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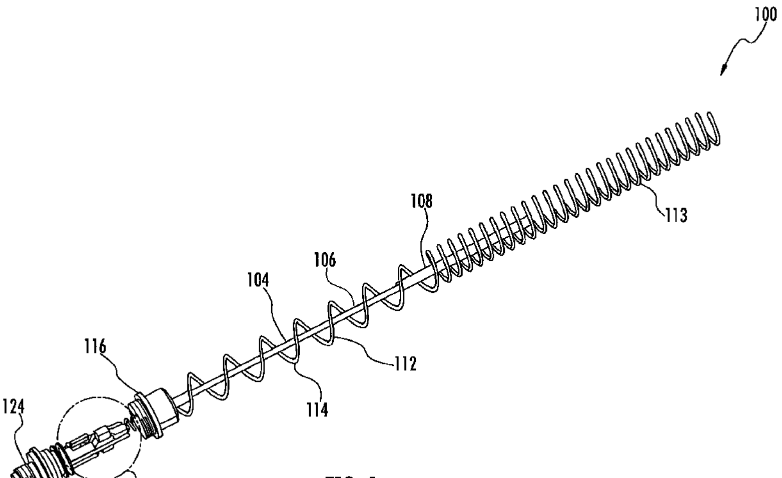

FIG. 1

(57) Abstract: Disclosed are exemplary embodiments of multiband antenna assemblies, which generally include helical and linear radiating elements. In an exemplary embodiment, a multiband antenna assembly generally includes at least one helical radiator having a central longitudinal axis. At least one linear radiator is aligned with or disposed at least partially along the longitudinal axis of the at least one helical radiator. The antenna assembly is resonant in at least three frequency bands.

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MULTIBAND ANTENNA ASSEMBLIES INCLUDING HELICAL AND LINEAR RADIATING ELEMENTS

FIELD

[0001] The present disclosure generally relates to multiband antenna assemblies including helical and linear radiating elements.

BACKGROUND

[0002] This section provides background information related to the present disclosure which is not necessarily prior art.

[0003] The users of portable wireless devices are putting increasing demands to provide more functionality in smaller and smaller portable wireless devices without degrading reception or connectivity. Thus, although the space available in a wireless device for an antenna continually decreases, the performance needs of the antenna continually increase. Moreover, many wireless devices today require the ability to operate over multiple frequency ranges that frequently require the use of multiple antennas to cover the functionality of the device, exasperating the problem.

SUMMARY

[0004] This section provides a general summary of the disclosure, and is not a comprehensive disclosure of its full scope or all of its features.

[0005] According to various aspects, exemplary embodiments are disclosed of antenna assemblies that include helical and linear radiating elements. For example, an exemplary embodiment of a multiband antenna assembly generally includes at least one helical radiator and at least one linear radiator. The linear radiator may be aligned with and/or disposed at least partially along a longitudinal axis of the helical radiator. The antenna assembly may be resonant in at least three frequency bands.

[0006] In another exemplary embodiment, a multiband antenna assembly generally includes a helical radiator having an upper portion and a lower portion. The lower portion has wider pitch coils than the upper portion. The antenna assembly also includes a linear radiator that extends through one or more coils of the helical radiator. The linear radiator includes a first conductor and a second conductor along an end

portion thereof. In this example, the antenna assembly is resonant in at least three frequency bands, including a very high frequency (VHF) band from 136 MHz to 174 MHz, an ultra high frequency (UHF) band from 380 MHz to 527 MHz, and a global positioning system (GPS) frequency band including a frequency of 1575 MHz.

[0007] In a further exemplary embodiment, a multiband antenna assembly generally includes a top helical radiator and a bottom helical radiator spaced apart from the top helical radiator. The antenna assembly also includes a linear radiator between the top and bottom helical radiators. The linear radiator includes a first conductor and a second conductor along an end portion of the first conductor. The linear radiator extends through one or more coils of at least one of the bottom and top helical radiators. In this example, the antenna assembly is resonant in at least three frequency bands, including an ultra high frequency (UHF) band from 380 MHz to 527 MHz, a 7-800 MHz frequency band from 764 MHz to 870 MHz, and a global positioning system (GPS) frequency band including a frequency of 1575 MHz.

[0008] Further areas of applicability will become apparent from the description provided herein. The description and specific examples in this summary are intended for purposes of illustration only and are not intended to limit the scope of the present disclosure.

DRAWINGS

[0009] The drawings described herein are for illustrative purposes only of selected embodiments and not all possible implementations, and are not intended to limit the scope of the present disclosure.

[0010] FIG. 1 is a perspective view of an exemplary embodiment of a multiband antenna assembly including helical and top loaded linear radiating elements and a matching network;

[0011] FIG. 2 is a perspective view illustrating the exemplary manner by which the antenna assembly shown in FIG. 1 may be externally mounted to a wireless device housing according to an exemplary embodiment;

[0012] FIG. 3A illustrates the antenna assembly shown in FIG. 1, and also illustrating the λ/4 electrical length of the dual pitch helical radiator for the VHF band and the λ/4 electrical length of the wider pitch, lower portion of the helical radiator for the

UHF band, where these electrical lengths and frequencies are provided for purposes of illustration only according to exemplary embodiments;

[0013] FIG. 3B illustrates the antenna assembly shown in FIG. 1, where the helical radiator is not shown to better illustrate the λ/4 electrical length of the linear radiator's inner, center conductor for the UHF band and the λ/4 electrical length of the linear radiator's top loaded conductor for the GPS band, where these electrical lengths and frequencies are provided for purposes of illustration only according to exemplary embodiments;

[0014] FIG. 4 illustrates an example of a linear radiator that may be used in the antenna assembly shown in FIG. 1, where the helical radiator is not shown to better illustrate the linear radiator's inner, center electrically conducting member and top loaded conductor, which are configured as radiating elements for respective low band operation and high band operation according to this example embodiment;

[0015] FIGS. 5 through 7 illustrate further examples of linear radiator that may be used in the antenna assembly shown in FIG. 1, where the helical radiator is not shown to better illustrate linear radiator's inner, center electrically conducting member and top loaded conductor according to alternative example embodiments;

[0016] FIGS. 8A and 8B illustrate an example matching network topology of a printed circuit board assembly with lumped components of the antenna assembly shown in FIG. 1 according to an exemplary embodiment;

[0017] FIG. 9 is an exemplary line graph illustrating return loss in decibels (dB) versus frequency in megahertz (MHz) measured for the antenna assembly shown in FIG. 1 and illustrating the antenna's resonance for VHF, UHF, and GPS bands when the antenna assembly was measured in free space condition;

[0018] FIG. 10 is another exemplary line graph illustrating return loss in decibels versus frequency in megahertz measured for the antenna assembly shown in FIG. 1 in a hand held position;

[0019] FIG. 11 is a table with performance summary data of measured efficiency and gain performance of the antenna assembly shown in FIG. 1 for the VHF band (in handheld position) and for the UHF and GPS bands (in free space);

[0020] FIGS. 12 through 15 illustrate radiation patterns (azimuth plane) measured for the antenna assembly shown in FIG. 1 in a hand held position at a frequency of 155 MHz and in free space at frequencies of 400 MHz, 450 MHz, 512 MHz, and 1574 MHz, respectively;

[0021] FIG. 16 illustrates a radiation pattern (phi zero degree plane) measured for the antenna assembly shown in FIG. 1 in free space at a frequency of 1575 MHz;

[0022] FIG. 17 is a perspective view of another exemplary embodiment of a multiband antenna assembly including helical and top loaded linear radiating elements and a matching network, where the linear radiating element is between a bottom helical radiating element and a top suspended helical radiating element;

[0023] FIG. 18 is a perspective view illustrating the exemplary manner by which the antenna assembly shown in FIG. 17 may be externally mounted to a wireless device housing according to an exemplary embodiment;

[0024] FIG. 19 illustrates an example sheath for the antenna assembly shown in FIG. 1 and/or FIG. 17 according to an exemplary embodiment;

[0025] FIG. 20A is an exploded perspective view illustrating components of the antenna assembly shown in FIG. 17 and sheath shown in FIG. 19 according to an exemplary embodiment;

[0026] FIG. 20B is a cross sectional view taken along the lines 20-20 in FIG. 19 and illustrating the exemplary manner by which the components shown in FIG. 20A may be assembled;

[0027] FIG. 21A illustrates the antenna assembly shown in FIG. 17, and also illustrating the λ/2 electrical length of the antenna assembly for the UHF band and the λ/4 and λ/2 electrical length of the bottom helical radiating element for the 7-800 MHz frequencies band and GPS band, where these electrical lengths and frequencies are provided for purposes of illustration only according to exemplary embodiments;

[0028] FIG. 21B illustrates the antenna assembly shown in FIG. 17, where the helical radiators are not shown to better illustrate the λ/4 electrical length of the linear radiator's inner, center conductor for the 7-800 band and the λ/4 combined electrical length of the linear radiator's center conductor and top loaded conductor for the UHF band, where these electrical lengths and frequencies are provided for purposes of illustration only according to exemplary embodiments;

[0029] FIG. 22 illustrates an example of a linear radiator that may be used in the antenna assembly shown in FIG. 17, where the helical radiator is not shown to better illustrate linear radiator's inner, center electrically conducting member and top loaded conductor;

[0030] FIGS. 23A and 24B illustrate an example matching network topology of a printed circuit board assembly with lumped components of the antenna assembly shown in FIG. 17 according to an exemplary embodiment;

[0031] FIG. 24 is an exemplary line graph illustrating return loss in decibels (dB) versus frequency in megahertz (MHz) measured for the antenna assembly shown in FIG. 17 and illustrating the coupling effect from the top suspended helical radiating element and the antenna's resonance for the GPS band;

[0032] FIG. 25 is an exemplary line graph illustrating return loss in decibels (dB) versus frequency in megahertz (MHz) measured for the antenna assembly shown in FIG. 17 when covered by the sheath shown in FIG. 19 and illustrating the GPS resonance shift to lower frequency due to load by sheath;

[0033] FIG. 26 is another exemplary line graph illustrating return loss in decibels versus frequency in megahertz measured for the antenna assembly shown in FIG. 17 in a hand held position;

[0034] FIG. 27 is a table with performance summary data of measured efficiency and gain performance of the antenna assembly shown in FIG. 17 (in free space) for the UHF, 7-800, and GPS bands;

[0035] FIGS. 28 through 33 illustrate radiation patterns (azimuth plane) measured for the antenna assembly shown in FIG. 17 in free space at frequencies of 400 MHz, 470 MHz, 520 MHz, 764 MHz, 830 MHz, and 870 MHz, respectively; and

[0036] FIGS. 34 and 35 illustrate respective radiation patterns (phi zero degree plane and phi ninety degree plane) measured for the antenna assembly shown in FIG. 17 in free space at a frequency of 1575 MHz.

DETAILED DESCRIPTION

[0037] Example embodiments will now be described more fully with reference to the accompanying drawings.

[0038] The inventor hereof has recognized that there is a demand for portable two way radios having interoperability capability, which leads to multiband and multimode two way radios. But with such multiband and multimode radios, the inventor hereof has recognized that it is a great challenge to provide a suitable antenna with various band capabilities. For example, the inventor hereof has recognized that convention helical antennas tend to have narrow bandwidths, especially for Very High Frequency (VHF) band (*e.g.*, 136 MHz to 174 MHz) and/or Ultra High Frequency (UHF) band (*e.g.*, 380 MHz to 527 MHz). The inventor has also recognized that the complexity of some existing multiband antennas only perform well at a limited portion of the entire UHF band. The inventor has further recognized that some existing multiband antennas also have poor manufacturability due to the complexity of integration of multiple radiating elements and having to also meet mechanical structural integrity requirements.

[0039] Accordingly, the inventor has disclosed herein multiband antenna assemblies that do not suffer from very narrow bandwidths especially in the UHF and VHF bands. Exemplary embodiments disclosed herein may be configured with the ability to achieve multiband application with an antenna assembly or unit having a suitably compact size in terms of diameter and length. An exemplary embodiment of an antenna assembly disclosed herein is configured to achieve multiband operation for frequencies associated with VHF (*e.g.*, 136 MHz to 174 MHz), UHF (*e.g.*, 380 MHz to 527 MHz), and GPS (*e.g.*, 1575 MHz). Another exemplary embodiment of an antenna assembly disclosed herein is configured to achieve multiband operation for frequencies associated with UHF (*e.g.*, 380 MHz to 527 MHz), 7-800 band (*e.g.*, 764 MHz to 870 MHz) and GPS (*e.g.*, 1575 MHz). These frequency bands are examples only as other exemplary embodiments of an antenna assembly may be configured to be resonant at other frequencies and/or frequency bands, such as one or more of a VHF frequency bandwidth from 163 MHz to 174 MHz, a UHF frequency bandwidth from 403 MHz to 470 MHz, and GPS frequency of 1575 MHz.

[0040] As disclosed herein, exemplary embodiments of the multiband antenna assemblies may be configured so as to provide GPS radiation patterns that tilt up and have open sky efficiency better than 25% and/or also be associated with good manufacturability.

[0041] Accordingly, the inventor hereof has disclosed herein various exemplary embodiments of antenna assemblies that include helical and linear radiating elements. For example, a multiband antenna assembly may generally include at least one helical radiator and at least one linear radiator. The linear radiator may be aligned with and/or disposed at least partially along a longitudinal axis of the helical radiator. The antenna assembly may be resonant in at least three frequency bands.

[0042] In another exemplary embodiment, a multiband antenna assembly generally includes a helical radiator having an upper portion and a lower portion. The lower portion has wider pitch coils than the upper portion. The antenna assembly also includes a linear radiator that extends through one or more coils of the helical radiator. The linear radiator includes a first conductor and a second conductor along an end portion thereof. In this example, the antenna assembly is resonant in at least three frequency bands, including a very high frequency (VHF) band from 136 MHz to 174 MHz, an ultra high frequency (UHF) band from 380 MHz to 527 MHz, and a global positioning system (GPS) frequency band including a frequency of 1575 MHz. These frequency bands are examples only as other exemplary embodiments of an antenna assembly may be configured to be resonant at other frequencies and/or frequency bands, such as one or more of a VHF frequency bandwidth from 163 MHz to 174 MHz, a UHF frequency bandwidth from 403 MHz to 470 MHz, and GPS frequency of 1575 MHz.

[0043] In a further exemplary embodiment, a multiband antenna assembly generally includes a top helical radiator and a bottom helical radiator spaced apart from the top helical radiator. The antenna assembly also includes a linear radiator between the top and bottom helical radiators. The linear radiator includes a first conductor and a second conductor along an end portion of the first conductor. The linear radiator extends through one or more coils of at least one of the bottom and top helical radiators. In this example, the antenna assembly is resonant in at least three frequency bands, including an ultra high frequency (UHF) band from 380 MHz to 527 MHz, a 7-800 MHz frequency band from 764 MHz to 870 MHz, and a global positioning system (GPS) frequency band including a frequency of 1575 MHz. These frequency bands are examples only as other exemplary embodiments of an antenna assembly may be configured to be resonant at other frequencies and/or frequency bands, such as one or more of a UHF frequency bandwidth from 380 MHz to 430 MHz, a 7-800 MHz frequency band frequency bandwidth from 764 MHz to 806 MHz, and GPS frequency of 1575 MHz.

[0044] With reference now to the figures, FIG. 1 illustrates an exemplary embodiment of a multiband antenna assembly 100 embodying one or more aspects of the present disclosure. This exemplary embodiment has a design generally based on a monopole concept with multiple radiating elements.

[0045] As shown in FIG. 1, the antenna assembly 100 generally includes linear and helical radiators 104 and 112 coupled to a matching network 120 via an adapter 116 and contact spring 132. As disclosed herein, the linear radiator 104 in this example is a top loaded conducting wire located generally inside the helical radiator 112, such that the linear radiator 104 extends along or is aligned generally with the central longitudinal axis of the helix of the helical radiators 112. The antenna assembly 100 terminates with a connector 124 (*e.g.*, 50 Ohm connector, etc.) for connecting the antenna assembly 100 to a device (*e.g.*, device housing 128 in FIG. 2, etc.), whereby the antenna assembly 100 depends to a ground plane of the device to excite.

[0046] As disclosed herein, this exemplary antenna assembly 100 is configured to be operable or to cover multiple frequency ranges or bands, including the VHF frequency band from about 136 MHz to about 174 MHz, the UHF frequency band from about 380 MHz to about 527 MHz, and the GPS frequency of about 1575 MHz. This particular antenna assembly 100 is configured so as to have the electrical lengths of one quarter wavelength ($\lambda/4$) and one half wavelength ($\lambda/2$) for the respective for the VHF, UHF, and GPS bands as shown in FIGS. 3A and 3B. The outer helical radiating element 112 corresponds to VHF and UHF bands. The total electrical length of the helical radiating element 112 is approximately equivalent to one quarter wavelength (λ/4) of the VHF band. The matching network 120 is operable to help broaden the bandwidth of the VHF for resonance from 136 MHz to 174 MHz.

[0047] With continued reference to FIG. 1, the helical radiator 112 in this exemplary embodiment is a dual pitch helical coil radiator or spring having narrower and wider pitch coils 113, 114, respectively, along the respective bottom and top portions of the helical radiator 112. In operation, the lower coils 114 having the wider pitch are more responsive and resonant at the UHF band and are approximately equivalent to one quarter wavelength (λ/4) for the UHF band frequencies as shown in FIG. 3A. The upper coils 113 having the narrower or closer pitch are operable for introducing another resonance at the VHF band. A third harmonic is also resonant at GPS band. Accordingly, multiple resonant frequencies may be introduced by the dual pitch helical radiator 112 without a whip or linear radiating element.

[0048] A wide range of electrically conducting materials, preferably highly conductive materials, may be used for the helical radiator 112. By way of example, the helical radiator 112 may be formed from copper wire, spring wire, copper/tin/nickel plating wire, enameled wire, among other materials that may be configured to have the helical/spring configuration shown in FIG. 1. In addition, the coils of the helical radiator 112 are configured (*e.g.*, dual pitch, spacing, size, shape, etc.) in this example for specific frequency bands. Alternative embodiments may be configured for use with additional and/or different frequencies such as by varying the windings of the helical radiator coils. For example, other embodiments may include one or more helical radiators having coils with a constant pitch or with more than two different pitches and/or with a tapering pitch such that the coil has an upper or lower section wider than the other section.

[0049] As shown in FIG. 4, the linear radiator 104 includes electrically conductive wire 106 (broadly, a first conductor) and a top loaded element 108 (broadly, a second conductor) at or along the end portion of the electrically conductive wire 106. The electrically conducting wire 106 and top loaded element 108 are positioned relative to the helical radiating element 112 such that they extend through at least some of the coils of the helical radiating element 112 along a central longitudinal axis of the helix of the helical radiating element 112 as shown in FIG. 1. The coils of the outer helical radiating element 112 coil or wind counterclockwise generally about the length of the inner linear radiating element 104, which is thus located generally inside the helical radiator 112.

[0050] By way of example, the first conductor 106 of the linear radiator 104 may be formed from the electrically conducting wire at the center core of a coaxial cable. The top loaded element or second conductor 108 of the linear radiator 104 may comprise the braid soldered at the end of the coaxial cable. Accordingly, the braid of the coaxial cable may work as the second conductor 108, while the center core of the coaxial cable works as the first conductor 106. The coaxial cable's dielectric insulator between the core and braid will operate to prevent direct contact therebetween. The first and second conductors 106, 108 are configured as radiating elements for respective low band operation (*e.g.*, UHF band, etc.) and high band operation (*e.g.*, GPS band, etc.) according to this example embodiment.

[0051] The first and second conductors 106, 108 are galvanically coupled or connected to each other at the top or end 109 of the linear radiator 104. This electrical connection between the first and second conductors 106, 108 allows the antenna assembly 100 to be operable simultaneously at the UHF and GPS bands in this example. As shown in FIG. 3B, the first conductor 106 has an electrical length of about 1/4 wavelength for the UHF band, while the second conductor 108 has an electrical length of about 1/4 wavelength for the GPS frequency of 1575 MHz.

[0052] In operation, coupling (e.g., parasitic coupling in this example, etc.) between the linear radiator 104 (top loaded conducting wire in this example) and the lower coils 114 of the helical radiating element 112 allows the antenna assembly 100 to maintain the bandwidth for the UHF band with antenna resonance from 380 MHz to 527 MHz as can be seen in FIG. 10. The linear radiator 104 and the additional closer pitch coils 113 at the top of the helical radiator 112 allow the antenna assembly 100 to operate at VHF, UHF and GPS at the same time. Overall, the outer helical radiating element 112 is more dominant when the antenna assembly 100 is operating at VHF band frequencies. But when the antenna assembly 100 is operating within the UHF and GPS bands, the H-field or E-field of the top loaded conducting wire 104 will couple to the outer helical radiating element 112 to radiate.

[0053] Also, with the combination of the top loaded linear and helical radiating elements 104, 112, the antenna assembly 100 is excited in omnidirectional radiation patterns for VHF and UHF bands as shown in FIGS. 12 through 15. In operation, the antenna assembly is able to achieve total efficiency and near horizon efficiency of more than 58% and 45% respectively for UHF band as shown in FIG. 11. The top loaded electrically conducting wire also tilts up the GPS radiation pattern (FIGS. 11 and 16) such that the antenna assembly 100 achieves more than 30% of open sky efficiency for the GPS frequency band in this example embodiment.

[0054] Alternative embodiments may include linear radiators having first and second conductors configured differently, including conductors formed from different materials other than coaxial cables and/or soldered braids at the end of the coaxial cables. Other exemplary embodiments may include a flexible electrically conducting wire or cable as the first conductor with a metal tube as the second conductor, which is crimped or soldered to the end of the wire or cable. In these example embodiments, an insulator jacket may be disposed or sandwiched between the metal tube and electrically conductive wire or cable. Examples of electrically conductive wires or cables that may be used as the first conductor include a speedometer cable, nickel titanium (NiTi) wire, among other suitable cables, wires, rods, and/or elongate generally straight conducting members.

[0055] In addition, other electrically conductive materials and/or configurations may be used for the first and/or second conductors of the linear radiator. For example, the second conductor may be formed from a spring or single wire instead of a soldered coaxial cable braid or metal tube. To this end, FIGS. 5 through 7 illustrate further examples of linear radiators 204, 304, 404, respectively, that may be used with the antenna assembly 100 with similar results in antenna performance.

[0056] As shown in FIG. 5, the linear radiator 204 includes a first conductor 206 and a second conductor 208 connected to each other at the top or end 209 of the first conductor 206. In this example, the second conductor 208 is a spring or helical conductor suspended from the end 209 of the first conductor 206, such that the spring 208 extends outwardly away from the first conductor 206.

[0057] The linear radiator 304 shown in FIG. 6 also includes a first conductor 306 and a second conductor 308 connected to each other at the top or end 309 of the first conductor 306. But in this example, the second conductor 308 is a spring or helical conductor that extends in the opposite direction than did the spring 208 in FIG. 5. As shown in FIG. 6, the spring 308 extends back along the first conductor 306 such that the coils of the spring 308 coil or wind generally about the length of the first conductor 306.

[0058] FIG. 7 illustrates another example of a linear radiator 406, which includes a first conductor 406 and a second conductor 408 connected to each other at the top or end 409 of the first conductor 406. But in this example, the second conductor 408 is a single straight portion of electrically conductive wire that extends parallel to and back along the first conductor 406.

[0059] FIGS. 8A and 8B illustrate an example matching network topology of a printed circuit board assembly that may be used in the antenna assembly 100. In this example, the matching network 120 comprises lumped components 136 residing on front and back oppositely facing surfaces of the printed circuit board 138. As shown in FIGS. 1 and 2, the matching network 120 is part of the antenna assembly 100 rather than the device to which the antenna assembly 100 will be connected. Accordingly, the antenna assembly 100 does not have to rely upon a matching network that is part of or internal to the device as the antenna assembly 100 instead includes its own (*e.g.*, embedded, etc.) matching network 120.

[0060] The matching network 120 may comprise one or more shunt or series capacitors and/or one or more shunt or series inductors depending on the matching network topology. Additionally, or alternatively, the circuit board 138 may also include other capacitors, inductors, resistors, or the like, as well as conductive traces. In operation, the matching network 120 helps to pull the antenna resonance to lower frequency compared to the structure capability to the low band. This means that the helical coil structure by itself may not have sufficient electrical length to achieve the full bandwidth of the low band. The impedance matching of the matching network 120 helps the antenna assembly to be tuned to the lower frequency. In this particular illustrated example, the matching network 120 is operable to help broaden the bandwidth of the VHF for resonance from 136 MHz to 174 MHz.

[0061] Moreover, the printed circuit board 138 and lumped components 136 thereon that provide the impedance matching of the matching network 120 may be configured such that they will be contained within or under a sheath or radome (*e.g.*, sheath 540 shown in FIGS. 19, 20A and 20B, etc.) of the antenna assembly 100. As shown in FIG. 2, the matching network 120 will be external to the device housing 128 when the antenna assembly 100 is coupled thereto.

[0062] In this particular example, the connector 124 of the antenna assembly 100 is a 50 ohm connector and is illustrated as a threaded connection. Alternative connectors may be used in other embodiments including a snap fit connection, etc. As shown in FIG. 2, the antenna assembly 100 may be threadedly connected to the device housing 128 such that the bulk of the antenna assembly or unit 100 is external to the device housing 128. That is, the radiating elements 104, 112 and circuit board 138 having the matching network 120 of the antenna assembly 100 are able to be entirely contained within or under the sheath (*e.g.*, sheath 540 shown in FIG. 19, etc.) and remain external to the wireless device housing 128. Thus, the antenna assembly 100 is able to provide multiband operation in the VHF, UHF, and GPS frequency bands without having to significantly increase the overall size or volume of the wireless device housing 128. By way of example only, the sheath may have a length of about 180 millimeters and a diameter of about 14.5 millimeters along the portion disposed over the connector 124.

[0063] The radiating elements 104, 112 may be mechanically and electrically coupled to the circuit board 138 by the adapter 116 and contact spring 132. The contact spring 132 may include a hook portion 134 (*e.g.*, J-shaped or L-shaped hook portion, etc.) that extends through a hole in the circuit board 138 as shown in FIGS. 8A and 8B. The circuit board 138 and radiating elements 104, 112 of the antenna assembly 100 may be coupled in a similar manner as that described below for the antenna assembly 500, although this is not required.

[0064] FIGS. 9 through 16 illustrate analysis results measured for a prototype of the antenna assembly 100 shown in FIG. 1. These analysis results shown in FIGS. 9 through 16 are provided only for purposes of illustration and not for purposes of limitation.

[0065] More specifically, FIGS. 9 and 10 are exemplary line graphs illustrating return loss in decibels versus frequency measured for the antenna assembly 100. In FIG. 9, the antenna's resonance for the VHF, UHF, and GPS bands can be seen when the antenna assembly 100 was measured in free space condition. The data shown in FIG. 10 was measured when the antenna assembly 100 was in the hand held position. Generally, FIGS. 9 and 10 show that the antenna assembly 100 is operable with relatively good/acceptable return loss and bandwidths for the VHF, UHF, and GPS bands.

[0066] FIG. 11 is a table with performance summary data of measured efficiency and gain performance of the antenna assembly 100 for the VHF band (in handheld position) and for the UHF and GPS bands (in free space). Generally, this performance summary data shows that the antenna assembly 100 has relatively good gain/efficiency for the VHF, UHF, and GPS bands, including good open sky efficiency of more than 30% for the GPS band.

[0067] FIGS. 12 through 16 illustrate radiation patterns measured for the antenna assembly 100. The image at the center of each graph represents a device (*e.g.*, two way radio, etc.) having the antenna assembly 100 mounted on top thereof. More specifically, FIG. 12 illustrates radiation patterns (azimuth plane) measured for the antenna assembly 100 in a hand held position at a VHF frequency of 155 MHz where the image below the device represent's the head of the person holding the device. The VHF band is measured in hand held position where the device is held in the user's hands with the distance from the head about two inches to represent a real world application. FIGS. 13 through 15 illustrate radiation patterns (azimuth plane) measured for the antenna assembly 100 in free space at UHF frequencies of 400 MHz, 450 MHz, and 512 MHz, respectively. FIG. 16 illustrates a radiation pattern (phi zero degree plane) measured for the antenna assembly 100 in free space at a GPS frequency of 1575 MHz.

[0068] Generally, FIGS. 12 through 16 show the radiation patterns for the antenna assembly at these various frequencies within the VHF, UHF, and GPS bands and the good efficiency of the antenna assembly 100. The antenna assembly 100 has relatively broad bandwidths for the VHF, UHF, and GPS bands and allows multiple operating bands for wireless communications devices.

[0069] FIG. 17 illustrates another exemplary embodiment of an antenna assembly 500 embodying one or more aspects of the present disclosure. This exemplary embodiment has a design generally based on a monopole concept with multiple radiating elements.

[0070] As shown in FIG. 17, the antenna assembly 500 generally includes linear and helical radiators 504, 508, and 512 coupled to a matching network 520 via an adapter 516 and contact spring 532. In this example, the linear radiator 504 is a top loaded conducting wire located generally between and inside two spaced-apart helical radiators 508, 512. The helical radiators 508, 512 are at or along opposite end portions of the linear radiator 504. The linear radiator 504 extends along and/or is aligned generally with the central longitudinal axes of the helixes of the helical radiators 508, 512. The top suspended helical radiator 508 may be coupled (*e.g.*, via the coil form 544 (FIGS. 20A and 20B), etc.) such that the top suspended helical radiator 508 does not make direct galvanic contact with the top loaded element 508. In operation, the top suspended helical radiator 508 parasitically couples to the linear radiator 504. The antenna assembly 500 terminates with a connector 524 (*e.g.*, 50 Ohm connector, etc.) for connecting the antenna assembly 500 to a device (*e.g.*, device housing 528 in FIG. 18, etc.), whereby the antenna assembly 500 depends to a ground plane of the device to excite.

[0071] As disclosed herein, this exemplary antenna assembly 500 is configured to be operable or to cover multiple frequency ranges or bands, including the UHF frequency band from about 380 MHz to about 527 MHz, the 7-800 band from about 764 MHz to about 870 MHz, and the GPS frequency of 1575 MHz. This particular antenna assembly 500 is configured to have the electrical lengths shown in FIGS. 21A and 21B.

[0072] As shown in FIG. 22, the linear radiator 504 includes electrically conductive wire 506 (broadly, a first conductor) and a top loaded element 508 (broadly, a second conductor) at the end of the electrically conductive wire 506. By way of example, the first conductor 506 of the linear radiator 504 may be formed from the electrically conducting wire at the center core of a coaxial cable. The top loaded element or second conductor 508 of the linear radiator 104 may comprise the braid soldered at the end of the coaxial cable. Accordingly, the braid of the coaxial cable may work as the second conductor 508, while the center core of the coaxial cable works as the first conductor 506. The coaxial cable's dielectric insulator 505 between the core and braid will operate to prevent direct contact therebetween.

[0073] In this example, the first conductor 506 is the center conductor of a conducting wire formed as a radiating element for the 7-800 band. The first and second conductors 506, 508 are galvanically coupled or connected (e.g., soldered, etc.) to each other at the top or end 509 of the linear radiator 504 as shown in FIG. 22. This configuration of the first and second conductors 506, 508 introduces a capacitance coupling to the antenna assembly 500 and creates another resonance for the antenna assembly 500 at the UHF band. The two conductor elements 506 and 508 also couple to each other such that the antenna assembly 500 is capable of simultaneously operating at the UHF and 7-800 bands at the same time.

[0074] As shown in FIG. 21B, the electrical length of the first conductor 506 is about 1/4 wavelength for the 7-800 MHz band. The electrical length is about 1/4 wavelength for the UHF band when the first and second conductors 506, 508 are connected. In operation, the first conductor 506 introduces a single band resonance frequency for 7-800 band, while the combination of the first and second conductors 506, 508 and matching network 520 introduce dual frequency resonance for UHF and 7-800 bands. A loading gap 507 (FIG. 22) between the first and second conductors 506, 508 changes the frequencies ratio for UHF and 7-800 bands and/or helps fine tune the frequency ratio between UHF and 7-800 bands.

[0075] Alternative embodiments may include linear radiators having first and second conductors configured differently, including conductors formed from different materials other than coaxial cables and/or soldered braids at the end of the coaxial cables. Other exemplary embodiments may include a flexible electrically conducting wire or cable as the first conductor with a metal tube as the second conductor, which is crimped or soldered to the end of the wire or cable. In these example embodiments, an insulator jacket may be disposed or sandwiched between the metal tube and electrically conductive wire or cable. Examples of electrically conductive wires or cables that may be used as the first conductor include a speedometer cable, nickel titanium (NiTi) wire, among other suitable cables or wires.

[0076] With continued reference to FIG. 17, the coils of the top suspended helical radiating element 508 have a constant pitch such that the same distance is between the turns in the helical radiator 508. Likewise, the coils of the bottom helical radiating element 512 include coils having a constant pitch, which, however, is less than the coils' pitch of the top suspended helical radiating element.

[0077] A wide range of electrically conducting materials, preferably highly conductive materials, may be used for the helical radiators 508, 512. By way of example, the helical radiators 508, 512 may be formed from copper wire, spring wire, copper/tin/nickel plating wire, enameled wire, among other suitable materials that may be configured to have a helical/spring configuration shown in FIG. 17. In addition, the coils of the helical radiators 508, 512 are configured (*e.g.*, dual pitch, spacing, size, shape, etc.) in this example for specific frequency bands. Alternative embodiments may be configured for use with additional and/or different frequencies such as by varying the windings of the helical radiator coils. For example, other embodiments may include one or more helical radiators having coils with a non-constant pitch, etc.

[0078] In operation, the bottom helical radiating element 512 is responsive and resonant at the 7-800 band. As shown in FIG. 21A, the electrical length of the bottom helical radiating element 512 is approximately equivalent to one quarter wavelength ($\lambda/4$) for the 7-800 band frequencies. The bottom helical radiating element 512 also introduces a second harmonic frequency for GPS band. And, the electrical length of the bottom helical radiating element 512 is approximately equivalent to one half wavelength ($\lambda/2$) for GPS band frequencies.

[0079] In operation, the bottom helical radiating element 512 couples parasitically to the gap 507 of the top loaded conducting wire 504. This coupling shifts the resonance of 7-800 MHz to a lower frequency while the UHF band resonance is maintained, such that the UHF and GPS bands resonate at the same time. The bottom helical radiating element 512 helps to fine tune the 7-800 MHz band.

[0080] In regard to the top suspended helical radiator 508, parasitic coupling between the top loaded conducting wire 504 and the top suspended helical radiator 508 will shift the UHF band bandwidth so as to be resonant from 380 MHz to 527 MHz. But the top loaded conducting wire 504 is dominant when the antenna assembly 500 is operating within the UHF frequency bandwidth. The coupling between the top suspended helical radiator 508 and top loaded conducting wire 504 also increases the UHF electrical length such that electrical length of the entire antenna is approximately equivalent to one half wavelength (λ/2) for the UHF frequencies as shown in FIG. 21A.

[0081] The coupling also improves 7-800 MHz bandwidths. For example, in this example embodiment, parasitic coupling of the top loaded conducting wire 504 and top suspended parasitic helical radiating element 508 broadens the bandwidth of the 7-800 MHz by introducing proximity resonance to the dominant resonance near 800 MHz as shown in FIG. 24.

[0082] The additional top suspended helical coil 508 helps to tilt up the 7-800 band and GPS band radiation patterns as shown in FIGS. 31-33 (7-800 band) and FIGS. 34-35 (GPS band), respectively. This improved the near horizon efficiency to at least 45% for 7-800 MHz as shown in FIG. 27. In addition, the coupling of the top loaded conductor 504 and top suspended helical radiating element 508 also helps to tilt up the GPS radiation pattern (FIGS. 34 and 35) to achieve more than 35% of open sky efficiency (FIG. 27) for the GPS band in this example embodiment.

[0083] Multiple wavelengths are thus introduced by the bottom helical radiating element 512, top suspended helical radiating element 508, and the top loaded conducting wire 504, including the UHF, 7-800 MHz, and GPS bands. Also, with the combination of the bottom helical radiating element 512, top suspended helical radiating element 508, and the top loaded conducting wire 504, the antenna assembly 500 radiates in omnidirectional radiation patterns for the UHF and 7-800 bands as shown in FIGS. 28-30 (UHF band) and FIGS. 31-33 (7-800 band), respectively. Overall the average total efficiency and near horizon efficiency for UHF and 7-800 bands, is achieve more than 55% and 40% respectively (see FIG. 27).

[0084] FIGS. 23A and 23B illustrate an example matching network topology of a printed circuit board assembly that may be used in the antenna assembly 500. In this example, the matching network 520 comprises lumped components 536 residing on front and back oppositely facing surfaces of the printed circuit board 538. As shown in FIGS. 17 and 18, the matching network 520 is part of the antenna assembly 500 rather than the device to which the antenna assembly 500 will be connected. Accordingly, the antenna assembly 500 does not have to rely upon a matching network that is part of or internal to the device as the antenna assembly 500 instead includes its own (*e.g.*, embedded, etc.) matching network 520. Placing circuit board 538 and matching network 520 in the antenna assembly 500 allows more volume in the wireless device for other components, such as for increased circuitry to further enhance performance of the wireless device.

[0085] The matching network 520 may comprise one or more shunt or series capacitors and/or one or more shunt or series inductors depending on the matching network topology. For example, the circuit board 538 may comprise, for example, a two-element L shaped network of a capacitor and shunt inductor. Additionally, or alternatively, the circuit board 538 may also include other capacitors, inductors, resistors, or the like, as well as conductive traces. In operation, the matching network 520 helps to improve impedance matching for 7-800 and GPS bands. For example, the matching network 520 may provide broadband impedance matching by generally providing a 50 ohm load across the operating frequencies of interest.

[0086] Moreover, the printed circuit board 538 and lumped components 536 thereon that provide the impedance matching of the matching network 520 may be configured such that they will be contained within or under a sheath or radome 540 as shown in FIG. 20B. As shown in FIG. 18, the matching network 520 will be external to the device housing 528 when the antenna assembly 500 is coupled thereto.

[0087] In this particular example, the connector 524 of the antenna assembly 500 is a 50 ohm connector and is illustrated as a threaded connection. Alternative connectors may be used in other embodiments including a snap fit connection, etc. As shown in FIG. 18, the antenna assembly 500 may be threadedly connected to the device housing 528 such that the bulk of the antenna assembly or unit 500 is external to the device housing 528. That is, the radiating elements 504, 508, 512 and circuit board 538 having the matching network 520 of the antenna assembly 500 are able to be entirely contained within or under the sheath 540 (FIG. 20B) and remain external to the wireless device housing 528. Thus, the antenna assembly 500 is able to provide multiband operation in the UHF, 7-800, and GPS frequency bands without having to significantly increase the overall size or volume of the wireless device housing 528.

[0088] By way of example only, the sheath 540 may have a length of about 180 millimeters and a diameter of about 14.5 millimeters along the portion disposed over the connector 524. The numerical dimensions in this paragraph (as are all dimensions herein) are provided for illustrative purposes only, as the sheath and antenna components may be sized differently than disclosed herein depending on the particular frequencies desired or intended end use of the antenna assembly.

[0089] The sheath 540 may be overmolded or constructed via other suitable processes. For space considerations, the sheath 540 generally conforms to the outermost shape of the coils of the helical radiators 508, 512.

[0090] FIGS. 20A and 20B illustrate an exemplary manner by which the antenna assembly 500 and its various components may be assembled together. As shown in FIG. 20A and 20B, the radiating elements 504, 508, 512, connector 524, and circuit board 538 may be coupled and assembled under the sheath 540 using the adapter 516, spring contact or contact spring 532, coil form 544 (*e.g.*, insert molded coil form, etc.), sleeve 552 (*e.g.*, tubular premold, etc.), contact 556 (*e.g.*, contact pin, etc.), and insulator 560.

[0091] As shown in FIG. 20B, the helical radiators 508, 512 may be wound or disposed around the coil form 544 such that the coils of the helical radiators 508, 512 are positioned in the grooves shown in FIG. 20A. The coils of the bottom helical radiator 512 are also wound or disposed around a portion 517 of the adapter 516. The coil form 544 is disposed over the top loaded conducting wire 504 as shown in FIG. 20B. In this assembled state, the top suspended helical radiator 508 does not make direct galvanic contact with the top loaded conducting wire 504.

[0092] The contact spring 532 includes a hook portion 534 (*e.g.*, J-shaped or L-shaped hook portion, etc.) that extends through an opening or hole in the circuit board 538 as shown in FIGS. 23A and 23B. The hook portion may terminate in a protrusion to provide additional resistance to pull through force tending to cause hook portion to pull out of the hole in the circuit board 538. The hook portion is sized to fit in and through the hole in the circuit board 538 to provide a mechanical connection between the circuit board and the adapter 516. For example, the coils of the spring contact 532 may be wrapped or wound about a portion of the adapter 516.

[0093] Electrical connection may be made by various means to connect conductive traces on the circuit board 538 with the spring contact 532, such as by soldering, a press fit connection, a stamped metal connection, etc. In this example embodiment, the contact spring 532 is shown as a separate component, but in other embodiments the contact spring 532 may comprise an integral piece or extension of the bottom helical radiating element 512.

[0094] With continued reference to FIGS. 20A and 20B, the insulator 560 electrically insulates the contact 556 (*e.g.*, contact pin, etc.) from the connector 524. The contact 556 is connected to the circuit board 538, which is coupled to the adapter 516 within the tubular sleeve 552.

[0095] Radio frequency power from a wireless device (e.g., two-way radio, etc.) may be provided to the antenna assembly 500 by the contact 556 through the circuit board 538 when the antenna assembly 500 is threaded connected to the device housing 528 (as shown in FIG. 18). The connector or contact 556 is coupled to the circuit board 538, such as by a soldered connection, a press fit connection, a snap fit connection, a crimp connection, etc. The circuit board 538 is coupled to the adapter 516 via the contact spring 532. Accordingly, the contact 506 provides radio frequency power to the top loaded linear radiator 504 through circuit board 538, spring contact 532, and adapter 516.

[0096] With continued reference to FIGS. 20A and 20B, the sleeve 552 fits over the circuit board 538 and extends from connector 524 to the adapter 516 as shown in FIG. 20B. In this example, the sleeve 552 may be coupled to the adapter 516 via a threaded connection via the threaded protruding portion of the adapter 516 and a threaded interior portion of the sleeve 552. But this threading arrangement may be reversed and/or replaced by other means (e.g., friction fit, etc.)

[0097] In this exemplary embodiment, the use of the adapter 516 and sleeve 552 helps to reduce the impact to the circuit board 538 when the antenna assembly 500 as the adapter 516 helps loads/force to the sleeve 552. In this exemplary way, the circuit board 538 can be protected from damage that might otherwise occur when the antenna assembly 500 is dropped.

[0098] In alternative embodiments, an antenna assembly may include a sheath 540, antenna coil form 544, and sleeve 552 made from a wide range of insulators/plastic materials for supporting the whole antenna structure. For example, an antenna assembly may be configured so as to be within a sheath where the interior of the antenna assembly is filled with air. In such example embodiment, the antenna's helical and linear radiators may be separated by a dielectric tubular member (e.g., straw, etc.) to prevent or at least inhibit direct electrical or galvanic contact between the helical and linear radiators. In such example, the antenna assembly may include at least one linear radiator aligned with or disposed at least partially along a longitudinal axis of at least one helical radiator. A dielectric tubular member may be disposed over the at least linear radiator. The at least one helical radiator may be external to the dielectric tubular member such that the dielectric tubular member prevents or at least inhibits direct electrical contact between the helical and linear radiators. A sheath may be disposed of the helical and linear radiators and dielectric tubular member. An interior of the sheath may be filled with air or other dielectric material. In alternative embodiments, an antenna assembly may not include any sheath.

[0099] FIGS. 24 through 35 illustrate analysis results measured for a prototype of the antenna assembly 500 shown in FIG. 1. These analysis results shown in FIGS. 24 through 35 are provided only for purposes of illustration and not for purposes of limitation.

[00100] More specifically, FIGS. 24 through 26 are exemplary line graphs illustrating return loss in decibels (dB) versus frequency in megahertz (MHz) measured for the antenna assembly 500. In FIG. 24, the coupling effect from the top suspended helical radiating element 508 and the antenna's resonance for the GPS band can be seen. The data shown in FIG. 25 was measured when the antenna assembly 500 was covered by the sheath 540 shown in FIG. 19 and illustrates the GPS resonance shift to lower frequency due to load by sheath 540. The data shown in FIG. 26 was measured when the antenna assembly 500 was in the hand held position. Generally, FIGS. 24

through 26 show that the antenna assembly 500 is operable with relatively good/acceptable return loss and bandwidths for the UHF, 7-800, and GPS bands.

[00101] FIG. 27 is a table with performance summary data of measured efficiency and gain performance of the antenna assembly 500 shown in FIG. 17 (in free space) for the UHF, 7-800, and GPS bands. Generally, this performance summary data shows that the antenna assembly 500 has relatively good gain/efficiency for the UHF, 7-800, and GPS bands, including good open sky efficiency of 36% for the GPS band.

[00102] FIGS. 28 through 35 illustrate radiation patterns measured for the antenna assembly 500. The image at the center of each graph represents a device (*e.g.*, two way radio, etc.) having the antenna assembly 500 mounted on top thereof. More specifically, FIGS. 28, 29, and 30 illustrate radiation patterns (azimuth plane) measured for the antenna assembly 500 in free space at UHF frequencies of 400 MHz, 470 MHz, and 520 MHz, respectively. FIGS. 31, 32, and 33 illustrate radiation patterns (azimuth plane) measured for the antenna assembly 500 in free space at frequencies of 764 MHz, 830 MHz, and 870 MHz, respectively, which are within the 7-800 band. FIGS. 34 and 35 illustrate radiation patterns (phi zero degree plane and phi ninety degree plane, respectively) measured for the antenna assembly 500 in free space at the GPS frequency of 1575 MHz. Generally, FIGS. 28 through 35 show the radiation patterns for the antenna assembly 500 at these various frequencies within the VHF, UHF, and GPS bands and the good efficiency of the antenna assembly 500. Accordingly, the antenna assembly 500 has relatively broad bandwidths for the UHF, 7-800, and GPS bands and allows multiple operating bands for wireless communications devices.

[00103] The various antenna assemblies (*e.g.*, 100, 500, etc.) disclosed herein may be used with various wireless devices within the scope of the present disclosure. By way of example, the antenna assemblies disclosed herein may be mounted externally to the housing of a two way radio by means of the threaded portions as shown in the figures. The antenna assembly may be mounted in its own sheath or housing and have a connector (*e.g.*, 50 ohm connector, etc.) for connecting to a connector within the housing of the two way radio, so as to depend to the device ground plane to excite. While described in connection with a two way radio, embodiments of the antenna assemblies disclosed herein should not be limited to use with only two way radios and/or to externally mounting via threaded connections as antenna assemblies disclosed herein may be used in conjunction with various electronic devices.

[00104] Numerical dimensions and values are provided herein for illustrative purposes only. The particular dimensions and values provided are not intended to limit the scope of the present disclosure.

[00105] Spatially relative terms, such as “inner,” “outer,” "beneath", "below", "lower", "above", "upper" and the like, may be used herein for ease of description to describe one element or feature's relationship to another element(s) or feature(s) as illustrated in the figures. Spatially relative terms may be intended to encompass different orientations of the device in use or operation in addition to the orientation depicted in the figures. For example, if the device in the figures is turned over, elements described as "below" or "beneath" other elements or features would then be oriented "above" the other elements or features. Thus, the example term "below" can encompass both an orientation of above and below. The device may be otherwise oriented (rotated 90 degrees or at other orientations) and the spatially relative descriptors used herein interpreted accordingly.

[00106] The terminology used herein is for the purpose of describing particular example embodiments only and is not intended to be limiting. As used herein, the singular forms "a", "an" and "the" may be intended to include the plural forms as well, unless the context clearly indicates otherwise. The terms "comprises," "comprising," “including,” and “having,” are inclusive and therefore specify the presence of stated features, integers, steps, operations, elements, and/or components, but do not preclude the presence or addition of one or more other features, integers, steps, operations, elements, components, and/or groups thereof. The method steps, processes, and operations described herein are not to be construed as necessarily requiring their performance in the particular order discussed or illustrated, unless specifically identified as an order of performance. It is also to be understood that additional or alternative steps may be employed.

[00107] When an element or layer is referred to as being "on", “engaged to”, "connected to" or "coupled to" another element or layer, it may be directly on, engaged, connected or coupled to the other element or layer, or intervening elements or layers may be present. In contrast, when an element is referred to as being "directly on," “directly engaged to”, "directly connected to" or "directly coupled to" another element or layer, there may be no intervening elements or layers present. Other words used to describe the relationship between elements should be interpreted in a like fashion (*e.g.*, “between” versus “directly between,” “adjacent” versus “directly adjacent,” etc.). As used herein, the term "and/or" includes any and all combinations of one or more of the associated listed items.

[00108] Although the terms first, second, third, etc. may be used herein to describe various elements, components, regions, layers and/or sections, these elements, components, regions, layers and/or sections should not be limited by these terms. These terms may be only used to distinguish one element, component, region, layer or section from another region, layer or section. Terms such as “first,” “second,” and other numerical terms when used herein do not imply a sequence or order unless clearly indicated by the context. Thus, a first element, component, region, layer or section discussed below could be termed a second element, component, region, layer or section without departing from the teachings of the example embodiments.

[00109] Example embodiments are provided so that this disclosure will be thorough, and will fully convey the scope to those who are skilled in the art. Numerous specific details are set forth such as examples of specific components, devices, and methods, to provide a thorough understanding of embodiments of the present disclosure. It will be apparent to those skilled in the art that specific details need not be employed, that example embodiments may be embodied in many different forms and that neither should be construed to limit the scope of the disclosure. In some example embodiments, well-known processes, well-known device structures, and well-known technologies are not described in detail.

[00110] The disclosure herein of particular values and particular ranges of values for given parameters are not exclusive of other values and ranges of values that may be useful in one or more of the examples disclosed herein. Moreover, it is envisioned that any two particular values for a specific parameter stated herein may define the endpoints of a range of values that may be suitable for the given parameter. The disclosure of a first value and a second value for a given parameter can be interpreted as disclosing that any value between the first and second values could also be employed for the given parameter. Similarly, it is envisioned that disclosure of two or more ranges of values for a parameter (whether such ranges are nested, overlapping or distinct) subsume all possible combination of ranges for the value that might be claimed using endpoints of the disclosed ranges.

[00111] The foregoing description of the embodiments has been provided for purposes of illustration and description. It is not intended to be exhaustive or to limit the invention. Individual elements or features of a particular embodiment are generally not limited to that particular embodiment, but, where applicable, are interchangeable and can be used in a selected embodiment, even if not specifically shown or described. The same may also be varied in many ways. Such variations are not to be regarded as a departure from the invention, and all such modifications are intended to be included within the scope of the invention.

CLAIMS

WHAT IS CLAIMED IS:

1. An external multiband antenna assembly for a portable wireless device, the antenna assembly comprising:

at least one helical radiator having a central longitudinal axis; and

at least one linear radiator aligned with or disposed at least partially along the longitudinal axis of the at least one helical radiator;

whereby the antenna assembly is resonant in at least three frequency bands.

2. The antenna assembly of claim 1, wherein:

the antenna assembly is omnidirectional for at least one or more frequency bands; and/or

the antenna assembly is resonant in an ultra high frequency (UHF) band and a global positioning system (GPS) frequency band; and wherein the antenna assembly is also resonant in:

a very high frequency (VHF) band; or

a 7-800 MHz frequency band.

3. The antenna assembly of any one of the preceding claims, wherein the at least linear radiator comprises a top loaded electrically conducting wire having an electrically conducting element along an end portion thereof, which extend through one or more coils of the at least one helical radiator at least partially along the central longitudinal axis of the at least one helical radiator.

4. The antenna assembly of any one of the preceding claims, wherein the at least one linear radiator comprises a first conductor and a second conductor along an end portion of the first conductor, and wherein:

the first conductor comprises a center core of a coaxial cable, the second conductor comprises a braid soldered at an end of the coaxial cable, and an insulator of the coaxial cable inhibits direct contact between the first and second conductors; or the first conductor comprises an electrically conductive wire or cable, the second conductor comprises a metal tube crimped or soldered at an end portion thereof, and an insulator jacket is between the metal tube and electrically conductive wire or cable; or

the second conductor comprises a single wire or spring.

5. The antenna assembly of any one of the preceding claims, wherein the at least one helical radiator comprises a bottom helical radiator and a top helical radiator, and wherein the at least one linear radiator is between the top and bottom helical radiators.

6. The antenna assembly of any one of the preceding claims, wherein the at least one linear radiator comprises a first conductor and a second conductor along an end portion of the first conductor, the first and second conductors galvanically coupled such that the electrical connection between the first and second conductors allows the antenna assembly to be operable simultaneously in at least two frequency bands.

7. The antenna assembly of any one of the preceding claims, further comprising a circuit board and a matching network on the circuit board.

8. The antenna assembly of claim 7, wherein the antenna assembly terminates with a connector for connecting the antenna assembly to a device such that the antenna assembly depends to a ground plane of the device to excite, and wherein the matching network on the circuit board is between the connector and the helical and linear radiators.

9. A portable wireless device comprising a housing and the antenna assembly of claim 7 or 8, wherein the antenna assembly includes a sheath disposed over the circuit board, the matching network, and the helical and linear radiators, such that the sheath, the circuit board, the matching network, and the helical and linear radiators are external to the housing of the portable wireless device.

10. A multiband antenna assembly comprising:

a helical radiator including an upper portion and a lower portion, the lower portion having wider pitch coils than the upper portion; and

a linear radiator including a first conductor and a second conductor along an end portion thereof, the linear radiator extending through one or more coils of the helical radiator;

whereby the antenna assembly is resonant in at least three frequency bands, including a very high frequency (VHF) band from 136 MHz to 174 MHz, an ultra high frequency (UHF) band from 380 MHz to 527 MHz, and a global positioning system (GPS) frequency band including a frequency of 1575 MHz.

11. The antenna assembly of claim 10, wherein the first and second conductors of the linear radiator respectively comprise a top loaded electrically conducting wire having an electrically conducting element along an end portion thereof, which extend through one or more coils of the helical radiator at least partially along a central longitudinal axis of the helical radiator.

12. The antenna assembly of claim 10 or 11, wherein the antenna assembly is configured such that:

the helical radiator has a total electrical length of about one quarter wavelength ($\lambda/4$) for the VHF band;

the lower, wider pitch portion of the helical radiator has an electrical length of about one quarter wavelength ($\lambda/4$) for the UHF band;

the an electrically conducting wire having an electrically conducting element

the first and second conductors of the linear radiator have a combined electrical length of about one quarter wavelength ($\lambda/4$) for the UHF band; and

the second conductor of the linear radiator has an electrical length of about one quarter wavelength ($\lambda/4$) for the GPS band.

13. The antenna assembly of any one of claims 10 to 12, wherein the wider pitch coils are more responsive and resonant within the UHF band, wherein the upper

narrower pitch coils are operable for introducing another resonance within the VHF band, and wherein the helical radiator is also resonant at a third harmonic within the GPS band.

14. The antenna assembly of any one of claims 10 to 13, further comprising a coil form disposed over the linear radiator, wherein the helical radiator is wound about and thereby supported by the coil form without making direct contact with the linear radiator.

15. The antenna assembly of any one of claims 10 to 14, wherein:

the first and second conductors are galvanically coupled such that the electrical connection between the first and second conductors allows the antenna assembly to be operable simultaneously for the UHF and GPS bands; and/or

the antenna assembly is omnidirectional for at least the UHF and VHF bands.

16. The antenna assembly of any one of claims 10 to 15, further comprising a circuit board, a matching network on the circuit board, and a sheath disposed over the circuit board, the matching network, and the helical and linear radiators, such that the sheath, the circuit board, the matching network, and the helical and linear radiators are external to a housing of the portable wireless device when the antenna assembly is connected to the portable wireless device.

17. A multiband antenna assembly comprising:

a top helical radiator;

a bottom helical radiator spaced apart from the top helical radiator; and

a linear radiator between the top and bottom helical radiators, the linear radiator including a first conductor and a second conductor along an end portion thereof, the linear radiator extending through one or more coils of at least one of the bottom and top helical radiators;

whereby the antenna assembly is resonant in at least three frequency bands, including an ultra high frequency (UHF) band from 380 MHz to 527 MHz, a 7-800 MHz frequency band from 764 MHz to 870 MHz, and a global positioning system (GPS) frequency band including a frequency of 1575 MHz.

18. The antenna assembly of claim 17, wherein the first and second conductors of the linear radiator respectively comprise a top loaded electrically conducting wire having an electrically conducting element along an end portion thereof, which extend at least partially along a central longitudinal axis of the top and bottom helical radiators.

19. The antenna assembly of claim 17 or 18, wherein the antenna assembly is configured such that:

the antenna assembly has a total electrical length of about one half wavelength (λ/2) for the UHF band;

the first and second conductors of the at least one linear radiator have a combined electrical length of about one quarter wavelength (λ/4) for the UHF band;

the bottom helical radiator and the first conductor of the at least one linear radiator each has an electrical length of about one quarter wavelength (λ/4) for the 7-800 MHz frequency band; and

the bottom helical radiator has an electrical length of about one half wavelength (λ/2) for the GPS band.

20. The antenna assembly of any one of claims 17 to 19, further comprising a coil form disposed over the linear radiator, wherein the top helical radiator is wound about and thereby supported by the coil form without making direct contact with the linear radiator.

21. The assembly of any one of claims 17 to 20, wherein a loading gap between the first and second conductors is operable for changing the frequencies ratio for the UHF band and the 7-800 MHz frequency band and/or helps fine tune the frequency ratio between the UHF band and the 7-800 MHz frequency band; and

wherein the bottom helical radiating element couples to the gap, which shifts the resonance of the 7-800 MHz frequency band to a lower frequency while the UHF band resonance is maintained, such that the UHF and GPS bands resonate at the same time.

22. The antenna assembly of any one of claims 17 to 21, wherein:

the first and second conductors are galvanically coupled such that the electrical connection between the first and second conductors allows the antenna assembly to be operable simultaneously at the UHF band and 7-800 MHz frequency band; and/or

the antenna assembly is omnidirectional for at least the UHF band and the 7-800 band.

23. The antenna assembly of any one of claims 17 to 22, further comprising a circuit board, a matching network on the circuit board, and a sheath disposed over the circuit board, the matching network, and the helical and linear radiators, such that the sheath, the circuit board, the matching network, and the helical and linear radiators are external to a housing of the portable wireless device when the antenna assembly is connected to the portable wireless device.

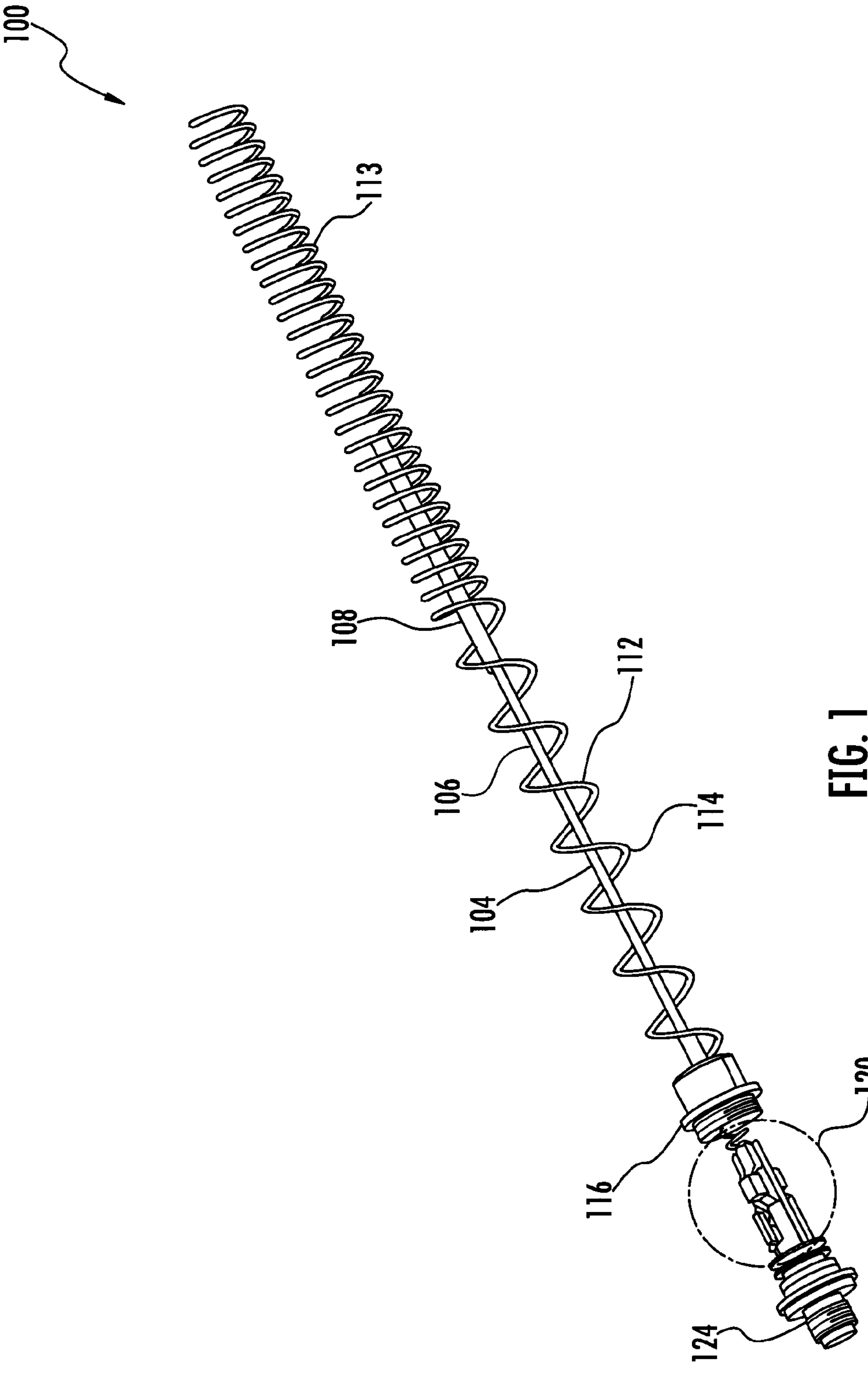


FIG. 1

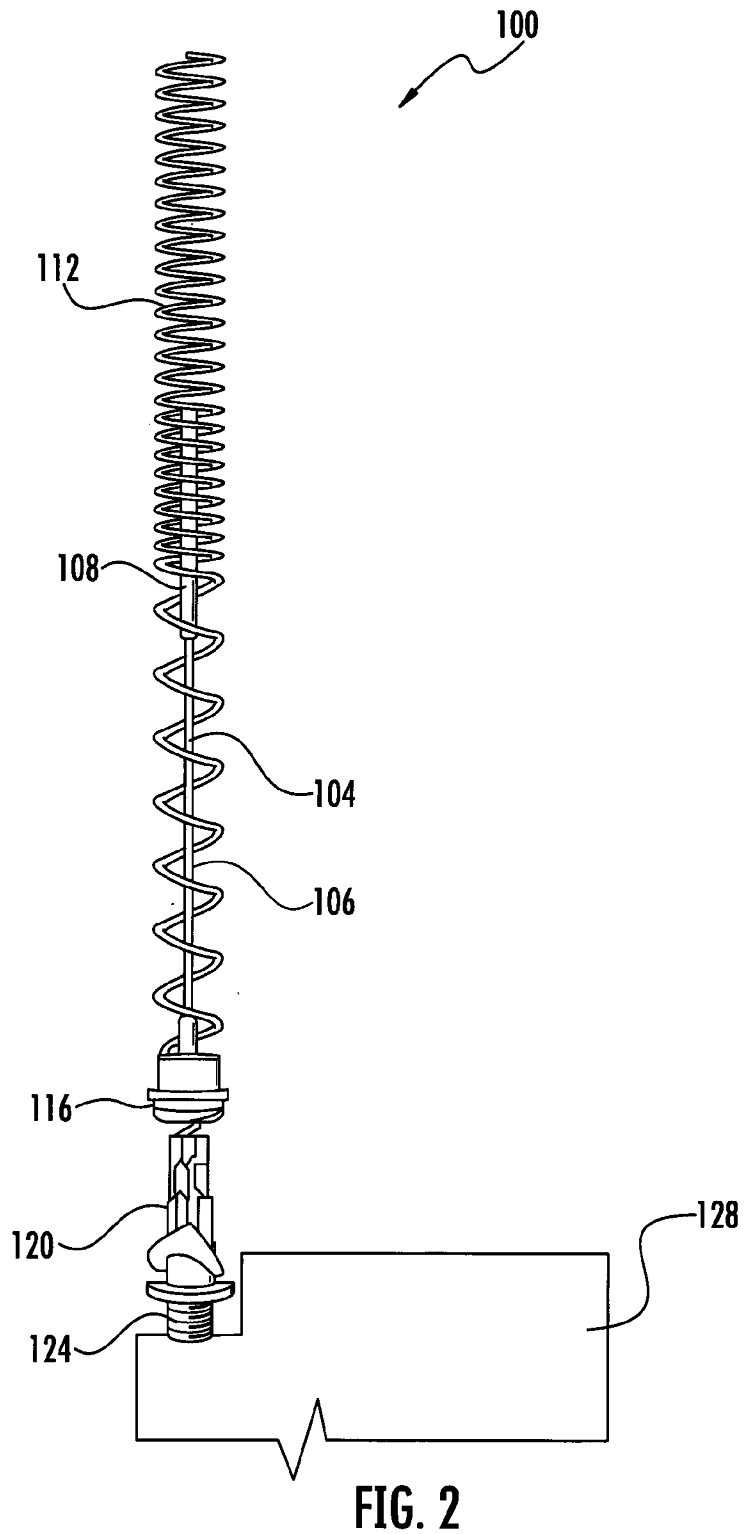


FIG. 2

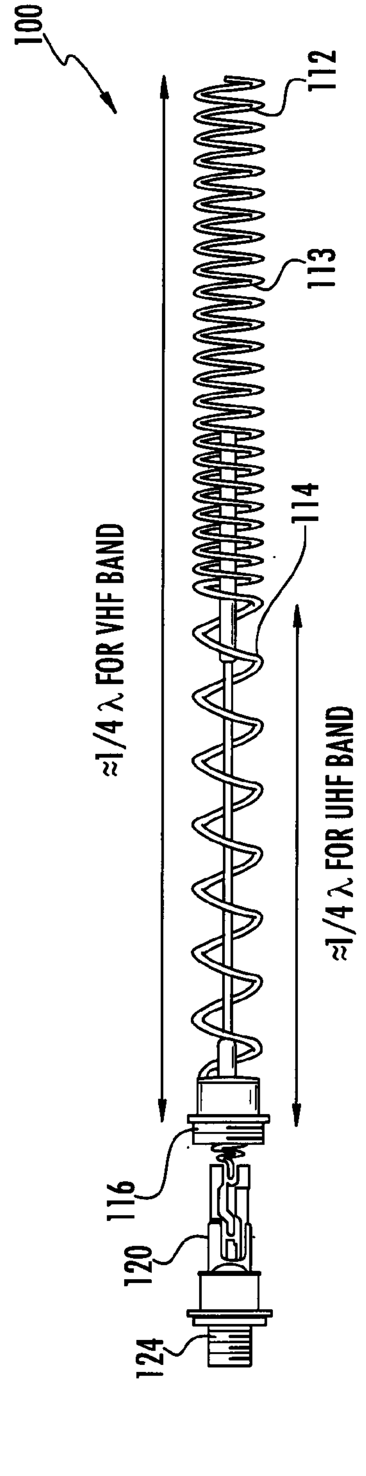

100
112
113
114
≈1/4 λ FOR VHF BAND
≈1/4 λ FOR UHF BAND
116
120
124

FIG. 3A

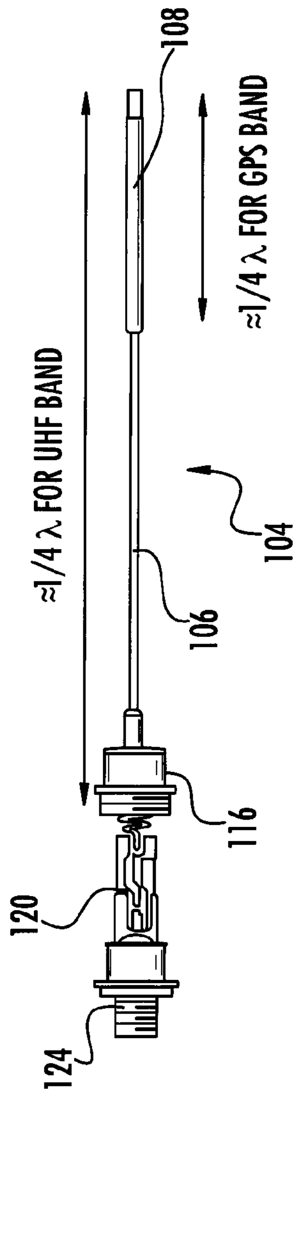

108
≈1/4 λ FOR UHF BAND
≈1/4 λ FOR GPS BAND
104
106
116
120
124

FIG. 3B

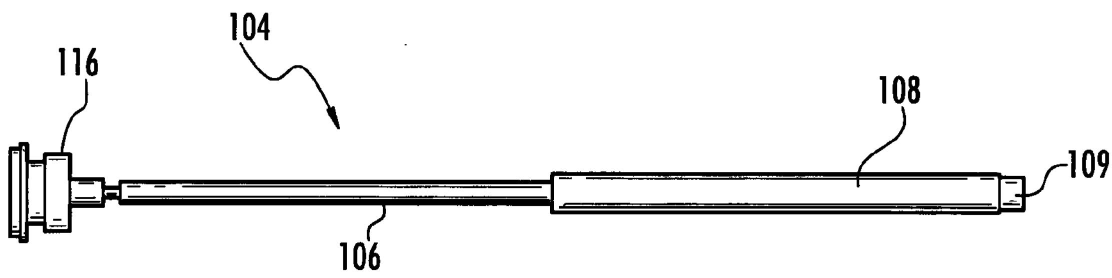


FIG. 4

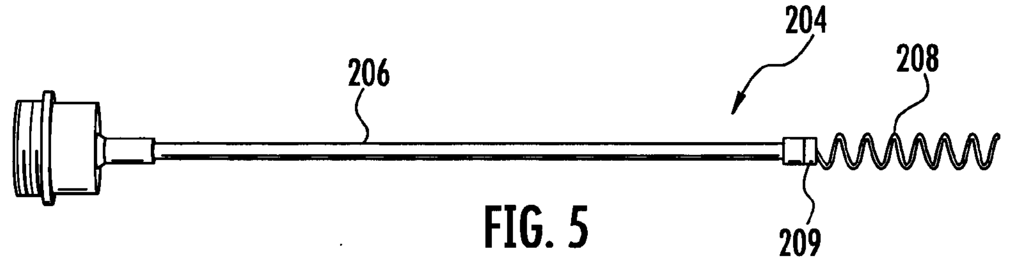


FIG. 5

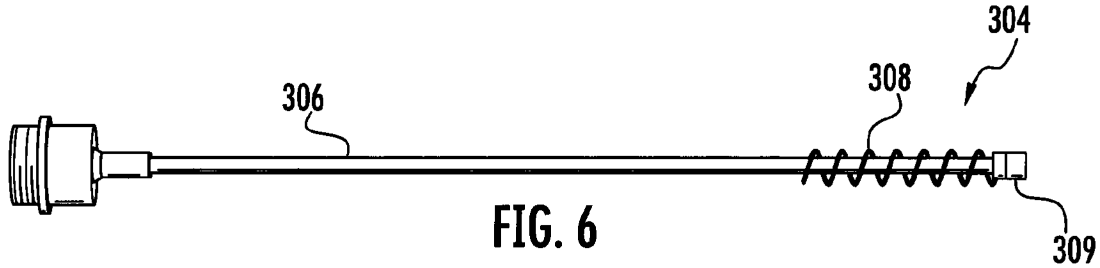


FIG. 6

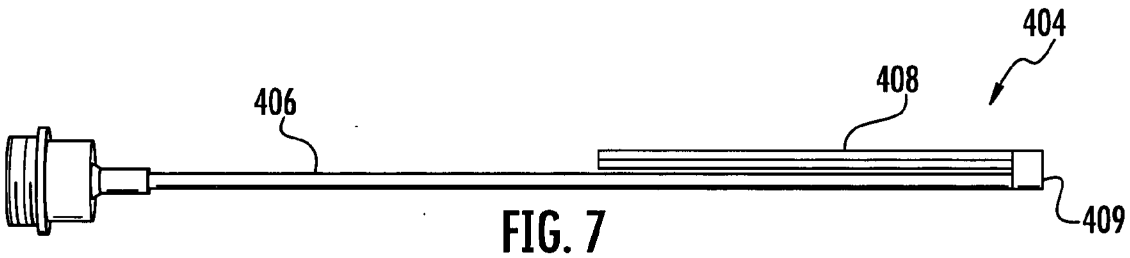


FIG. 7

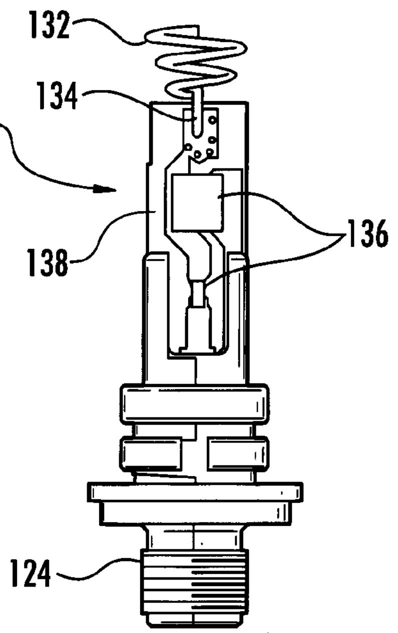


FIG. 8A

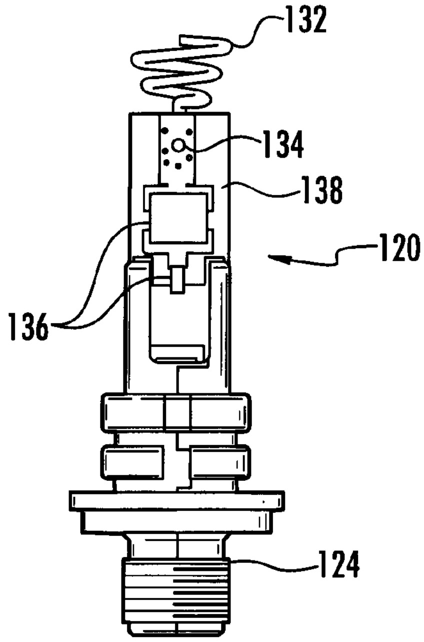


FIG. 8B

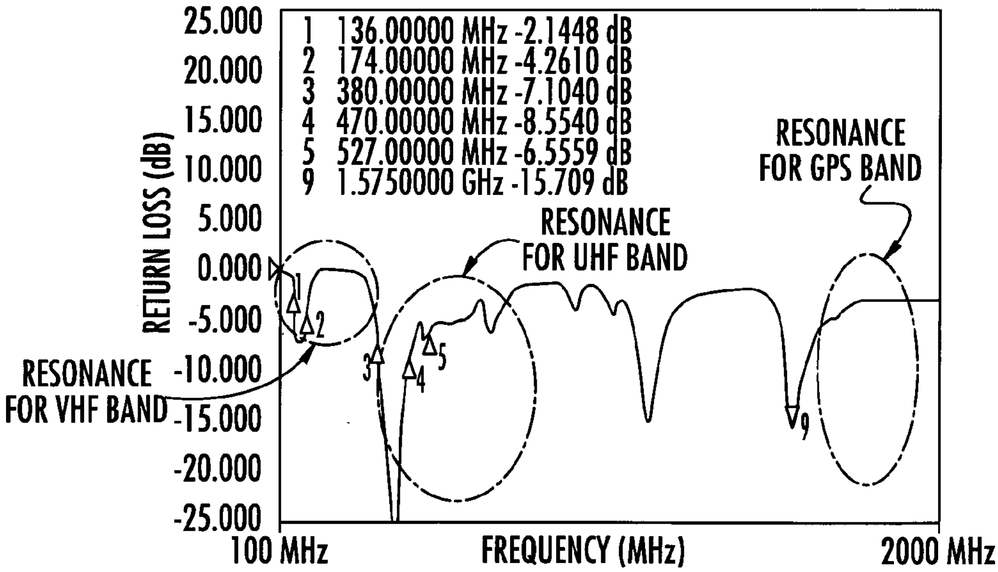


FIG. 9

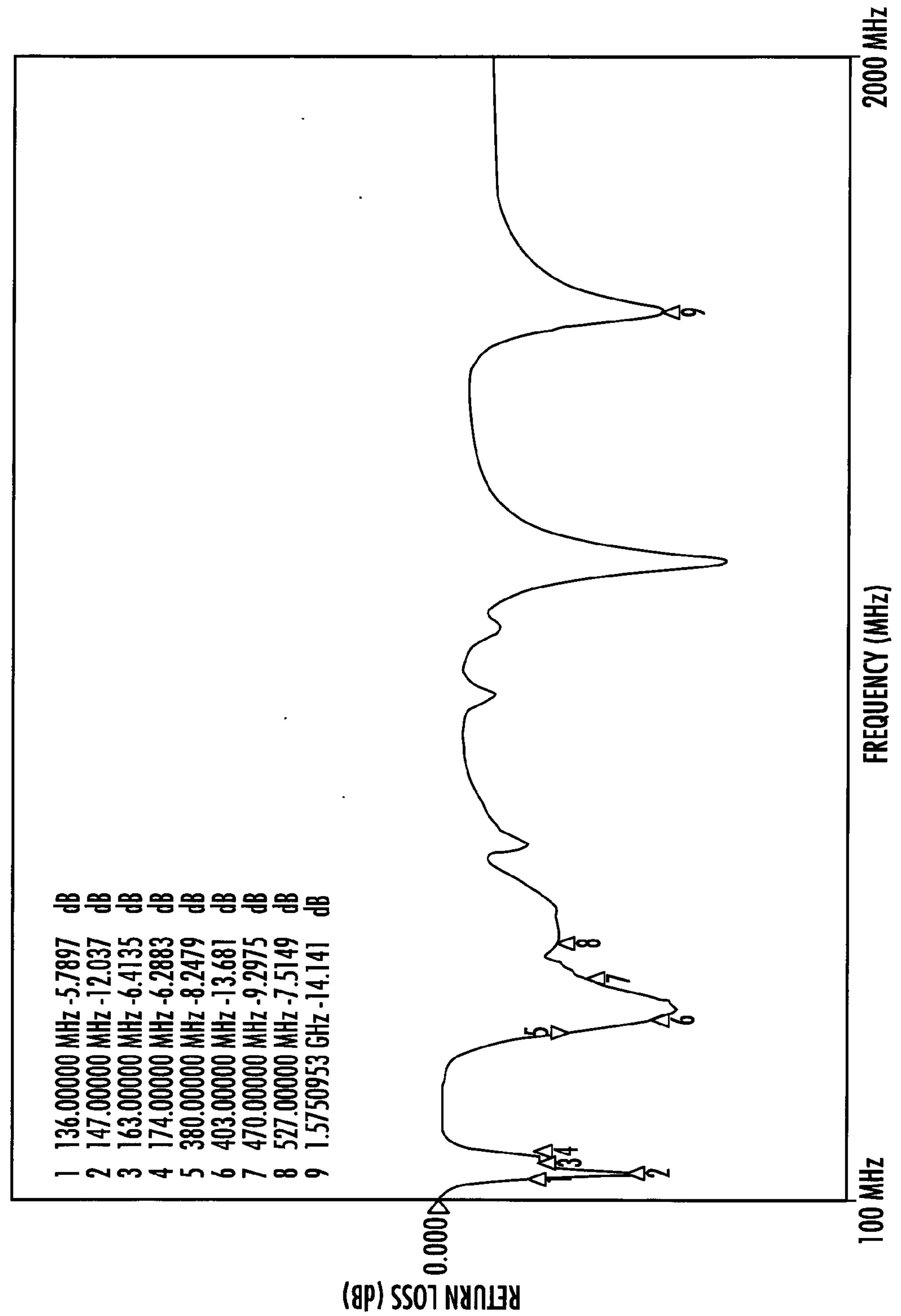

1 136.00000 MHz -5.7897 dB
2 147.00000 MHz -12.037 dB
3 163.00000 MHz -6.4135 dB
4 174.00000 MHz -6.2883 dB
5 380.00000 MHz -8.2479 dB
6 403.00000 MHz -13.681 dB
7 470.00000 MHz -9.2975 dB
8 527.00000 MHz -7.5149 dB
9 1.5750953 GHz -14.141 dB
RETURN LOSS (dB)
0.000
100 MHz
2000 MHz
FREQUENCY (MHz)

FIG. 10

PERFORMANCE SUMMARY DATA VHF 380/UHF GPS

FREQUENCY (MHz)	3D		AZIMUTH		ELEVATION 0		ELEVATION 90		EFFICIENCY	
	EFFICIENCY	MAX GAIN	MAX GAIN	AVERAGE GAIN	MAX GAIN	AVERAGE GAIN	MAX GAIN	AVERAGE GAIN	HORIZONTAL	OPEN SKY
400	71%	0.82	0.50	0.27	0.45	-4.73	0.82	-5.06	49%	
415	80%	1.42	1.03	0.76	0.91	-3.95	1.42	-4.35	53%	
430	77%	1.06	1.03	0.86	0.87	-3.94	1.06	-4.46	52%	
450	80%	1.44	1.24	1.04	1.15	-4.32	1.42	-4.93	51%	
470	76%	1.00	0.92	0.78	0.80	-4.61	1.00	-5.31	51%	
512	58%	0.64	0.62	-0.09	-0.09	-5.55	0.63	-5.91	45%	
527	64%	1.07	1.07	0.37	0.49	-5.35	1.06	-5.88	47%	
1570	64%	2.10	0.29	-1.72	1.53	-2.21	1.87	-4.33		30%
1575	64%	2.10	0.17	-1.89	1.55	-2.03	1.86	-4.31		31%
1580	64%	2.25	0.12	-2.15	1.76	-1.97	1.69	-4.35		31%

FREQUENCY (MHz)	VHF AZIMUTH	
	MAX GAIN	AVG GAIN
136	-9.67	-12.08
147	-6.55	-8.89
155	-5.53	-7.72
163	-5.42	-7.26
174	-6.41	-7.80

FIG. 11

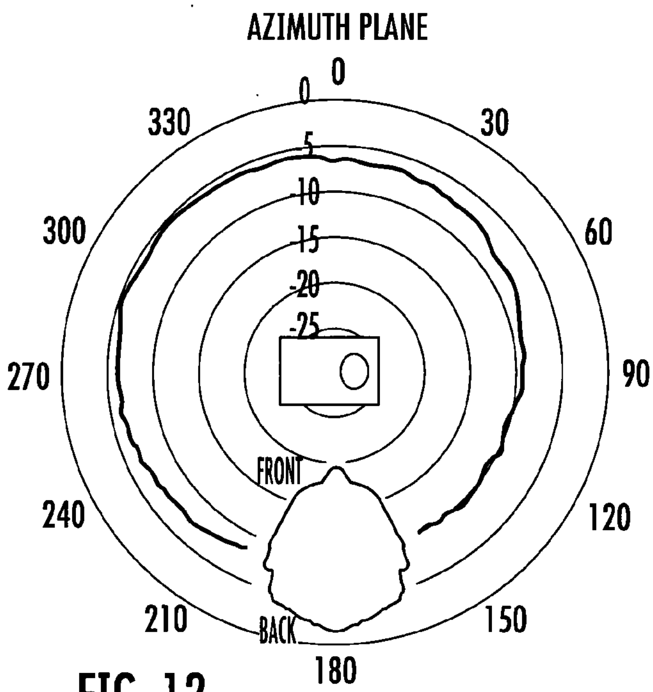


FIG. 12

@155 MHz (HAND HELD)

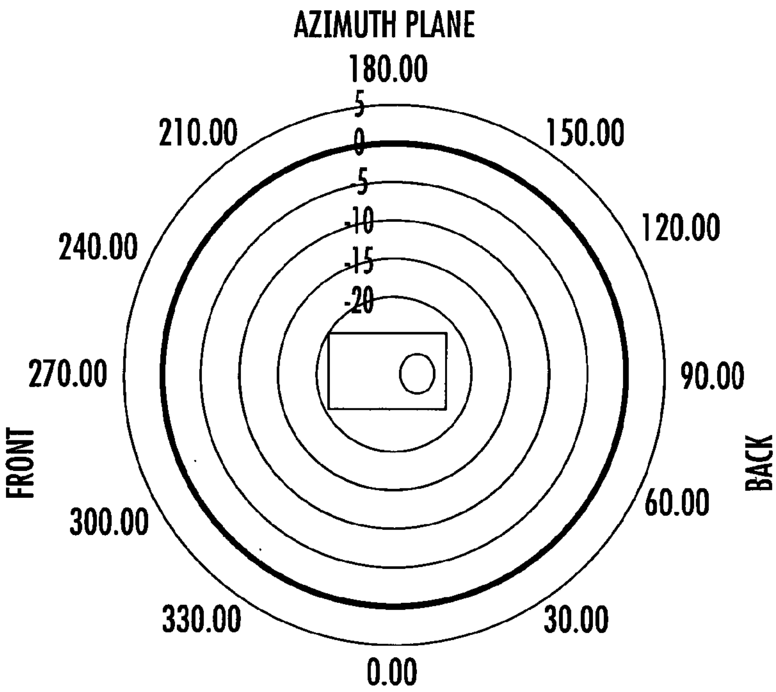


FIG. 13

@400 MHz (FREE SPACE)

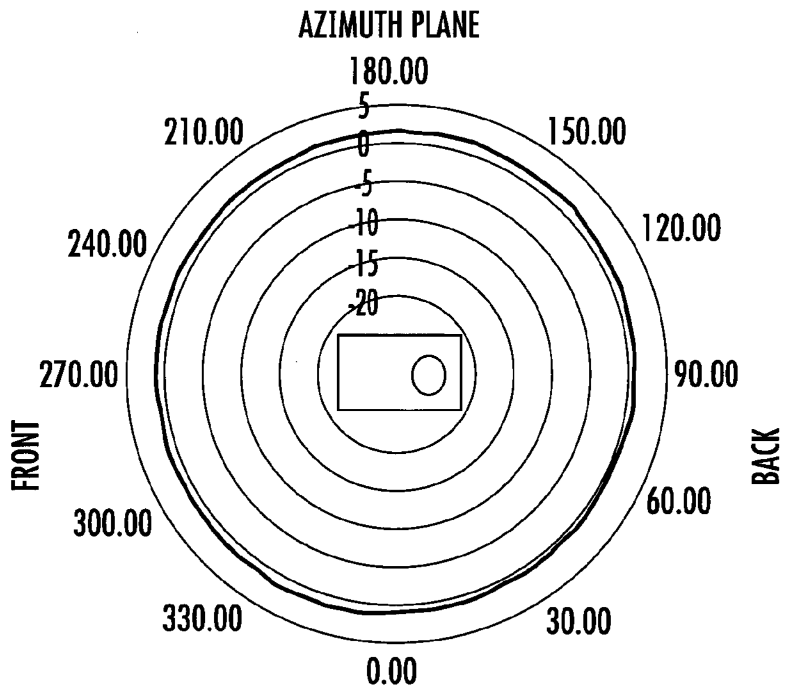


FIG. 14

@450 MHz (FREE SPACE)

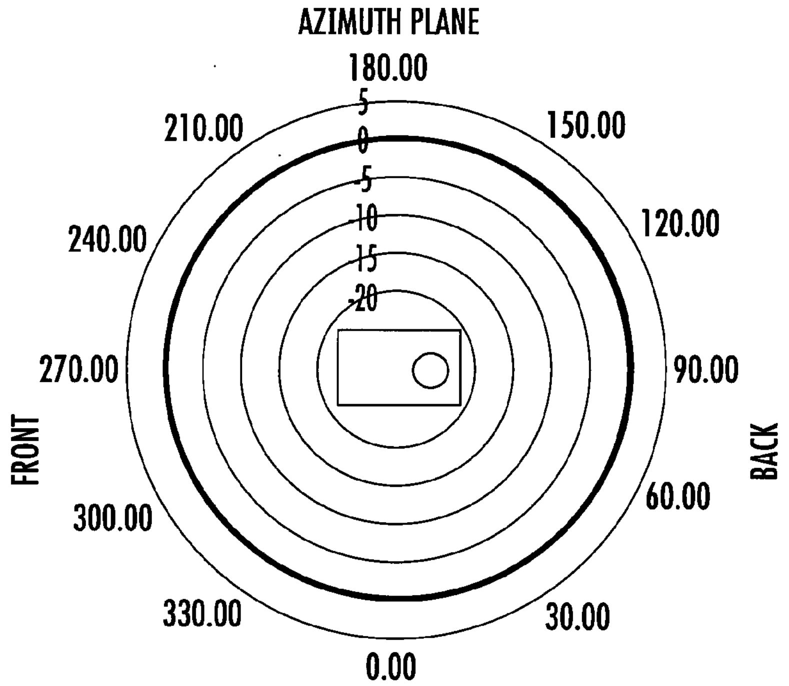
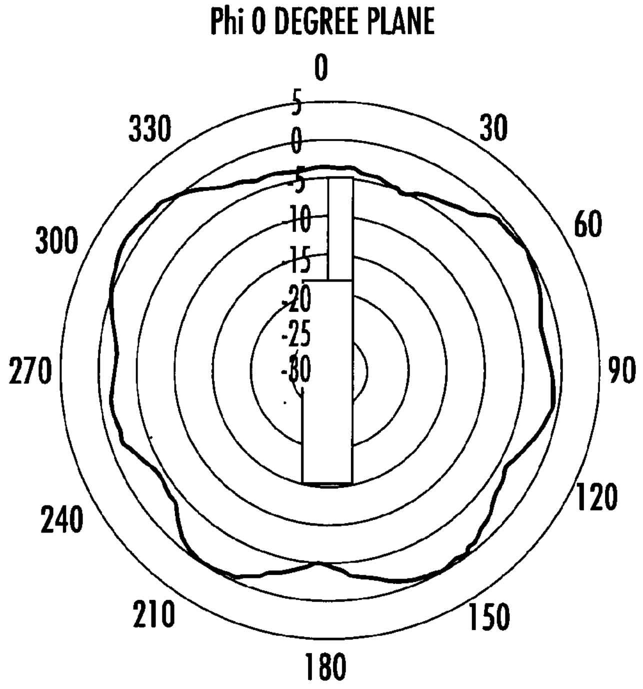


FIG. 15

@512 MHz (FREE SPACE)



@1575 MHz (FREE SPACE)

FIG. 16

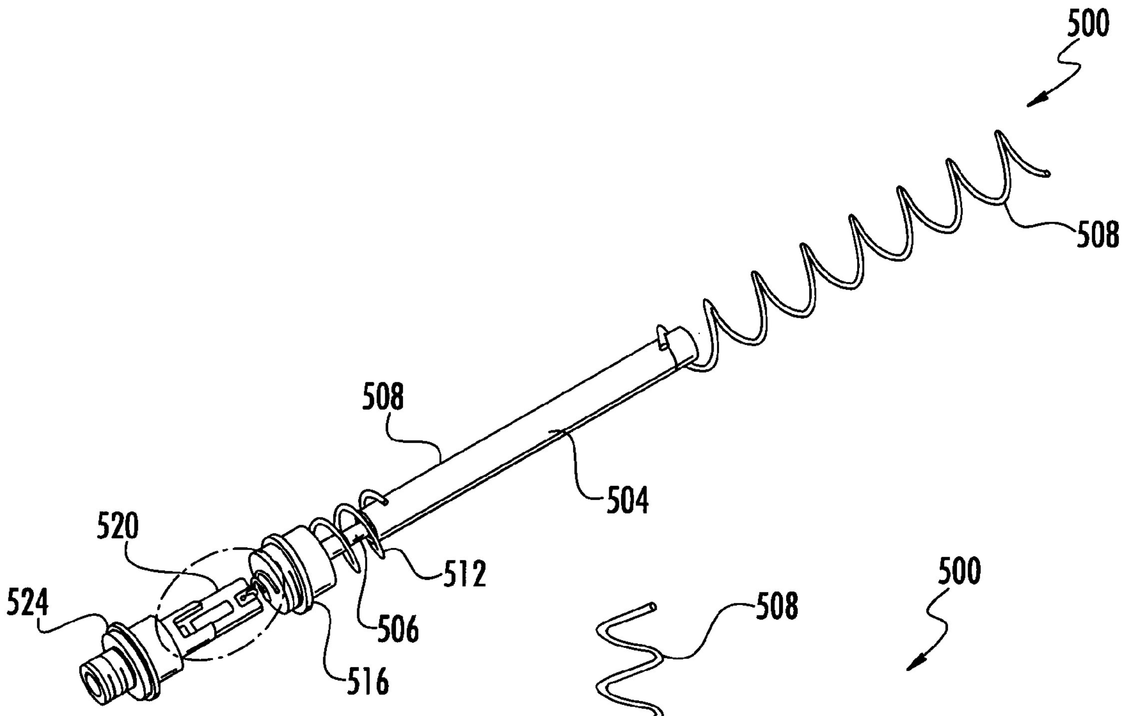

500
508
508
504
520
512
524
506
516

FIG. 17

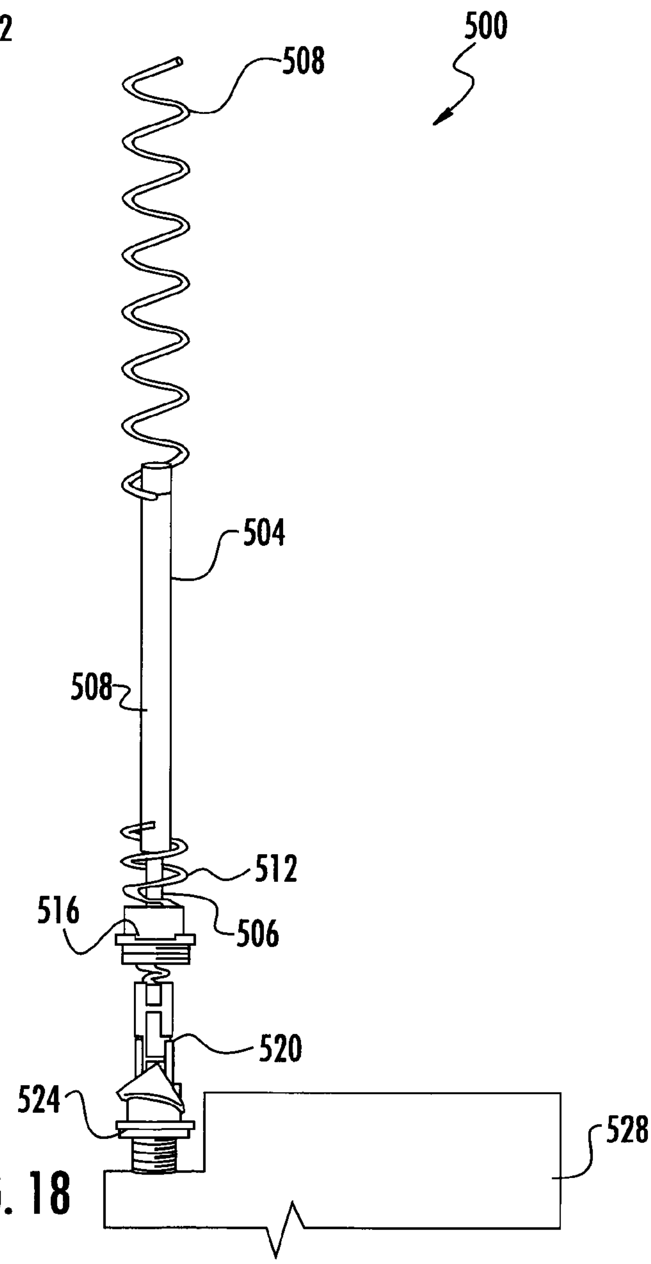

500
508
504
508
512
516
506
520
524
528

FIG. 18

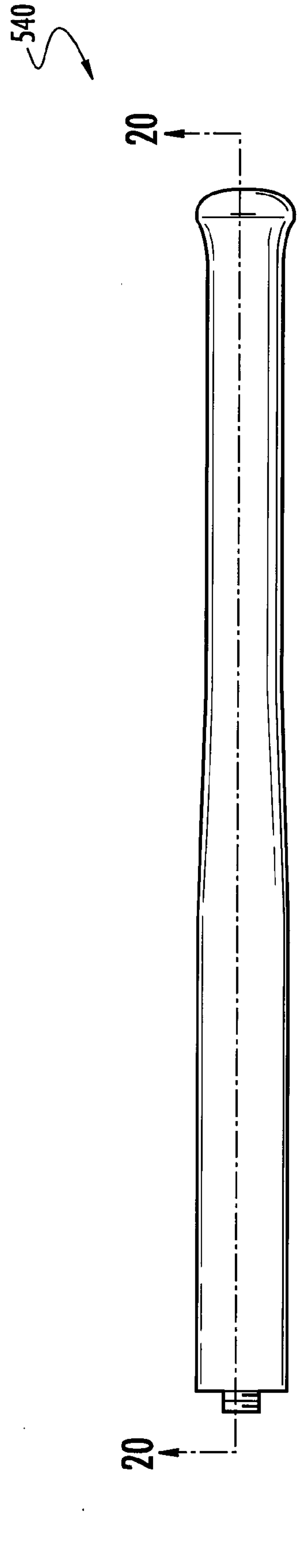


FIG. 19

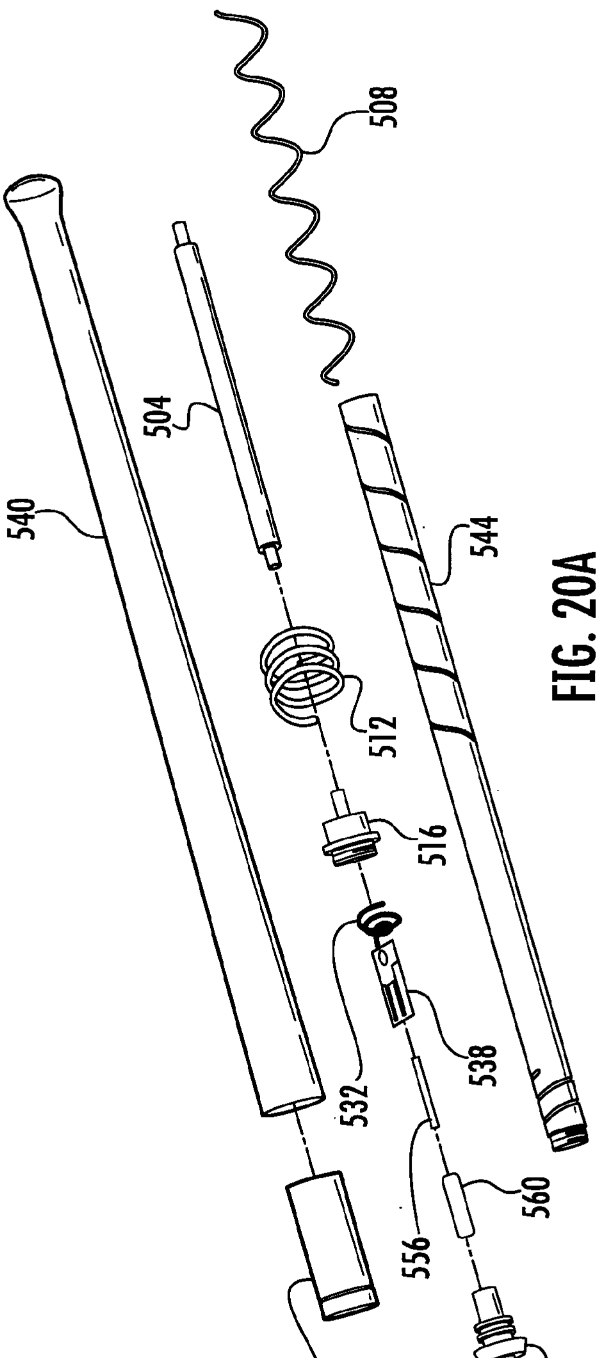


FIG. 20A

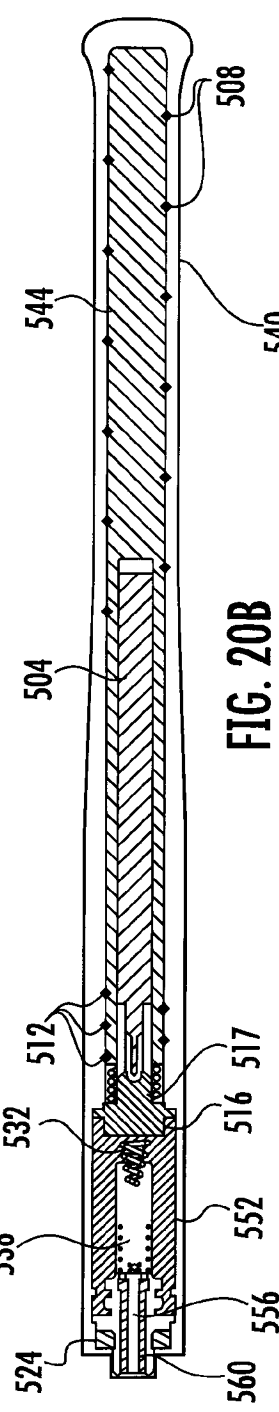


FIG. 20B

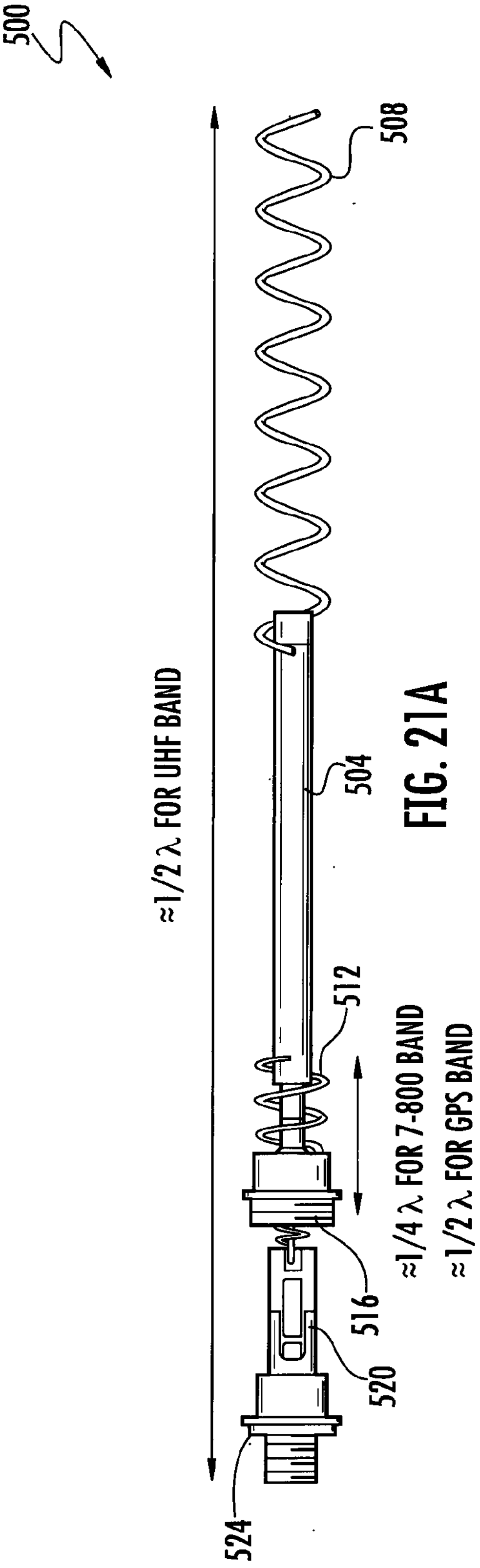


FIG. 21A

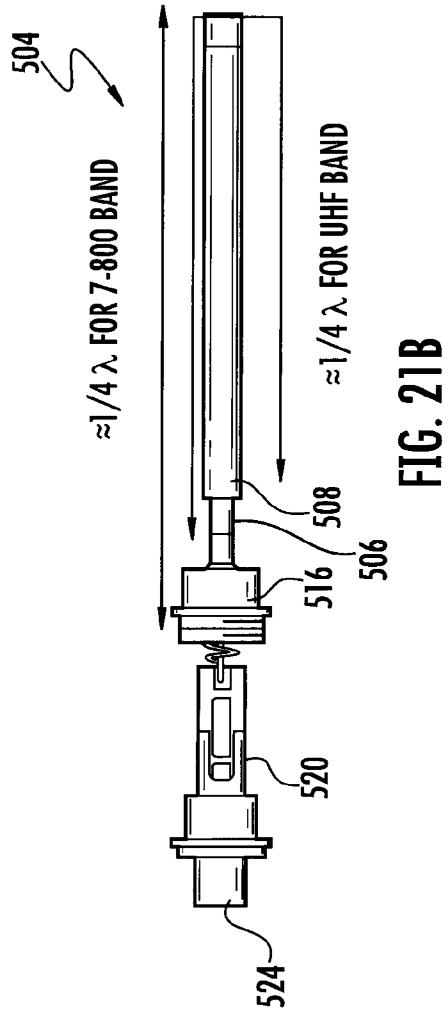


FIG. 21B

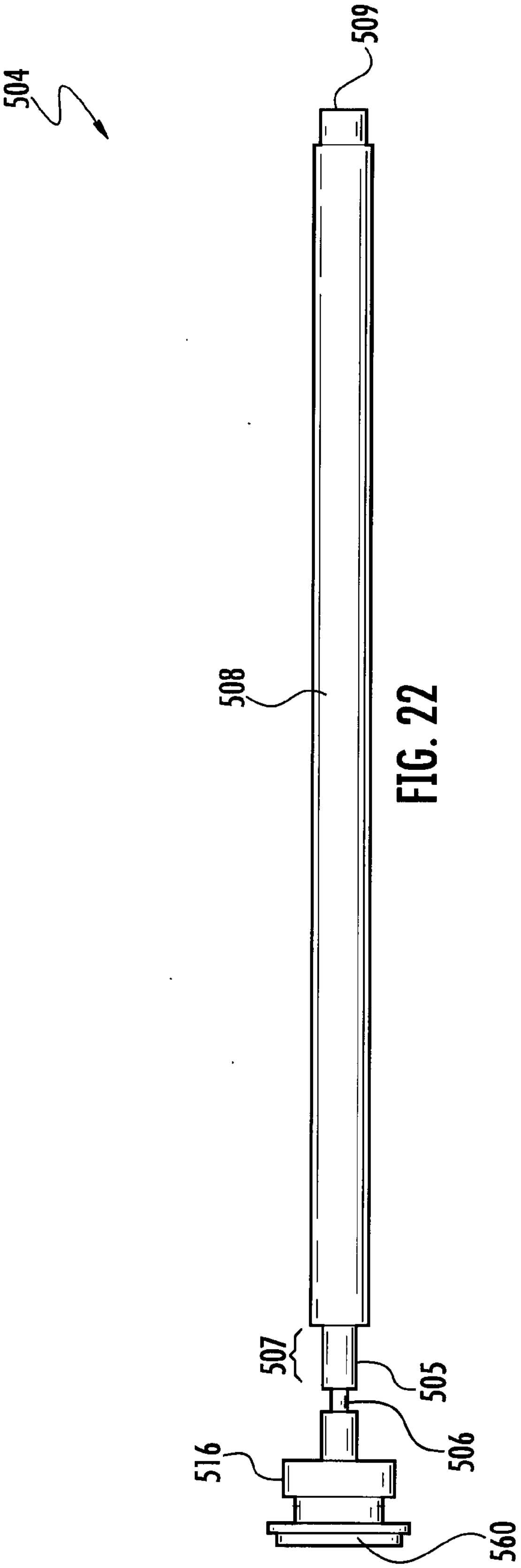


FIG. 22

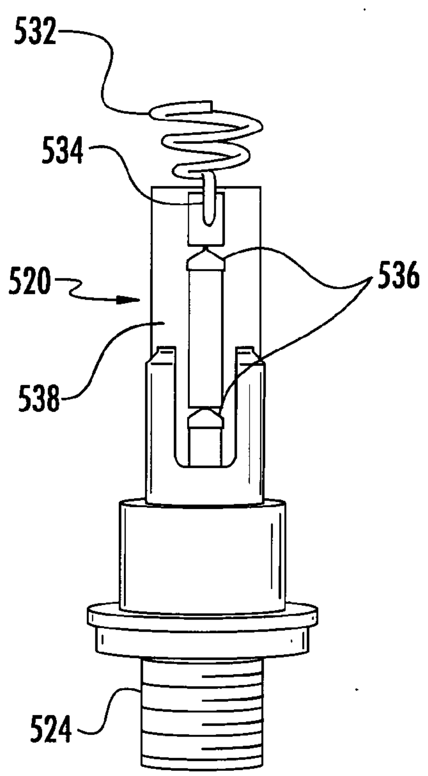


FIG. 23A

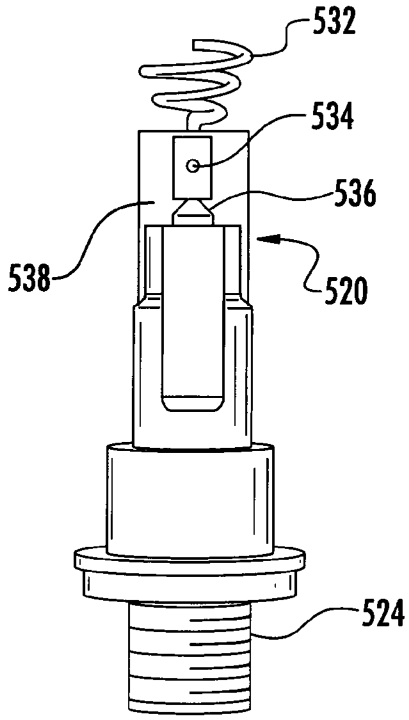


FIG. 23B

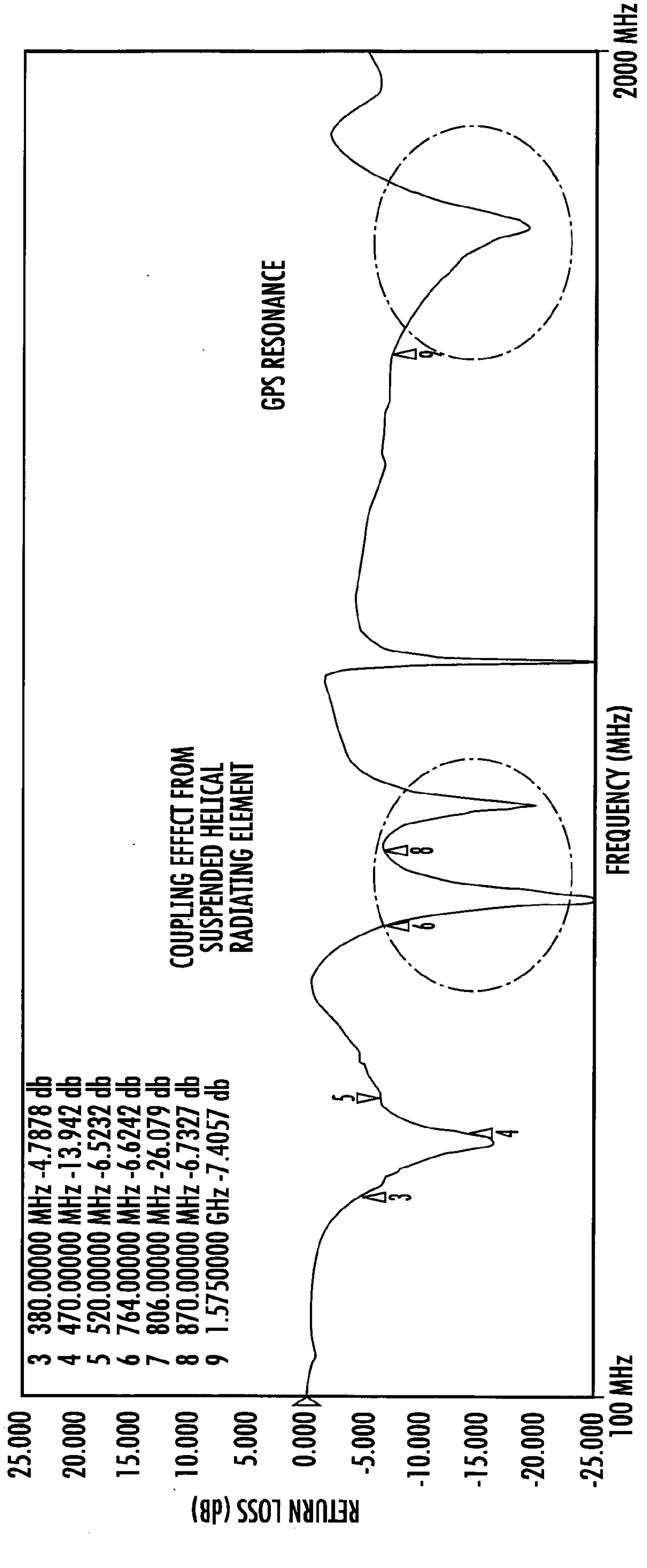

3 380.00000 MHz -4.7878 db
4 470.00000 MHz -13.942 db
5 520.00000 MHz -6.5232 db
6 764.00000 MHz -6.6242 db
7 806.00000 MHz -26.079 db
8 870.00000 MHz -6.7327 db
9 1.5750000 GHz -7.4057 db
COUPLING EFFECT FROM SUSPENDED HELICAL RADIATING ELEMENT
GPS RESONANCE
RETURN LOSS (dB)
25.000
20.000
15.000
10.000
5.000
0.000
-5.000
-10.000
-15.000
-20.000
-25.000
100 MHz
FREQUENCY (MHz)
2000 MHz

FIG. 24

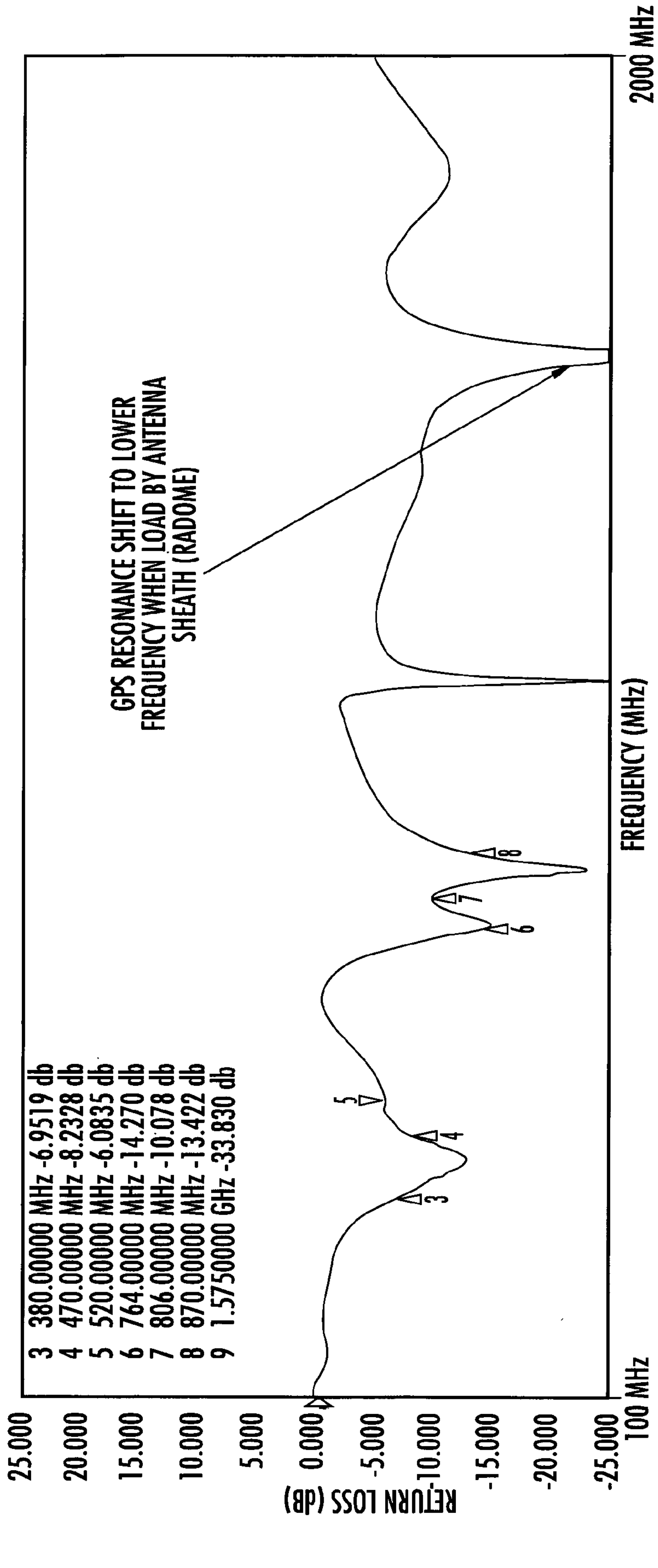

3 380.00000 MHz -6.9519 db
4 470.00000 MHz -8.2328 db
5 520.00000 MHz -6.0835 db
6 764.00000 MHz -14.270 db
7 806.00000 MHz -10.078 db
8 870.00000 MHz -13.422 db
9 1.5750000 GHz -33.830 db
GPS RESONANCE SHIFT TO LOWER FREQUENCY WHEN LOAD BY ANTENNA SHEATH (RADOME)
RETURN LOSS (dB)
25.000
20.000
15.000
10.000
5.000
0.000
-5.000
-10.000
-15.000
-20.000
-25.000
100 MHz
2000 MHz
FREQUENCY (MHz)
3
4
5
6
7
8

FIG. 25

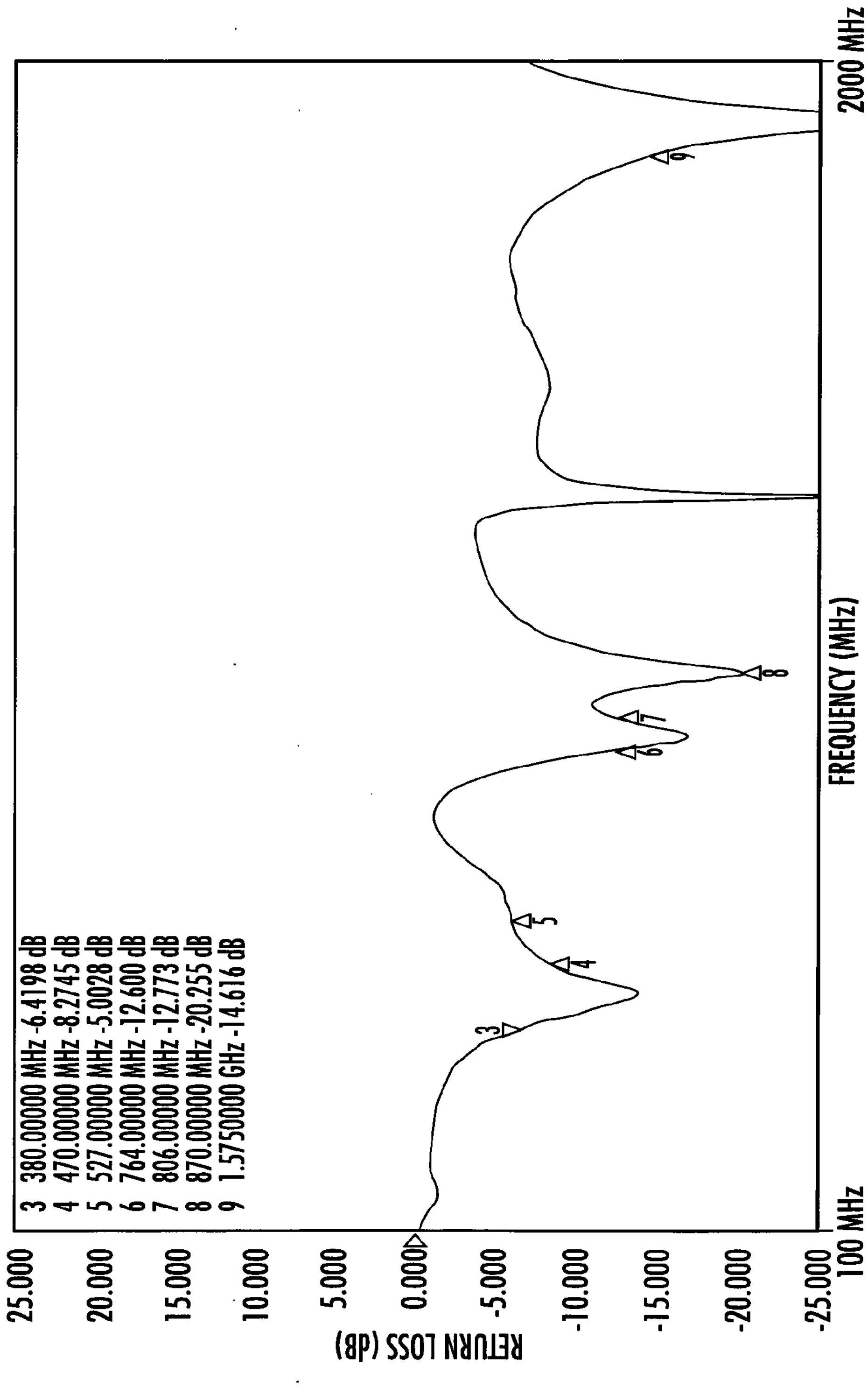

3 380.00000 MHz -6.4198 dB
4 470.00000 MHz -8.2745 dB
5 527.00000 MHz -5.0028 dB
6 764.00000 MHz -12.600 dB
7 806.00000 MHz -12.773 dB
8 870.00000 MHz -20.255 dB
9 1.5750000 GHz -14.616 dB
RETURN LOSS (dB)
25.000
20.000
15.000
10.000
5.000
0.000
-5.000
-10.000
-15.000
-20.000
-25.000
100 MHz
2000 MHz
FREQUENCY (MHz)

FIG. 26

PERFORMANCE SUMMARY DATA

BAND	FREQUENCY (MHz)	3D		AZIMUTH		ELEVATION 0		ELEVATION 90		EFF	EFF
		EFFICIENCY	MAX GAIN	MAX GAIN	AVERAGE GAIN	MAX GAIN	AVERAGE GAIN	MAX GAIN	AVERAGE GAIN	HORIZONTAL	OPEN SKY
UHF	400	57%	-0.10	-0.47	-0.68	-0.44	-5.63	-0.11	-5.94	44%	
	430	78%	1.23	1.16	1.05	1.16	-4.01	1.16	-4.57	53%	
	470	76%	1.03	0.95	0.78	0.97	-4.64	0.87	-5.22	52%	
	512	61%	0.89	0.81	0.20	0.38	-5.84	0.88	-5.86	46%	
	520	60%	1.00	0.97	0.19	0.39	-5.87	0.98	-6.00	46%	
7-800	764	76%	3.31	2.42	-0.63	2.70	-4.74	3.29	-5.64	42%	
	806	70%	2.78	2.22	-0.44	1.89	-4.56	2.76	-4.61	43%	
	830	69%	2.52	2.29	0.19	1.13	-4.47	2.52	-4.65	46%	
	870	66%	2.83	2.58	1.24	1.49	-4.54	2.83	-5.85	49%	
GPS	1575	67%	2.10	-1.47	-5.04	1.68	-1.11	1.64	-4.29		36%

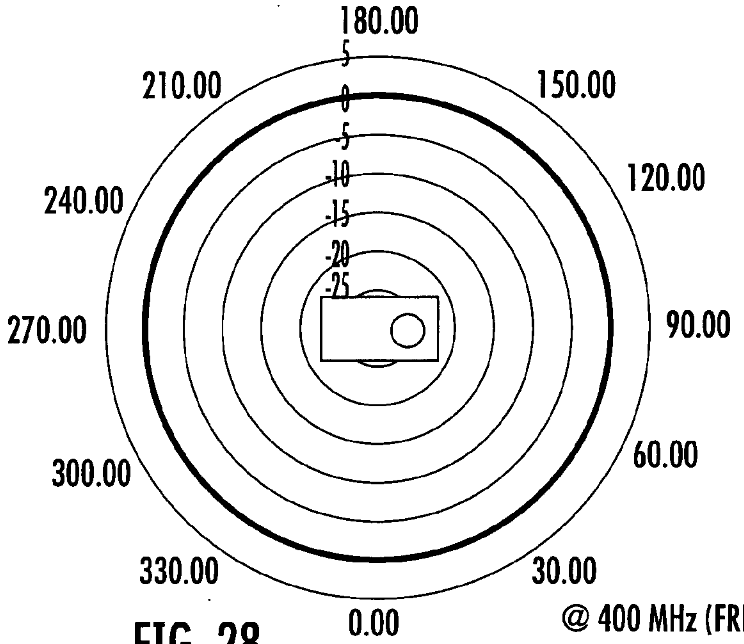
AVERAGE EFFICIENCY
66% (UHF BAND)
70% (7-800 MHz BAND)
67% (GPS BAND)

AVERAGE NEAR HORIZONTAL EFFICIENCY
48% (UHF BAND)
45% (7-800 MHz BAND)

OPEN SKY EFFICIENCY
36% (GPS BAND)

FIG. 27

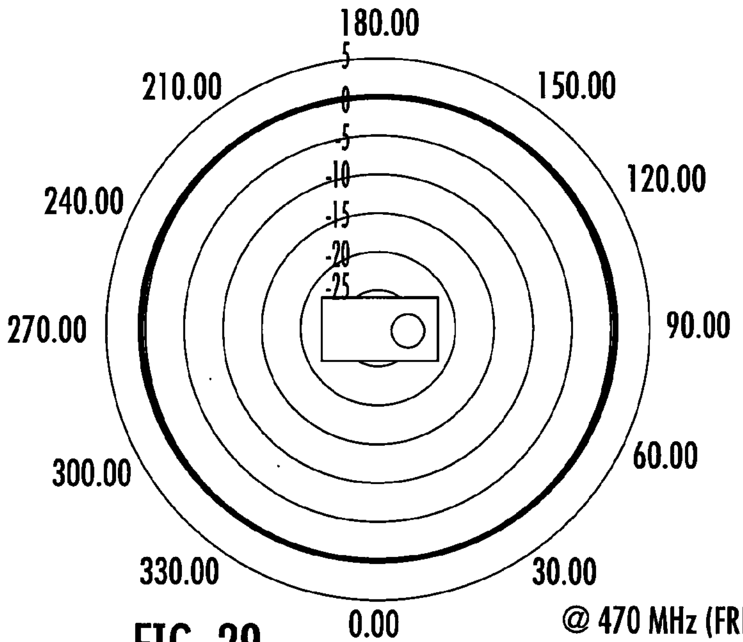
AZIMUTH PLANE



@ 400 MHz (FREE SPACE)

FIG. 28

AZIMUTH PLANE



@ 470 MHz (FREE SPACE)

FIG. 29

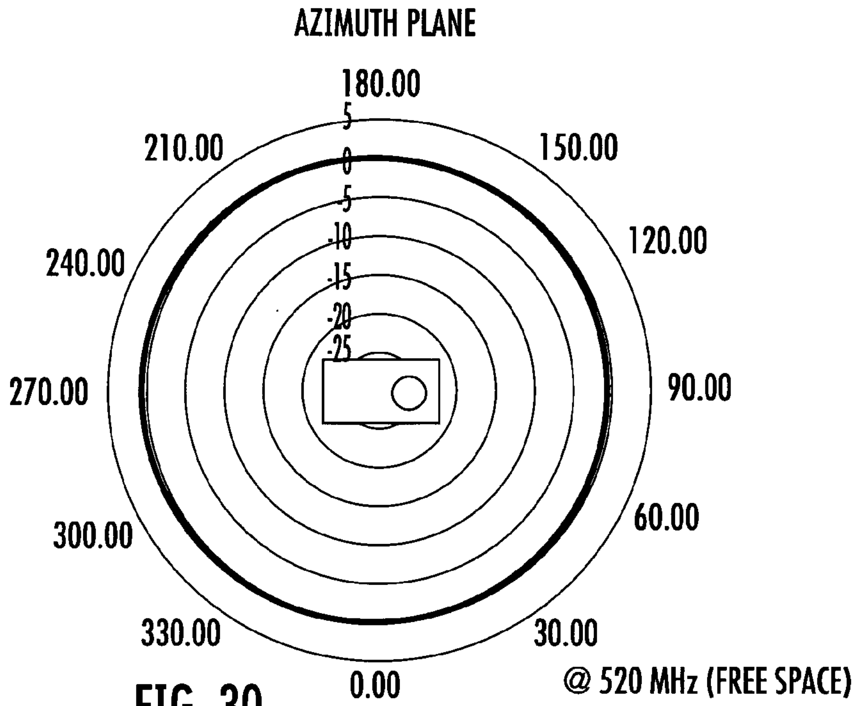

AZIMUTH PLANE
180.00
210.00
150.00
240.00
120.00
270.00
90.00
300.00
60.00
330.00
30.00
0.00
5
0
-5
-10
-15
-20
-25
@ 520 MHz (FREE SPACE)

FIG. 30

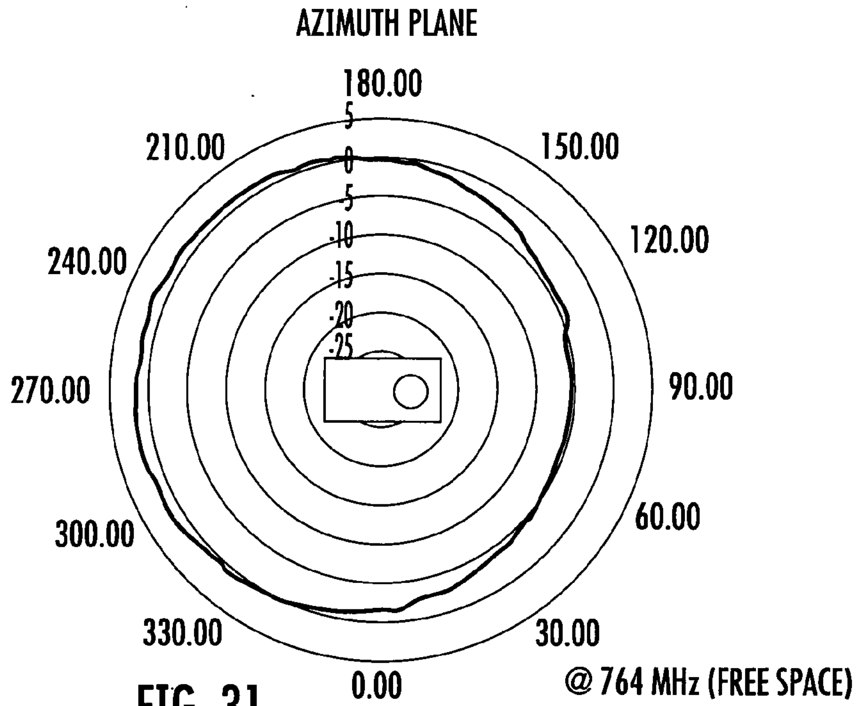

AZIMUTH PLANE
180.00
210.00
150.00
240.00
120.00
270.00
90.00
300.00
60.00
330.00
30.00
0.00
5
0
-5
-10
-15
-20
-25
@ 764 MHz (FREE SPACE)

FIG. 31

AZIMUTH PLANE

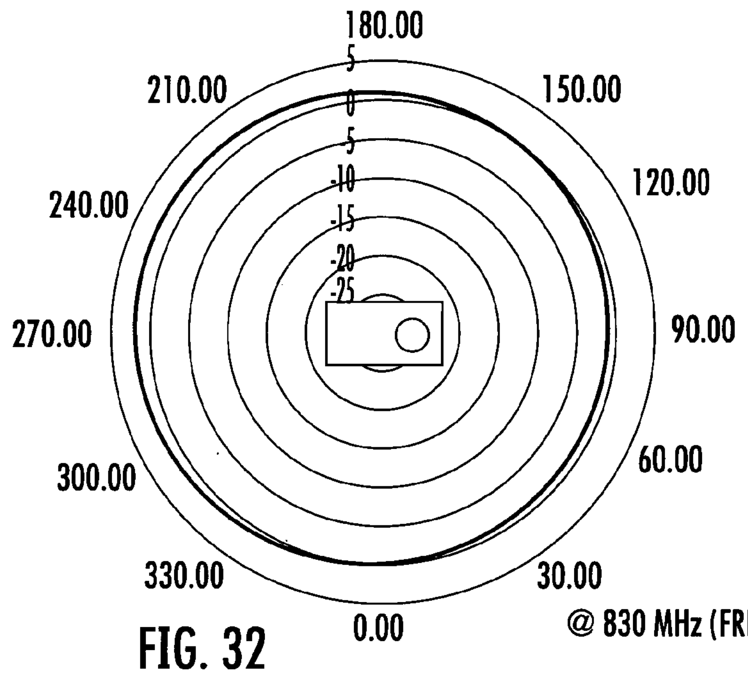


FIG. 32

@ 830 MHz (FREE SPACE)

AZIMUTH PLANE

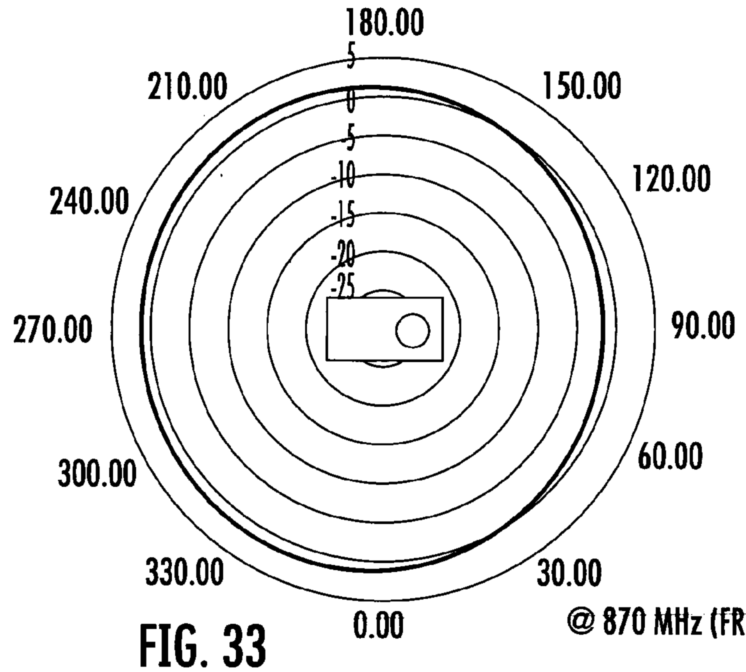


FIG. 33

@ 870 MHz (FREE SPACE)

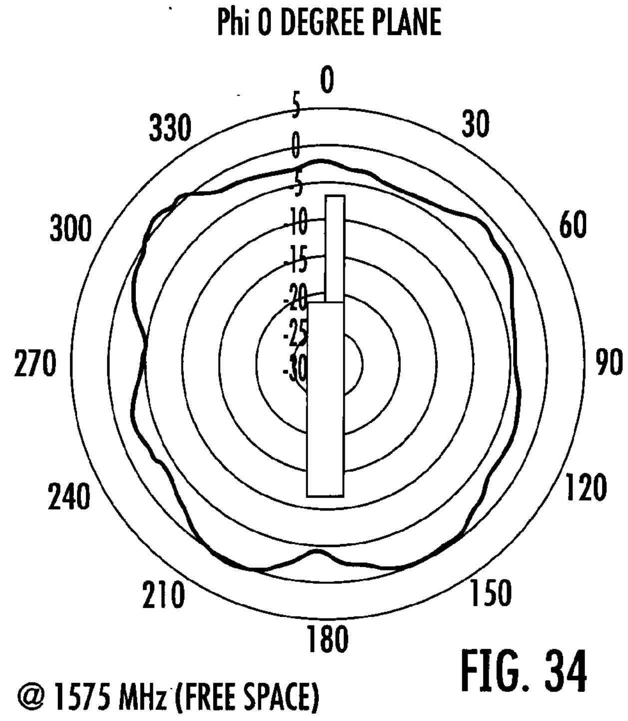

Phi 0 DEGREE PLANE
0
30
60
90
120
150
180
210
240
270
300
330
5
0
-5
-10
-15
-20
-25
-30
@ 1575 MHz (FREE SPACE)

FIG. 34

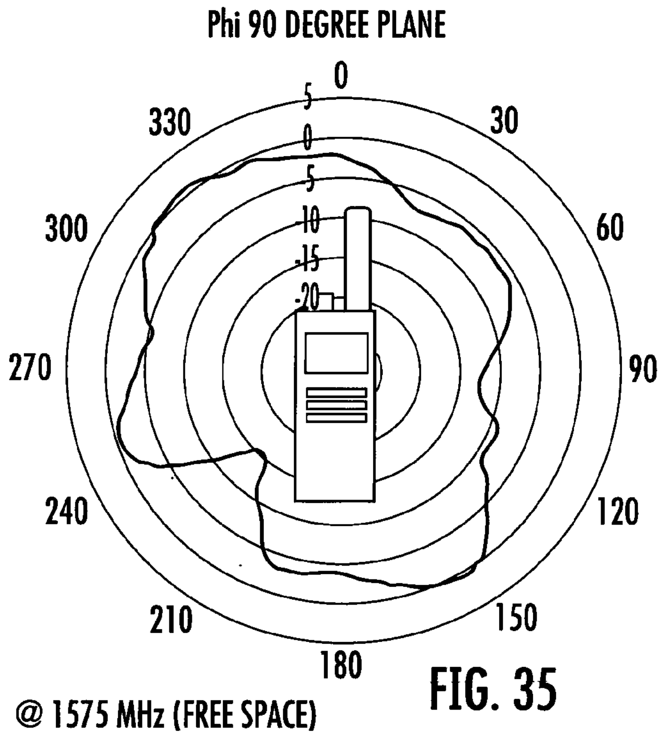

Phi 90 DEGREE PLANE
0
30
60
90
120
150
180
210
240
270
300
330
5
0
-5
-10
-15
-20
@ 1575 MHz (FREE SPACE)

FIG. 35

INTERNATIONAL SEARCH REPORT

International application No.
PCT/MY2011/000194

A. CLASSIFICATION OF SUBJECT MATTER

H01Q 5/00(2006.01)i, H01Q 1/24(2006.01)i, H01Q 1/10(2006.01)i

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

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
H01Q 5/00; H01Q 1/50; H01Q 1/36; H01Q 1/24

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched
Korean utility models and applications for utility models
Japanese utility models and applications for utility models

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
eKOMPASS(KIPO internal) & Keywords:helical,linear,omni,UHF,GPS,VHF,radiator,coaxial,multi,rod,circuit,matching

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y A	US 2009-0219220 A1 (STEPHEN L. KERSTEN et al.) 03 September 2009 See abstract,paragraphs [0012]-[0015],claims 1,8 and figures 1-3	1,2,7-10,13,16,17,23 3-6,11,12,14,15,18-22
Y A	US 2004-0189535 A1 (YOUNG JOON KIM) 30 September 2004 See paragraphs [0066]-[0080],[0099]-[0102] and figures 3A-3H,5,6	1,2,7-10,13,16,17,23 3-6,11,12,14,15,18-22
Y A	US 2007-0120747 A1 (ALEJANDRO CANDAL et al.) 31 May 2007 See abstract,paragraphs[0023]-[0037] and figures 1-4	1,2,9,10,17 3-8,11-16,18-23
Y A	US 2005-0243012 A1 (BYUNG-HOON RYOU et al.) 03 November 2005 See abstract,paragraphs [0069]-[0072] and figures 10a-10d	1,2,9,10,17 3-8,11-16,18-23

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

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

Date of the actual completion of the international search	Date of mailing of the international search report
16 MARCH 2012 (16.03.2012)	**20 MARCH 2012 (20.03.2012)**

Name and mailing address of the ISA/KR	Authorized officer
Korean Intellectual Property Office Government Complex-Daejeon, 189 Cheongsa-ro, Seo-gu, Daejeon 302-701, Republic of Korea	Byeon Jong Gil
Facsimile No. 82-42-472-7140	Telephone No. 82-42-481-8719

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No.
PCT/MY2011/000194

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US 2009-0219220 A1	03.09.2009	US 7817103 B2	19.10.2010
		WO 2009-108735 A1	03.09.2009
US 2004-0189535 A1	30.09.2004	CA 2465665 A1	08.05.2003
		CN 1633734 A	29.06.2005
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US 2007-0120747 A1	31.05.2007	None	
US 2005-0243012 A1	03.11.2005	AU 2002-315830 A1	06.01.2004
		CN 1630961 A	22.06.2005
		EP 1516387 A1	23.03.2005
		JP 04-067049 B2	26.03.2008
		JP 2005-536088 A	24.11.2005
		US 7132998 B2	07.11.2006
		WO 04-001896 A1	31.12.2003