side of the metal chassis, and a second surface having a conductive coating disposed thereon, the conductive coating being shaped so as to form a radiator structure and configured to form at least a portion of a ground plane. The radiator structure comprises a ground point configured to couple a portion of the ground plane to the ground of the electronics assembly, a first portion, a second portion coupled to the first portion, and a conductive element that extends form the second portion to a feed point.

Further features of the present invention, its nature and various advantages will be more apparent from the accompanying drawings and the following detailed description.

BRIEF DESCRIPTION OF THE DRAWINGS

The features, objectives, and advantages of the invention will become more apparent from the detailed description set forth below when taken in conjunction with the drawings, wherein:

FIG. **1** is a perspective view diagram detailing the configuration of a first embodiment of an antenna assembly of the invention.

FIG. **1**A is a perspective view diagram detailing the electrical configuration of the antenna radiator of the embodiment of FIG. **1**.

FIG. **1**B is a perspective view diagram detailing the isolator structure for the antenna radiator of the embodiment of FIG. **1**A.

FIG. **1**C is a perspective view diagram showing an interior view of a device enclosure, showing the antenna assembly of the embodiment of FIG. **1**A installed therein.

FIG. **1**D is an elevation view diagram of a device enclosure showing the antenna assembly of the embodiment of FIG. **1**A installed therein.

FIG. **1**E is an elevation view illustration detailing the configuration of a second embodiment of the antenna assembly of the invention.

FIG. **2**A is an isometric view of a mobile communications device configured in accordance with a first embodiment of the present invention.

FIG. **2**B is an isometric view of a mobile communications device configured in accordance with a second embodiment of the present invention.

FIG. **2**C is an isometric view of a mobile communications device configured in accordance with a third embodiment of the present invention.

FIG. **3** is a plot of measured free space input return loss for the exemplary lower-band and upper-band antenna elements configured in accordance with the embodiment of FIG. **2**C.

FIG. **4** is a plot of measured total efficiency for the exemplary lower-band and upper-band antenna elements configured in accordance with the embodiment of FIG. **2**C.

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DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT

Reference is now made to the drawings wherein like numerals refer to like parts throughout.

As used herein, the terms "antenna," "antenna system," "antenna assembly", and "multi-band antenna" refer without limitation to any system that incorporates a single element, multiple elements, or one or more arrays of elements that receive/transmit and/or propagate one or more frequency bands of electromagnetic radiation. The radiation may be of numerous types, e.g., microwave, millimeter wave, radio frequency, digital modulated, analog, analog/digital encoded, digitally encoded millimeter wave energy, or the like. The energy may be transmitted from location to another location, using, or more repeater links, and one or more locations may be mobile, stationary, or fixed to a location on earth such as a base station.

As used herein, the terms "board" and "substrate" refer generally and without limitation to any substantially planar or curved surface or component upon which other components can be disposed. For example, a substrate may comprise a single or multi-layered printed circuit board (e.g., FR4), a semi-conductive die or wafer, or even a surface of a housing or other device component, and may be substantially rigid or alternatively at least somewhat flexible.

The terms "frequency range", "frequency band", and "frequency domain" refer without limitation to any fre-

quency range for communicating signals. Such signals may be communicated pursuant to one or more standards or wireless air interfaces.

The terms "near field communication", "NFC", and "proximity communications", refer without limitation to a short-range high frequency wireless communication technology which enables the exchange of data between devices over short distances such as described by ISO/IEC 18092/ECMA-340 standard and/or ISO/ELEC 14443 proximity-card standard.

As used herein, the terms "portable device", "mobile computing device", "client device", "portable computing device", and "end user device" include, but are not limited to, personal computers (PCs) and minicomputers, whether desktop, laptop, or otherwise, set-top boxes, personal digital assistants (PDAs), handheld computers, personal communicators, tablet computers, portable navigation aids, J2ME equipped devices, cellular telephones, smartphones, personal integrated communication or entertainment devices, or literally any other device capable of interchanging data with a network or another device.

Furthermore, as used herein, the terms "radiator," "radiating plane," and "radiating element" refer without limitation to an element that can function as part of a system that receives and/or transmits radio-frequency electromagnetic radiation; e.g., an antenna.

The terms "RF feed," "feed," "feed conductor," and "feed network" refer without limitation to any energy conductor and coupling element(s) that can transfer energy, transform impedance, enhance performance characteristics, and conform impedance properties between an incoming/outgoing RF energy signals to that of one or more connective elements, such as for example a radiator.

As used herein, the terms "top", "bottom", "side", "up", "down", "left", "right", and the like merely connote a relative position or geometry of one component to another, and in no way connote an absolute frame of reference or any required orientation. For example, a "top" portion of a component may actually reside below a "bottom" portion when the component is mounted to another device (e.g., to the underside of a PCB).

As used herein, the term "wireless" means any wireless signal, data, communication, or other interface including without limitation Wi-Fi, Bluetooth, 3G (e.g., 3GPP, 3GPP2, and UMTS), HSDPA/HSUPA, TDMA, CDMA (e.g., IS-95A, WCDMA, etc.), FESS, DSSS, GSM, PAN/802.15, WiMAX (802.16), 802.20, narrowband/FDMA, OFDM, PCS/DCS, Long Term Evolution (LTE) or LTE-Advanced (LTE-A), analog cellular, CDPD, satellite systems such as GPS, millimeter wave or microwave systems, optical, acoustic, and infrared (i.e., IrDA).

Overview

The present invention provides, in one salient aspect, an antenna apparatus for use in a mobile radio device which advantageously provides reduced size and cost, and improved antenna performance. In one embodiment, the mobile radio device includes two separate antenna assemblies located on the opposing sides of the device: i.e., (i) on the top and bottom sides; or (ii) on the left and right sides. In another embodiment, two antenna assemblies are placed on the adjacent sides, e.g., one element on a top or bottom side, and the other on a left or the right side.

Each antenna assembly of the exemplary embodiment includes a radiator element that is coupled to the metal portion of the mobile device housing (e.g., side surface). The radiator element is mounted for example directly on the metal enclosure side, or alternatively on an intermediate metal carrier (antenna support element), that is in turn fitted within the mobile device metal enclosure. To reduce potentially adverse influences during use under diverse operating conditions, e.g., hand usage scenario, a dielectric cover is fitted against the radiator top surface, thereby insulating the antenna from the outside elements.

In one embodiment, a single multi-feed transceiver is configured to provide feed to both antenna assemblies. Each antenna may utilize a separate feed; each antenna radiator element directly is coupled to a separate feed port of the mobile radio device electronics via a separate feed conductor. This, inter alia, enables operation of each antenna element in a separate frequency band (e.g., a lower band and an upper band). Advantageously, antenna coupling to the device electronics is much simplified, as each antenna element requires only a single feed and a single ground point connections. The phone chassis acts as a common ground plane for both antennas.

In one implementation, the feed conductor comprises a coaxial cable that is routed through an opening in the mobile device housing. A portion of the feed cable is routed along lateral dimension of the antenna radiator from the opening point to the feed point on the radiator. This section of the feed conductor, in conjunction with the antenna radiator element, forms the loop antenna, which is coupled to the metallic chassis and hence referred to as the "coupled loop antenna".

In one variant, one of the antenna assemblies is configured to provide near-field communication functionality to enables the exchange of data between the mobile device and another device or reader (e.g., during device authentication, payment transaction, etc.).

In another variant, two or more antennas configured in accordance with the principles of the present invention are configured to operate in the same frequency band, thus providing diversity for multiple antenna applications (such as e.g., Multiple In Multiple Out (MIMO), Multiple In Single Out (MISO), etc.).

In yet another variant, a single-feed antenna is configured to operate in multiple frequency bands.

DETAILED DESCRIPTION OF EXEMPLARY EMBODIMENTS

Detailed descriptions of the various embodiments and variants of the apparatus and methods of the invention are now provided. While primarily discussed in the context of mobile devices, the various apparatus and methodologies discussed herein are not so limited. In fact, many of the apparatus and methodologies described herein are useful in any number of complex antennas, whether associated with mobile or fixed devices that can benefit from the coupled loop chassis excited antenna methodologies and apparatus described herein.

Exemplary Antenna Apparatus

Referring now to FIGS. **1** through **2**C, exemplary embodiments of the radio antenna apparatus of the invention are described in detail.

It will be appreciated that while these exemplary embodiments of the antenna apparatus of the invention are implemented using a coupled loop chassis excited antenna (selected in these embodiments for their desirable attributes and performance), the invention is in no way limited to the loop antenna configurations, and in fact can be implemented using other technologies, such as patch or microstrip antennas.

One exemplary embodiment **100** of an antenna component for use in a mobile radio device is presented in FIG. **1**, showing an end portion of the mobile device housing **102**. The housing **102** (also referred to as metal chassis or enclosure) is fabricated from a metal or alloy (such as aluminum alloy) and is configured to support a display element **104**. In one variant, the housing **102** comprises a sleeve-type form, and is manufactured by extrusion. In another variant, the chassis **102** comprises a metal frame structure with an opening to accommodate the display **104**. A variety of other manufacturing methods may be used consistent with the invention including, but not limited to, stamping, milling, and casting.

In one embodiment, the display **104** comprises a display-only device configured only to display content or data. In another embodiment, the display **104** is a touch screen display (e.g., capacitive or other technology) that allows for user input into the device via the display **104**. The display **104** may comprise, for example, a liquid crystal display (LCD), light-emitting diode (LED) display, organic light emitting diode (OLED) display, or TFT-based device. It is appreciated by those skilled in the art that methodologies of the present invention are equally applicable to any future display technology, provided the display module is generally mechanically compatible with configurations such as those described in FIG. **1**-FIG. **2**C.

The antenna assembly of the embodiment of FIG. **1** further comprises a rectangular radiator element **108** configured to be fitted against a side surface **106** of the enclosure **102**. The side **106** can be any of the top, bottom, left, right, front, or back surfaces of the mobile radio device. Typically, modern portable devices are manufactured such that their thickness **111** is much smaller than the length or the width of the device housing. As a result, the radiator element of the illustrated embodiment is fabricated to have an elongated shape such that the length **110** is greater than the width **112**, when disposed along a side surface (e.g., left, right, top, bottom).

To access the device feed port, an opening is fabricated in the device enclosure. In the embodiment shown in FIG. **1**, the opening **114** extends through the side surface **106** and serves to pass through a feed conductor **116** from a feed engine that is a part of the device RF section (not shown), located on the inside of the device. Alternatively, the opening is fabricated proximate to the radiator feed point as described in detail below.

The antenna assembly of FIG. **1** further comprises a dielectric antenna cover **118** that is installed directly above the radiator element **108**. The cover **118** is configured to provide electrical insulation for the radiator from the outside environment, particularly to prevent direct contact between a user hand and the radiator during device use (which is often detrimental to antenna operation). The cover **118** is fabricated from any suitable dielectric material (e.g. plastic or glass). The cover **118** is attached by a variety of suitable means: adhesive, press-fit, snap-in with support of additional retaining members as described below.

In one embodiment, the cover **118** is fabricated from a durable oxide or glass (e.g. Zirconium dioxide ZrO_2, (also referred to as "zirconia"), or Gorilla® Glass, manufactured by Dow Corning) and is welded (such as via a ultrasonic-welding (USW) technique) onto the device body. Other attachment methods may be used including but not limited to adhesive, snap-fit, press-fit, heat staking, etc.

In a different embodiment (not shown), the cover comprises a non-conductive film, or non-conductive paint bonded onto one or more exterior surfaces of the radiator element(s).

The detailed structure of an exemplary embodiment **120** of radiator element **108** configured for mounting in a radio device is presented in FIG. **1**A. The radiator element **108** comprises a conductive coating **129** disposed on a rigid substrate **141**, such as a PCB fabricated from a dielectric material (e.g., FR-4). Other suitable materials, such as glass, ceramic, air are useable as well. In one variant, a conductive layer is disposed on the opposing surface of the substrate, thereby forming a portion of a ground plane. In another implementation, the radiator element is fabricated as a flex circuit (either a single-sided, or double-sided) that is mounted on a rigid support element.

The conductive coating **129** is shaped to form a radiator structure **130**, which includes a first portion **122** and a second portion **124**, and is coupled to the feed conductor **116** at a feed point **126**. The second portion **124** is coupled to the feed point **126** via a conductive element **128**, which acts as a transmission line coupling antenna radiator to chassis modes.

The first portion **122** and the second portion **124** are connected via a coupling element **125**. In the exemplary embodiment of FIG. **1**A, the transmission line element **128** is configured to form a finger-like projection into the first portion **122**, thereby forming two narrow slots **131**, **133**, one on each side of the transmission line **128**. The radiator **108** further includes a several ground clearance portions (**135**, **137**, **139**), which are used to form a loop structure and to tune the antenna to desired specifications (e.g., frequency, bandwidth, etc).

The feed conductor **116** of exemplary embodiment of FIG. **1**A is a coaxial cable, comprising a center conductor **140**, connected to the feed point **126**, a shield **142**, and an exterior insulator **146**. In the embodiment of FIG. **1**A, a portion of the feed conductor **116** is routed lengthwise along the radiator PCB **108**.

The shield **142** is connected to the radiator ground plane **129** at one or more locations **148**, as shown in FIG. **1**A. The other end of the feed conductor **116** is connected to an appropriate feed port (not shown) of the RF section of the device electronics. In one variant this connection is effected via a radio frequency connector.

In one embodiment, a lumped reactive component **152** (e.g. inductive L or capacitive C) is coupled across the second portion **124** in order to adjust radiator electrical length. Many suitable capacitor configurations are useable in the embodiment **120**, including but not limited to, a single or multiple discrete capacitors (e.g., plastic film, mica, glass, or paper), or chip capacitors. Likewise, myriad inductor configurations (e.g., air coil, straight wire conductor, or toroid core) may be used with the invention.

The radiating element **108** further comprises a ground point **136** that is configured to couple the radiating element **108** to the device ground (e.g., housing/chassis). In one variant, the radiating element **108** is affixed to the device via a conductive sponge at the ground coupling point **136** and to the feed cable via a solder joint at the feed point **126**. In another variant, both above connections are effected via solder joints. In yet another variant, both connections are effected via a conductive sponge. Other electrical coupling methods are useable with embodiments of the invention including, but not limited to, c-clip, pogo pin, etc. Addition-

ally, a suitable adhesive or mechanical retaining means (e.g., snap fit) may be used if desired to affix the radiating element to the device housing.

In one exemplary implementation, the radiator element is approximately 10 mm (0.3 in) in width and 50 mm (2 in) in length. It will be appreciated by those skilled in the art that the above antenna sizes are exemplary and are adjusted based on the actual size of the device and its operating band. In one variant, the electrical size of the antenna is adjusted by the use of a lumped reactive component **152**.

Referring now to FIGS. **1**B through **1**D, the details of installing one or more antenna radiating elements **108** of the embodiment of FIG. **1**A into a portable device are presented. At step **154** shown in FIG. **1**B, in order to ensure that radiator is coupled to ground only at the desired location (e.g. ground point **136**), a dielectric screen **156** is placed against the radiating element **108** to electrically isolate the conductive structure **140** and the feed point from the device metal enclosure/chassis **102**. The dielectric screen **156** comprises an opening **158** that corresponds to the location and the size of the ground point **136**, and is configured to permit electrical contact between the ground point and the metal chassis. A similar opening (not shown) is fabricates at the location of the feed point. The gap created by the insulating material prevents undesirable short circuits between the radiator conductive structure **140** and the metal enclosure. In one variant, the dielectric screen comprises a plastic film or non-conducting spray, although it will be recognized by those of ordinary skill given the present disclosure that other materials may be used with equal success.

FIG. **1**C shows an interior view of the radiating element **108** assembly installed into the housing **102**. At step **160** the radiating element is mounted against the housing side **106**, with the dielectric screen **156** fitted in-between. A channel or a groove **162** is fabricated in the side **106**. The groove **162** is configured to recess the conductor flush with the outer surface of the enclosure/chassis, while permitting access to the radiator feed point. This configuration decreases the gap between the radiator element **108** and the housing side **106**, thereby advantageously reducing thickness of the antenna assembly. As mentioned above, a suitable adhesive or mechanical retaining means (e.g., snap fit) may be used if desired to affix the radiating element to the device housing.

FIG. **1**D shows an exterior view of the radiating element **108** assembly installed into the housing **102**. At step **166** the radiating element **108** is mounted against the housing side **106**, with the dielectric screen **156** fitted in between. FIG. **1**D reveals the conductive coating forming a portion of the ground plane of the radiating element, described above with respect to FIG. **1**A. The conductive coating features a ground clearance element **168** approximately corresponding to the location and the size of the ground clearance elements **135**, **137** and the second portion **124** of the radiator, disposed on the opposite side of the radiator element **108**.

The exemplary antenna radiator illustrated in FIG. **1**A through **1**D, uses the radiator structure that is configured to form a coupled loop chassis excited resonator. The feed configuration described above, wherein a portion of the feed conductor is routed along the dimension **110** of the radiator, cooperates to form the coupled loop resonator. A small gap between the loop antenna and the chassis facilitates electromagnetic coupling between the antenna radiator and the chassis. At least a portion of the metal chassis **102** forms a part of an antenna resonance structure, thereby improving antenna performance (particularly efficiency and bandwidth). In one variant, the gap is on the order of 0.1 mm, although other values may be used depending on the application.

The transmission line **128** forms a part of loop resonator and helps in coupling the chassis modes. The length of the transmission line controls coupling and feed efficiency including, e.g., how efficiently the feed energy is transferred to the housing/chassis. The optimal length of the transmission line is determined based, at least in part on, the frequency of operation: e.g., the required length of transmission line for operating band at approximately 1 GHz is twice the length of the transmission line required for the antenna operating at approximately 2 GHz band.

The use of a single point grounding configuration of the radiator to the metal enclosure/chassis (at the ground point **136**) facilitates formation of a chassis excited antenna structure that is efficient, simple to manufacture, and is lower in cost compared to the existing solutions (such as conventional inverted planar inverted-F (PIFA) or monopole antennas). Additionally, when using a planar configuration of the loop antenna, the thickness of the portable communication device may be reduced substantially, which often critical for satisfying consumer demand for more compact communication devices.

Returning now to FIGS. **1**A-**1**D, the ground point of the radiator **108** is coupled directly to the metal housing (chassis) that is in turn is coupled to ground of the mobile device RF section (not shown). The location of the grounding point is determined based on the antenna design parameters such as dimension of the antenna loop element, and desired frequency band of operation. The antenna resonant frequency is further a function of the device dimension. Therefore, the electrical size of the loop antenna (and hence the location of the grounding point) depends on the placement of the loop. In one variant, the electrical size of the loop PCB is about 50 mm for the lower band radiator (and is located on the bottom side of the device enclosure), and about 30 mm for the upper band radiator (and is located on the top side of the device enclosure). It is noted that positioning of the antenna radiators along the longer sides of the housing (e.g., left side and right side) produces loop of a larger electrical size. Therefore, the dimension(s) of the loop may need to be adjusted accordingly in order to match the desired frequency band of operation

The length of the feed conductor is determined by a variety of design parameters for a specific device (e.g., enclosure dimensions, operating frequency band, etc.). In the exemplary embodiment of FIG. **1**A, the feed conductor **116** is approximately 50 mm (2 in) in length, and it is adjusted according to device dimension(s), location of RF electronics section (on the main PCB) and antenna dimension(s) and placement.

The antenna configuration described above with respect to FIGS. **1**-**1**D allows construction of an antenna that results in a very small space used within the device size: in effect, a 'zero-volume' antenna. Such small volume antennas advantageously facilitate antenna placement in various locations on the device chassis, and expand the number of possible locations and orientations within the device. Additionally, the use of the chassis coupling to aid antenna excitation allows modifying the size of loop antenna element required to support a particular frequency band.

Antenna performance is improved in the illustrated embodiments (compared to the existing solutions) largely because the radiator element(s) is/are placed outside the metallic chassis, while still being coupled to the chassis.

The resonant frequency of the antenna is controlled by (i) altering the size of the loop (either by increasing/decreasing the length of the radiator, or by adding series capacitor/inductor); and/or (ii) the coupling distance between the antenna and the metallic chassis.

The placement of the antenna is chosen based on the device specification, and accordingly the size of the loop is adjusted in accordance with antenna requirements.

In the exemplary implementation illustrated in FIGS. **1**A-**1**D the radiating structure **130** and the ground point **138** are position such that both faces the device enclosure/chassis. It is recognized by those skilled in the art that other implementations are suitable, such as one or both elements **130**, **138** facing outwards towards the cover **118**. When the radiator structure **130** faces outwards from the device enclosure, a matching hole is fabricated in the substrate **141** to permit access to the feed center conductor **140**. In one variation, the ground point **136** is placed on the ground plane **143**, instead of the ground plane **129**.

FIG. **1**E shows another embodiment of the antenna assembly of the invention that is specifically configured to fit into a top or a bottom side **184** of the portable device housing **188**. In this embodiment, the housing comprises a sleeve-like shape (e.g., with the top 184 and the bottom sides open). A metal support element **176** is used to mount the antenna radiator element **180**.

The implementation of FIG. **1**E provides a fully metallic chassis, and ensures rigidity of the device. In one variant, the enclosure and the support element are manufactured from the same material (e.g., aluminum alloy), thus simplifying manufacturing, reducing cost and allowing to achieve a seamless structure for the enclosure via decorative post processing processes.

In an alternative embodiment (e.g., as shown above in FIGS. **1**C and **1**D), the device housing comprises a metal enclosure with closed vertical sides (e.g., right, left, top and bottom), therefore, not requiring additional support elements, such as the support element **168** of FIG. **1**D.

The device display (not shown) is configured to fit within the cavity **192** formed on the upper surface of the device housing. An antenna cover **178** is disposed above the radiator element **180** so as to provide isolation from the exterior influences.

The support element **176** is formed to fit precisely into the opening **184** of the housing and is attached to the housing via any suitable means including for example press fit, micro-welding, or fasteners (e.g. screws, rivets, etc.), or even suitable adhesives. The exterior surface **175** of the support element **176** is shaped to receive the antenna radiator **180**. The support element **178** further comprises an opening **194** that is designed to pass through the feed conductor **172**. The feed conductor **172** is connected to the PCB **189** of the portable device and to the feed point (not shown) of the antenna radiator element **180**.

In one embodiment, the feed conductor, the radiator structure, and the ground coupling arrangement are configured similarly to the embodiments described above with respect to FIGS. **1**A-**1**B.

In one variant, a portion of the feed conductor length is routed lengthwise along the dimension **174** of the antenna support element **176**: e.g., along an interior surface of the element **176**, or along the exterior surface. Matching grooves may also be fabricated on the respective surface of the support element **168** to recess the feed conductor flush with the surface if desired.

In a different embodiment (not shown), a portion of the feed conductor **172** is routed along a lateral edge of the support element **178**. To accommodate this implementation, the opening **194** is fabricated closer to that lateral edge.

The radiating element **180** is affixed to the chassis via a conductive sponge at the ground coupling point and to the feed cable via a solder joint at the feed point. In one variant, both couplings are effected via solder joints. Additionally or alternatively, a suitable adhesive or mechanical retaining means (e.g., snap fit, c-clip) may be used if desired.

The radiator cover **178** is, in the illustrated embodiment, fabricated from any suitable dielectric material (e.g. plastic). The radiator cover **178** is attached to the device housing by any of a variety of suitable means, such as: adhesive, press-fit, snap-in fit with support of additional retaining members **182**, etc.

In a different construction (not shown), the radiator cover **178** comprises a non-conductive film, laminate, or non-conductive paint bonded onto one or more of the exterior surfaces of the respective radiator element.

In one embodiment, a thin layer of dielectric is placed between the radiating element **180**, the coaxial cable **172** and the metal support **176** in order to prevent direct contact between the radiator and metal carrier in all but one location: the ground point. The insulator (not shown) has an opening that corresponds to the location and size of the ground point on the radiator element **180**, similarly to the embodiment described above with respect to FIG. **1**A.

The cover **178** is fabricated from a durable oxide or glass (e.g. zirconia, or Gorilla® Glass manufactured by Dow Corning) and is welded (i.e., via a ultrasonic-welding (USW) technique) onto the device body. Other attachment methods are useable including but not limited to adhesive, snap-fit, press-fit, heat staking, etc.

Similarly to the prior embodiment of FIG. **1**A, the antenna radiator element **180**, the feed conductor **172**, the metal support **176**, and the device enclosure cooperate to form a coupled loop resonator, thereby facilitating formation of the chassis excited antenna structure that is efficient, simple to manufacture and is lower cost compared to the existing solutions.

As with exemplary antenna implementation described above with respect to FIGS. **1**A-**1**D, antenna performance for the device of FIG. **1**E is improved compared to the existing implementations, largely because the radiator element is placed outside the metallic enclosure/chassis, while still being coupled to the chassis.

Exemplary Mobile Device Configuration

Referring now to FIG. **2**A, an exemplary embodiment **200** of a mobile device comprising two antenna components configured in accordance with the principles of the present invention is shown and described. The mobile device comprises a metal enclosure (or chassis) **202** having a width **204**, a length **212**, and a thickness (height) **211**. Two antenna elements **210**, **230**, configured similarly to the embodiment of FIG. **1**A, are disposed onto two opposing sides **106**, **206** of the housing **202**, respectively. Each antenna element is configured to operate in a separate frequency band (e.g., one antenna **210** in a lower frequency band, and one antenna **230** in an upper frequency band, although it will be appreciated that less or more and/or different bands may be formed based on varying configurations and/or numbers of antenna elements). Other configurations may be used consistent with the present invention, and will be recognized by those of ordinary skill given the present disclosure. For example, both antennas can be configured to operate in the same frequency band, thereby providing diversity for MIMO operations. In another embodiment, one antenna assembly is

configured to operate in an NFC-compliant frequency band, thereby enabling short range data exchange during, e.g., payment transactions.

The illustrated antenna assembly **210** comprises a rectangular antenna radiator **108** disposed on the side **106** of the enclosure, and coupled to the feed conductor **116** at a feed point (not shown). To facilitate mounting of the radiator **108**, a pattern **107** is fabricated on the side **106** of the housing. The feed conductor **116** is fitted through an opening **114** fabricated in the housing side. A portion of the feed conductor is routed along the side **106** lengthwise, and is coupled to the radiator element **108**. An antenna cover **118** is disposed directly on top of the radiator **108** so as to provide isolation for the radiator.

The illustrated antenna assembly **230** comprises a rectangular antenna radiator **238** disposed on the housing side **206** and coupled to feed conductor **236** at a feed point (not shown). The feed conductor **236** is fitted through an opening (not shown) fabricated in the housing side **206**. A portion of the feed conductor is routed along the side **206** lengthwise, in a way that is similar to the feed conductor **116**, and is coupled to the radiator element **238** at a feed point.

In one embodiment, the radiating elements **108**, **238** are affixed to the chassis via solder joints at the coupling points (ground and feed. In one variant, the radiating elements are affixed to the device via a conductive sponge at the ground coupling point and to the feed cable via a solder joint at the feed point. In another variant, both connections are effected via a conductive sponge. Other electrical coupling methods are useable with embodiments of the invention including, but not limited to, c-clip, pogo pin, etc. Additionally, a suitable adhesive or mechanical retaining means (e.g., snap fit) may be used if desired to affix the radiating element to the device housing.

The cover elements **118**, **240** are in this embodiment also fabricated from any suitable dielectric material (e.g. plastic, glass, zirconia) and are attached to the device housing by a variety of suitable means, such as e.g., adhesive, press-fit, snap-in with support of additional retaining members (not shown), or the like. Alternatively, the covers may be fabricated from a non-conductive film, or non-conductive paint bonded onto one or more exterior surfaces of the radiator element(s) as discussed supra.

A single, multi-feed transceiver may be used to provide feed to both antennas. Alternatively, each antenna may utilize a separate feed, wherein each antenna radiator directly is coupled to a separate feed port of the mobile radio device via a separate feed conductor (similar to that of the embodiment of FIG. **1**A) so as to enable operation of each antenna element in a separate frequency band (e.g., lower band, upper band). The device housing/chassis **102** acts as a common ground for both antennas.

FIG. **2**B shows another embodiment **250** of the mobile device of the invention, wherein two antenna components **170**, **258** are disposed on top and bottom sides of the mobile device housing **102**, respectively. Each antenna component **170**, **258** is configured similarly to the antenna embodiment depicted in FIG. **1**C, and operates in a separate frequency band (e.g., antenna **170** in an upper frequency band and antenna **258** in a lower frequency band). It will further be appreciated that while the embodiments of FIGS. **2**A and **2**B show two (2) radiating elements each, more radiating elements may be used (such as for the provision of more than two frequency bands, or to accommodate physical features or attributes of the host device). For example, the two radiating elements of each embodiment could be split into two sub-elements each (for a total of four sub-elements), and/or radiating elements could be placed both on the sides and on the top/bottom of the housing (in effect, combining the embodiments of FIGS. **2**A and **2**B). Yet other variants will be readily appreciated by those of ordinary skill given the present disclosure.

In the embodiment of FIG. **2**B, the antenna assemblies **170**, **258** are specifically configured to fit in a substantially conformal fashion onto a top or a bottom side of the device housing **252**. As the housing **252** comprises a sleeve-like shape, metal support elements **168**, **260** are provided. Support elements **168**, **260** are shaped to fit precisely into the openings of the housing, and are attached to the housing via any suitable means, such as for example press fit, micro-welding, adhesives, or fasteners (e.g., screws or rivets). The outside surfaces of the support elements **168**, **260** are shaped receive the antenna radiators **180** and **268**, respectively. The support elements **168**, **260** include openings **170**, **264**, respectively, designed to fit the feed conductors **172**, **262**. The feed conductors **172**, **262** are coupled to the main PCB **256** of the portable device. The device display (not shown) is configured to fit within the cavity **254** formed on the upper surface of the device housing. Antenna cover elements **178**, **266** are disposed above the radiators **180**, **268** to provide isolation from the exterior influences. In another implementation (not shown) the antenna elements

In one variant, the radiating elements **180**, **268** are affixed to the respective antenna support elements via solder joints at the coupling points (ground and feed). In another variant, conductive sponge and suitable adhesive or mechanical retaining means (e.g., snap fit, press fit) are used. **170**, **258** are configured in a non-conformal arrangement.

As described above, the cover elements **178**, **266** may be fabricated from any suitable dielectric material (e.g., plastic, zirconia, or tough glass) and attached to the device housing by any of a variety of suitable means, such as e.g., adhesives, press-fit, snap-in with support of additional retaining members **182**, **270**, **272**

In a different embodiment (not shown), a portion of the feed conductor is routed along a lateral edge of the respective support element (**168**, **268**). To accommodate this implementation, opening **170**, **264** are fabricated closer to that lateral edge.

The phone housing or chassis **252** acts as a common ground for both antennas in the illustrated embodiment.

A third embodiment **280** of the mobile device is presented in FIG. **2**C, wherein the antenna assemblies **210**, **290** are disposed on the left and the bottom sides of the mobile device housing **202**, respectively. The device housing **202** comprises a metal enclosure supporting one or more displays **254**. Each antenna element of FIG. **2**C is configured to operate in a separate frequency band (e.g., antenna **290** in a lower frequency band and antenna **210** in an upper frequency band). Other configurations (e.g., more or less elements, different placement or orientation, etc.) will be recognized by those of ordinary skill given the present disclosure.

The antenna assemblies **210**, **290** are constructed similarly to the antenna assembly **210** described above with respect to FIG. **2**A. The device housing **202** of the exemplary implementation of FIG. **2**C is a metal enclosure with closed sides, therefore not requiring additional support element(s) (e.g., **168**) to mount the antenna radiator(s).

In one embodiment, the lower frequency band (i.e., that associated with one of the two radiating elements operating at lower frequency) comprises a sub-GHz Global System for Mobile Communications (GSM) band (e.g., GSM710, GSM750, GSM850, GSM810, GSM900), while the higher

band comprises a GSM1900, GSM1800, or PCS-1900 frequency band (e.g., 1.8 or 1.9 GHz).

In another embodiment, the low or high band comprises the Global Positioning System (GPS) frequency band, and the antenna is used for receiving GPS position signals for decoding by e.g., an internal GPS receiver. In one variant, a single upper band antenna assembly operates in both the GPS and the Bluetooth frequency bands.

In another variant, the high-band comprises a Wi-Fi (IEEE Std. 802.11) or Bluetooth frequency band (e.g., approximately 2.4 GHz), and the lower band comprises GSM1900, GSM 1800, or PCS 1900 frequency band.

In another embodiment, two or more antennas, configured in accordance with the principles of the present invention, operate in the same frequency band thus providing, inter alia, diversity for Multiple In Multiple Out (MIMO) or for Multiple In Single Out (MISO) applications.

In yet another embodiment, one of the frequency bands comprises a frequency band suitable for Near Field Communications applications, e.g., ISM 13.56 MHz band.

Other embodiments of the invention configure the antenna apparatus to cover LTE/LTE-A (e.g., 698 MHz-740 MHz, 900 MHz, 1800 MHz, and 2.5 GHz-2.6 GHz), WWAN (e.g., 824 MHz-960 MHz, and 1710 MHz-2170 MHz), and/or WiMAX (2.3, and 2.5 GHz) frequency bands.

In yet another diplexing implementation (not shown) a single radiating element and a single feed are configured provide a single feed solution that operates in two separate frequency bands. Specifically, a single dual loop radiator forms both frequency bands using a single fee point such that two feed lines (transmission lines **128**) of different lengths configured to form two loops, which are joined together at a single diplexing point. The diplexing point is, in turn, coupled to the port of the device via a feed conductor **116**.

As persons skilled in the art will appreciate, the frequency band composition given above may be modified as required by the particular application(s) desired. Moreover, the present invention contemplates yet additional antenna structures within a common device (e.g., tri-band or quad-band) with one, two, three, four, or more separate antenna assemblies where sufficient space and separation exists. Each individual antenna assembly can be further configured to operate in one or more frequency bands. Therefore, the number of antenna assemblies does not necessarily need to match the number of frequency bands.

The invention further contemplates using additional antenna elements for diversity/MIMO type of application. The location of the secondary antenna(s) can be chosen to have the desired level of pattern/polarization/spatial diversity. Alternatively, the antenna of the present invention can be used in combination with one or more other antenna types in a MIMO/SIMO configuration (i.e., a heterogeneous MIMO or SIMO array having multiple different types of antennas).

Business Considerations and Methods

An antenna assembly configured according to the exemplary embodiments of FIGS. **1**-**2**C can advantageously be used to enable e.g., short-range communications in a portable wireless device, such as so-called Near-Field Communications (NFC) applications. In one embodiment, the NFC functionality is used to exchange data during a contactless payment transaction. Any one of a plethora of such transactions can be conducted in this manner, including e.g., purchasing a movie ticket or a snack; Wi-Fi access at an NFC-enabled kiosk; downloading the URL for a movie trailer from a DVD retail display; purchasing the movie through an NFC-enabled set-top box in a premises environment; and/or purchasing a ticket to an event through an NFC-enabled promotional poster. When an NFC-enabled portable device is disposed proximate to a compliant NFC reader apparatus, transaction data are exchanged via an appropriate standard (e.g., ISO/IEC 18092/ECMA-340 standard and/or ISO/ELEC 14443 proximity-card standard). In one exemplary embodiment, the antenna assembly is configured so as to enable data exchange over a desired distance; e.g., between 0.1 and 0.5 m.

Performance

Referring now to FIGS. **3** through **4**, performance results obtained during testing by the Assignee hereof of an exemplary antenna apparatus constructed according invention are presented. The exemplary antenna apparatus comprises separate lower band and upper band antenna assemblies, which is suitable for a dual feed front end. The lower band assembly is disposed along a bottom edge of the device, and the upper band assembly is disposed along a top edge of the device. The exemplary radiators each comprise a PCB coupled to a coaxial feed, and a single ground point per antenna.

FIG. **3** shows a plot of free-space return loss S**11** (in dB) as a function of frequency, measured with: (i) the lower-band antenna component **258**; and (ii) the upper-band antenna assembly **170**, constructed in accordance with the embodiment depicted in FIG. **2**B. Exemplary data for the lower (**302**) and the upper (**304**) frequency bands show a characteristic resonance structure between 820 MHz and 960 MHz in the lower band, and between 1710 MHz and 2170 MHz for the upper frequency band. Measurements of band-to-band isolation (not shown) yield isolation values of about −21 dB in the lower frequency band, and about −29 dB in the upper frequency band.

FIG. **4** presents data regarding measured free-space efficiency for the same two antennas as described above with respect to FIG. **3**. The antenna efficiency (in dB) is defined as decimal logarithm of a ratio of radiated and input power:

$$AntennaEfficiency = 10\ \log_{10}\left(\frac{\text{Radiated Power}}{\text{Input Power}}\right) \qquad \text{Eqn. (1)}$$

An efficiency of zero (0) dB corresponds to an ideal theoretical radiator, wherein all of the input power is radiated in the form of electromagnetic energy. The data in FIG. **4** demonstrate that the lower-band antenna of the invention positioned at bottom side of the portable device achieves a total efficiency (**402**) between −4.5 and −3.75 dB over the exemplary frequency range between 820 and 960 MHz. The upped band data (**404**) in FIG. **4**, obtained with the upper-band antenna positioned along the top-side of the portable device, shows similar efficiency in the exemplary frequency range between 1710 and 2150 MHz.

The exemplary antenna of FIG. **2**B is configured to operate in a lower exemplary frequency band from 700 MHz to 960 MHz, as well as the higher exemplary frequency band from 1710 MHz to 2170 MHz. This capability advantageously allows operation of a portable computing device with a single antenna over several mobile frequency bands such as GSM710, GSM750, GSM850, GSM810, GSM1900, GSM1800, PCS-1900, as well as LTE/LTE-A and WiMAX (IEEE Std. 802.16) frequency bands. As persons skilled in the art appreciate, the frequency band composition given

above may be modified as required by the particular application(s) desired, and additional bands may be supported/used as well.

Advantageously, an antenna configuration that uses the distributed antenna configuration as in the illustrated embodiments described herein allows for optimization of antenna operation in the lower frequency band independent of the upper band operation. Furthermore, the use of coupled loop chassis excited antenna structure reduces antenna size, particularly height, which in turn allows for thinner portable communication devices. As previously described, a reduction in thickness can be a critical attribute for a mobile wireless device and its commercial popularity (even more so than other dimensions in some cases), in that thickness can make the difference between something fitting in a desired space (e.g., shirt pocket, travel bag side pocket, etc.) and not fitting.

Moreover, by fitting the antenna radiator(s) flush with the housing side, a near 'zero volume' antenna is created. At the same time, antenna complexity and cost are reduced, while robustness and repeatability of mobile device antenna manufacturing and operation increase. The use of zirconia or tough glass materials for antenna covers in certain embodiments described herein also provides for an improved aesthetic appearance of the communications device and allows for decorative post-processing processes.

Advantageously, a device that uses the antenna configuration as in the illustrated embodiments described herein allows the use of a fully metal enclosure (or metal chassis) if desired. Such enclosures/chassis provide a robust support for the display element, and create a device with a rigid mechanical construction (while also improving antenna operation). These features enable construction of thinner radio devices (compared to presently available solutions, described above) with large displays using fully metal enclosures.

Experimental results obtained by the Assignee hereof verify a very good isolation (e.g., −21 dB) between an antenna operating in a lower band (e.g., 850/900 MHz) and about −29 dB for an antenna operating an upper band (1800/1900/2100 MHz) in an exemplary dual feed configuration. The high isolation between the lower band and the upper band antennas allows for a simplified filter design, thereby also facilitating optimization of analog front end electronics.

In an embodiment, several antennas constructed in accordance with the principles of the present invention and operating in the same frequency band are utilized to construct a multiple in multiple out (MIMO) antenna apparatus.

It will be recognized that while certain aspects of the invention are described in terms of a specific sequence of steps of a method, these descriptions are only illustrative of the broader methods of the invention, and may be modified as required by the particular application. Certain steps may be rendered unnecessary or optional under certain circumstances. Additionally, certain steps or functionality may be added to the disclosed embodiments, or the order of performance of two or more steps permuted. All such variations are considered to be encompassed within the invention disclosed and claimed herein.

While the above detailed description has shown, described, and pointed out novel features of the invention as applied to various embodiments, it will be understood that various omissions, substitutions, and changes in the form and details of the device or process illustrated may be made by those skilled in the art without departing from the invention. The foregoing description is of the best mode presently contemplated of carrying out the invention. This description is in no way meant to be limiting, but rather should be taken as illustrative of the general principles of the invention. The scope of the invention should be determined with reference to the claims.

What is claimed is:

1. An antenna apparatus for use in a portable communications device, the device comprising a metal enclosure having a plurality of sides, the device substantially housing an electronics assembly comprising a ground and at least one feed port, the antenna apparatus comprising:

a first antenna assembly configured to operate in a first frequency band, the first antenna assembly comprising:

a first radiator element comprising a dielectric substrate, the dielectric substrate comprising opposing first and second surfaces, the first surface of the dielectric substrate being in contact with a first side of the metal enclosure and the opposing second surface comprising a planar radiator structure disposed substantially parallel to the first side and the first surface of the dielectric substrate, where the first radiator element is disposed on an exterior surface of the first side, and the planar radiator structure faces outward with respect to the metal enclosure; and

a first feed conductor disposed along a first side of the metal enclosure and fed through an opening located on the first side; and

a second antenna assembly configured to operate in a second frequency band, the second antenna assembly comprising a second radiator element and a second feed conductor disposed along a second side of the metal enclosure;

wherein (i) at least a portion of the first side of the metal enclosure, (ii) the first radiator element, and (iii) at least a portion of the first feed conductor disposed along the first side of the metal enclosure are configured to together form a first coupled loop antenna structure; and

wherein (i) at least a portion of the second side of the metal enclosure, (ii) the second radiator element, and (iii) at least a portion of the second feed conductor disposed along the second side of the metal enclosure are configured to together form a second coupled loop antenna structure.

2. The antenna apparatus of claim **1**, wherein the first side of the metal enclosure is arranged substantially opposite the second side of the metal enclosure.

3. The antenna apparatus of claim **1**, wherein:

the first radiator element further comprises a first ground point and a first feed point, and a first non-conductive cover is disposed proximate the first radiator element so as to substantially cover the first radiator element disposed along the first side of the metal enclosure; and

the first feed conductor is coupled to the first feed point and to the at least one feed port.

4. The antenna apparatus of claim **3**, wherein:

the second radiator element further comprises a second ground point and a second feed point, and a second non-conductive cover is disposed proximate the second radiator element so as to substantially cover the second radiator element disposed along the second side of the metal enclosure;

the second feed conductor is coupled to the second feed point and to the at least one feed port; and

the first and second ground points are electrically coupled to the metal enclosure.

5. The antenna apparatus of claim 4, wherein the substrate is configured to electrically isolate at least a portion of the first surface of the first radiator element from the first side of the metal enclosure.

6. The antenna apparatus of claim 5, further comprising a second substrate disposed between a first surface of the second radiator element and the second side of the metal enclosure, the second dielectric element configured to electrically isolate at least a portion of the first surface of the second radiator element from the second side of the metal enclosure.

7. The antenna apparatus of claim 4, further comprising a first retaining member and a second retaining member;

wherein the first retaining member is configured to attach the first non-conductive cover onto the device via the first retaining member; and

wherein the second retaining member is configured to attach the second non-conductive cover onto the device via the second retaining member.

8. The antenna apparatus of claim 7, wherein the first and second retaining members are metallic.

9. The antenna apparatus of claim 1, wherein the first frequency band comprises a frequency band between 700 and 960 MHz, and the second frequency band comprises an upper frequency band.

10. The antenna apparatus of claim 9, wherein the upper frequency band comprises a frequency band between 1710 and 2150 MHz.

11. The antenna apparatus of claim 9, wherein the upper frequency band comprises a global positioning system (GPS) frequency band.

12. The antenna apparatus of claim 1, wherein:

the metal enclosure comprises a sleeve-like shape having a first cavity and a second cavity; and

the first side comprises a first metal support element disposed within the first cavity and is configured to receive the first radiator element; and

the second side comprises a second metal support element disposed within the second cavity and configured to receive the second radiator element.

13. The antenna apparatus of claim 1, wherein:

the first side of the metal enclosure comprises a discrete first support element configured to mount the first radiator element;

the first support element comprises the opening located on the first side which is configured to feed the first feed conductor through the first side; and

the first feed conductor is configured to be attached to a feed point.

14. The antenna apparatus of claim 13, wherein:

the second side of the metal enclosure comprises a discrete second support element configured to mount the first radiator element;

the second support element comprises an opening located on the second side which is configured to feed the second feed conductor through the second side; and

the second feed conductor is configured to be attached to another feed point.

15. The antenna apparatus of claim 14, wherein:

the first feed conductor is routed along a dimension of the first side of the metal enclosure; and

the second feed conductor is routed along a dimension of the second side of the metal enclosure.

16. The antenna apparatus of claim 1, wherein the portable communications device comprises a substantially metallic structure.

17. A mobile communications device configured to house an electronics assembly, the electronics assembly comprising a ground and at least one feed port, the mobile communications device comprising:

a metal enclosure comprising a plurality of sides; and

an antenna apparatus disposed at least partially exterior to the metal enclosure, the antenna apparatus comprising:

a first antenna assembly configured to operate in a first frequency band, the first antenna assembly comprising:

a first radiator element comprising a dielectric substrate, the dielectric substrate comprising opposing first and second surfaces, the first surface of the dielectric substrate being in contact with a first side of the metal enclosure and the opposing second surface comprising a planar radiator structure disposed substantially parallel to the first side and the first surface of the dielectric substrate, where the first radiator element is disposed on an exterior surface of the first side, and the planar radiator structure faces outward with respect to the metal enclosure; and

a first feed conductor disposed along a first side of the metal enclosure and fed through an opening located on the first side; and

a second antenna assembly configured to operate in a second frequency band, the second antenna assembly comprising a second radiator element and a second feed conductor disposed along a second side of the metal enclosure;

wherein (i) at least a portion of the first side of the metal enclosure, (ii) the first radiator element, and (iii) at least a portion of the first feed conductor disposed along the first side of the metal enclosure are configured to together form a first coupled loop antenna structure; and

wherein (i) at least a portion of the second side of the metal enclosure, (ii) the second radiator element, and (iii) at least a portion of the second feed conductor disposed along the second side of the metal enclosure are configured to together form a second coupled loop antenna structure.

18. The mobile communications device of claim 17, wherein the first side of the metal enclosure is arranged substantially opposite the second side of the metal enclosure.

19. The mobile communications device of claim 17, wherein:

the first radiator element further comprises a first ground point and a first feed point, and a first non-conductive cover is disposed proximate the first radiator element so as to substantially cover the first radiator element disposed along the first side of the metal enclosure; and

the first feed conductor is coupled to the first feed point and to the at least one feed port.

20. The mobile communications device of claim 19, wherein:

the second radiator element further comprises a second ground point and a second feed point, and a second non-conductive cover is disposed proximate the second radiator element so as to substantially cover the second radiator element disposed along the second side of the metal enclosure;

the second feed conductor is coupled to the second feed point and to the at least one feed port; and

the first and second ground points are electrically coupled to the metal enclosure.

21. The mobile communications device of claim 20, wherein the substrate is configured to electrically isolate at least a portion of the first surface of the first radiator element from the first side of the metal enclosure.

22. The mobile communications device of claim 21, further comprising a second substrate disposed between a first surface of the second radiator element and the second side of the metal enclosure, the second dielectric element configured to electrically isolate at least a portion of the first surface of the second radiator element from the second side of the metal enclosure.

23. The mobile communications device of claim 20, wherein:

the antenna apparatus further comprises a first retaining member and a second retaining member;

the first retaining member is configured to attach the first non-conductive cover onto the device via the first retaining member; and

the second retaining member is configured to attach the second non-conductive cover onto the device via the second retaining member.

24. The mobile communications device of claim 23, wherein the first and second retaining members are metallic.

25. The mobile communications device of claim 17, wherein the first frequency band comprises a frequency band between 700 and 960 MHz, and the second frequency band comprises an upper frequency band.

26. The mobile communications device of claim 25, wherein the upper frequency band comprises a frequency band between 1710 and 2150 MHz.

27. The mobile communications device of claim 26, wherein the upper frequency band comprises a global positioning system (GPS) frequency band.

28. The mobile communications device of claim 17, wherein:

the metal enclosure comprises a sleeve-like shape having a first cavity and a second cavity;

the first side comprises a first metal support element disposed within the first cavity and is configured to receive the first radiator element; and

the second side comprises a second metal support element disposed within the second cavity and configured to receive the second radiator element.

29. The mobile communications device of claim 17, wherein:

the first side of the metal enclosure comprises a discrete first support element configured to mount the first radiator element;

the first support element comprises the opening located on the first side which is configured to feed the first feed conductor through the first side; and

the first feed conductor is configured to be attached to the at least one feed point of the electronics assembly.

30. The mobile communications device of claim 29, wherein:

the second side of the metal enclosure comprises a discrete second support element configured to mount the first radiator element;

the second support element comprises an opening located on the second side which is configured to feed the second feed conductor through the second side; and

the second feed conductor is configured to be attached to another one of the at least one feed point of the electronics assembly.

31. The mobile communications device of claim 30, wherein:

the first feed conductor is routed along a dimension of the first side of the metal enclosure; and

the second feed conductor is routed along a dimension of the second side of the metal enclosure.

32. The mobile communications device of claim 17, wherein the electronics assembly comprises a ground point disposed at a location determined based on (i) one or more dimensions of at least the first coupled loop antenna structure and (ii) a desired frequency band of operation.

33. The mobile communications device of claim 17, wherein the first antenna assembly or the second antenna assembly is configured to provide near-field communication functionality and to enable exchange of data with another mobile communications device via the near-field communication functionality.

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