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(54) GROUND PLANE BOOSTER ANTENNA TECHNOLOGY FOR WEARABLE DEVICES

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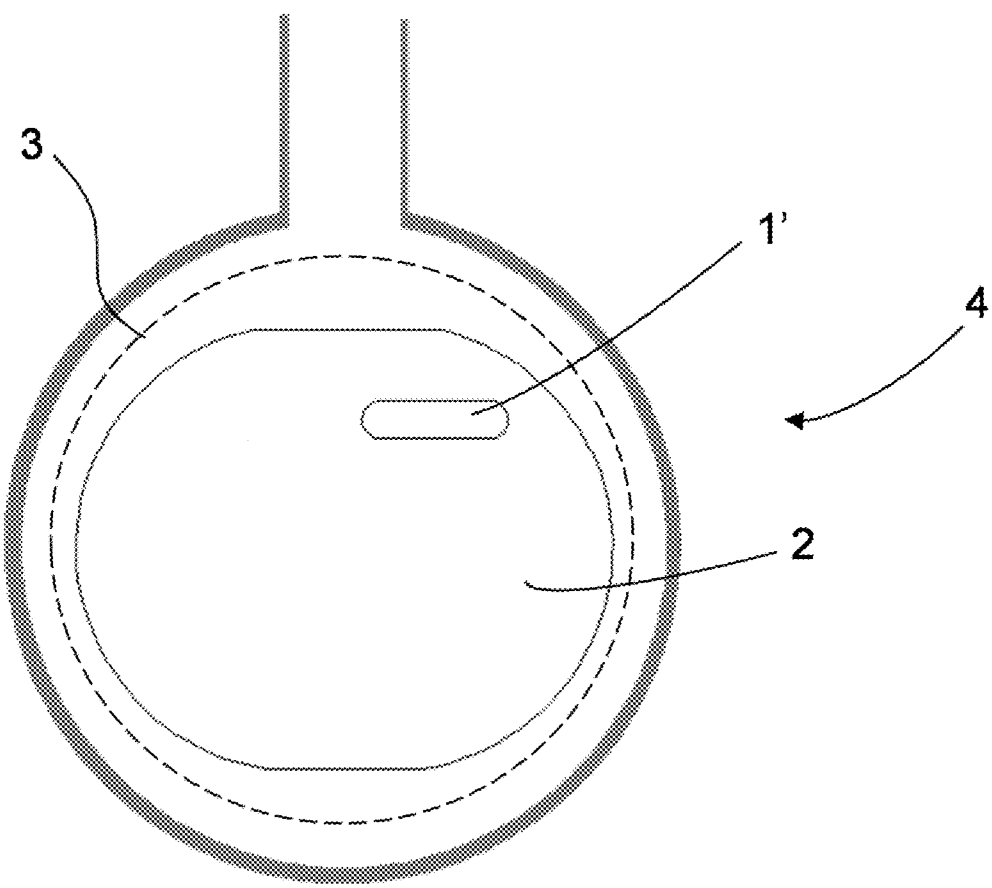
H01Q 9/04	(2006.01)
H01Q 1/24	(2006.01)

(52) **U.S. Cl.**

CPC ***H01Q 1/273*** (2013.01); ***H01Q 9/0407*** (2013.01); ***H01Q 1/245*** (2013.01); ***H01Q 1/48*** (2013.01); ***H01Q 1/526*** (2013.01)

(57) **ABSTRACT**

A wireless wearable device comprises a radiating system that contains at least a non-resonant element disposed in different arrangements within a radiating structure in the radiating system, featuring compact dimensions and an adequate performance when operating on a carrier living body.



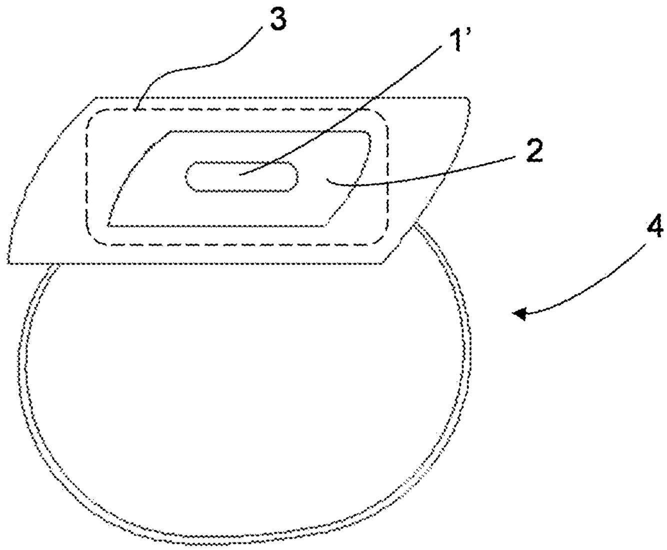


Fig. 1

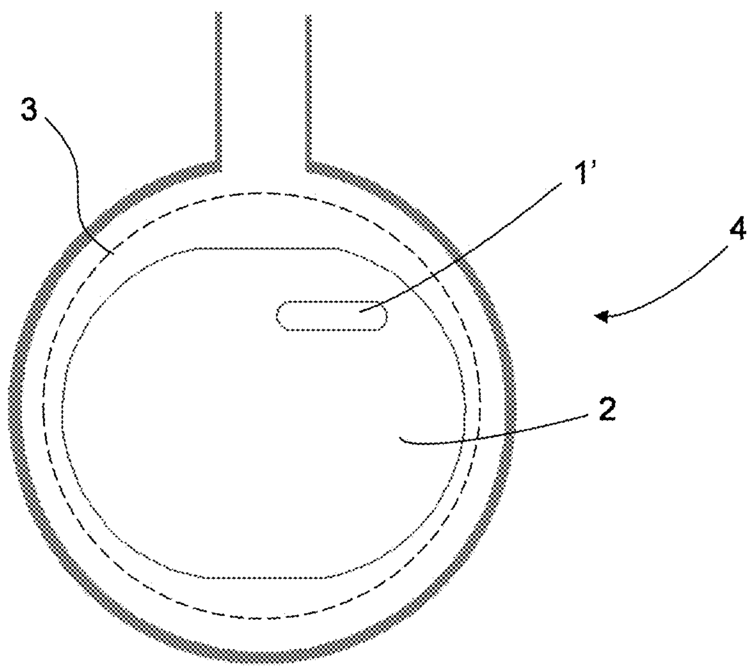


Fig. 2

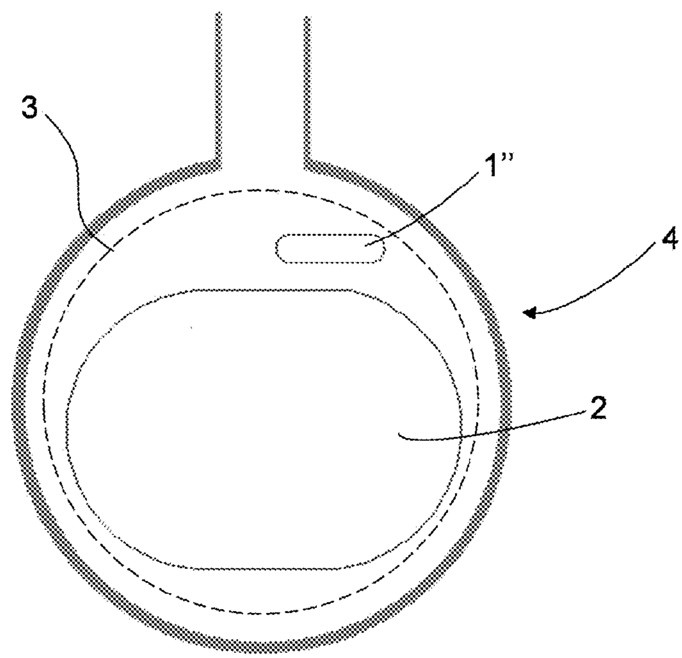


Fig. 3

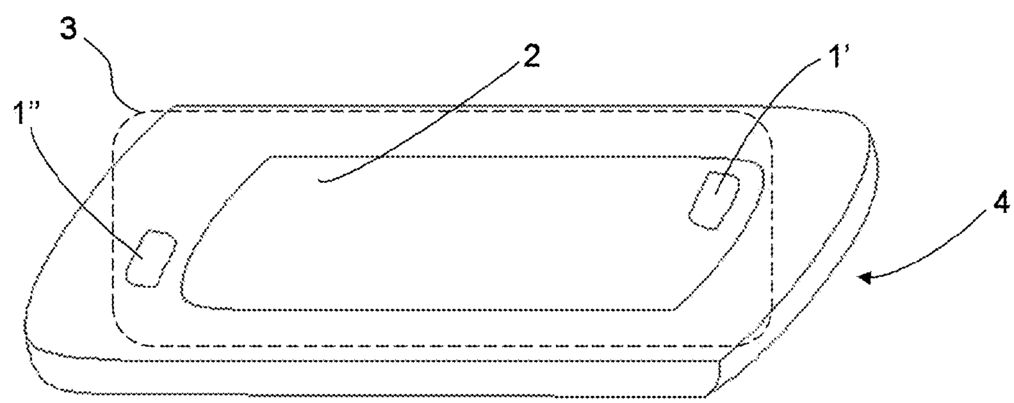


Fig. 4

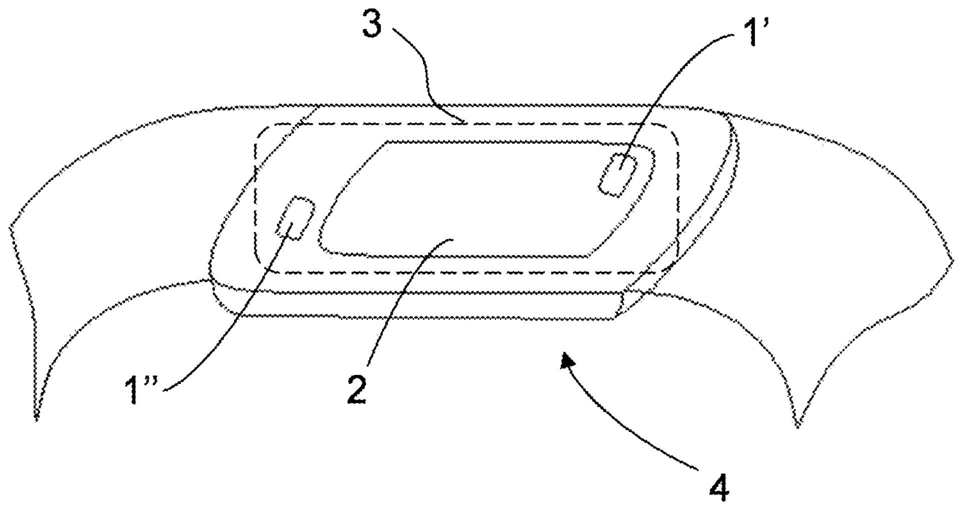


Fig. 5

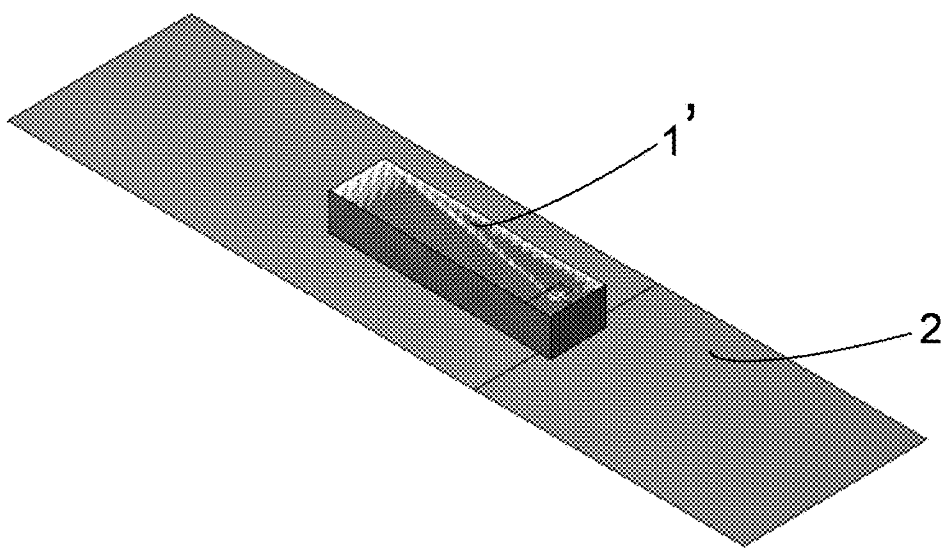


Fig. 6a

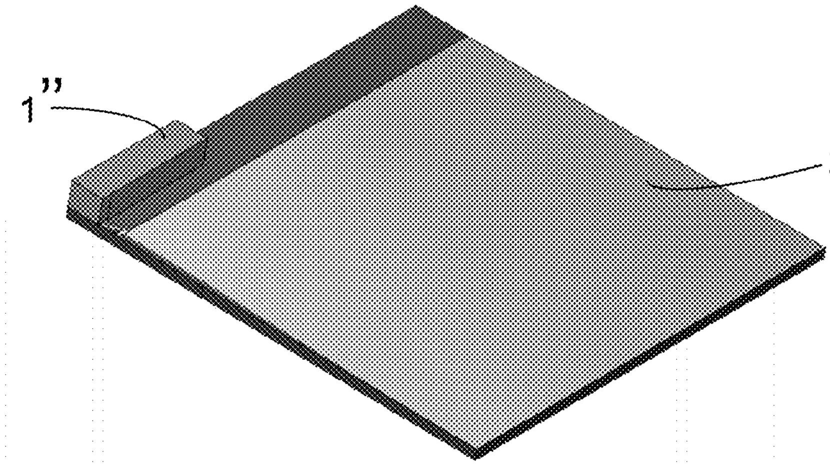


Fig. 6b

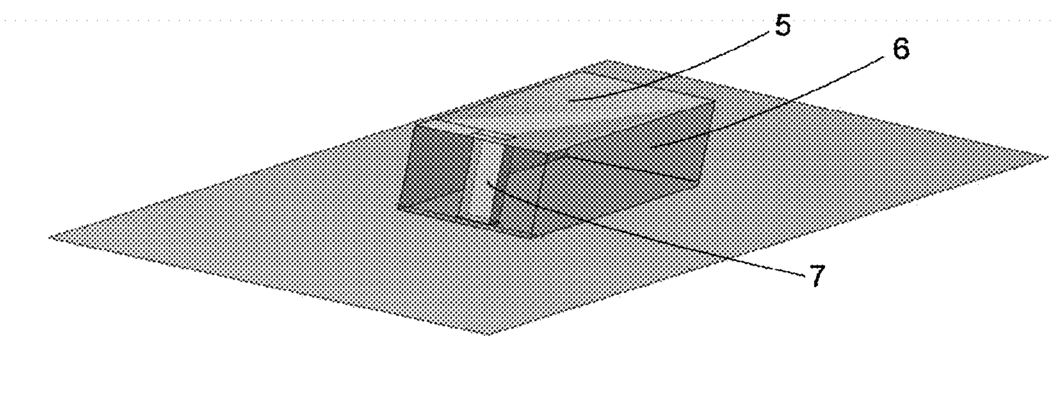


Fig. 7

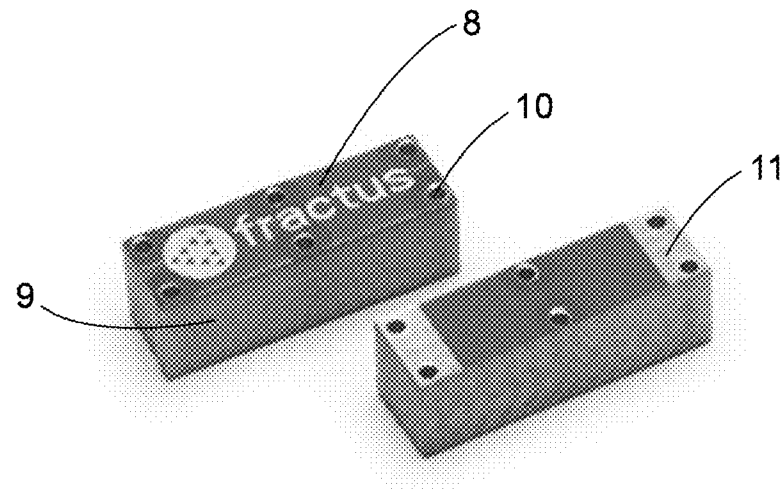


Fig. 8a

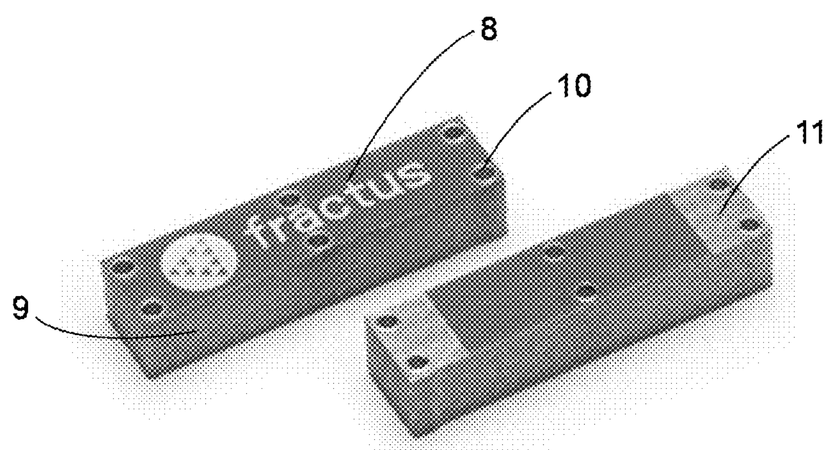


Fig. 8b

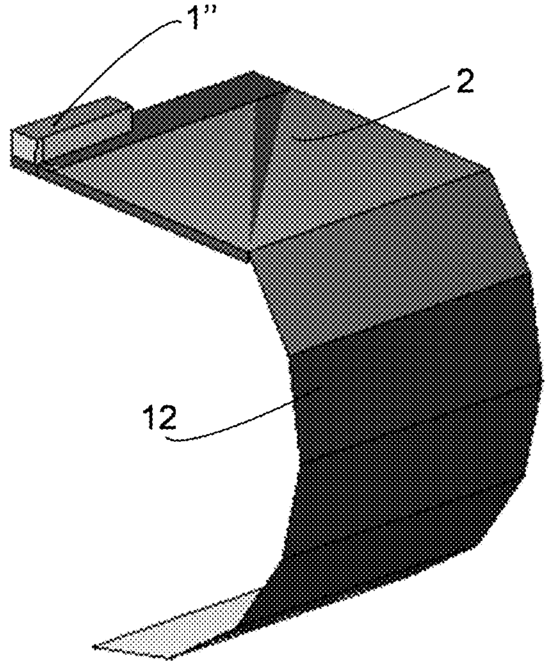


Fig. 9

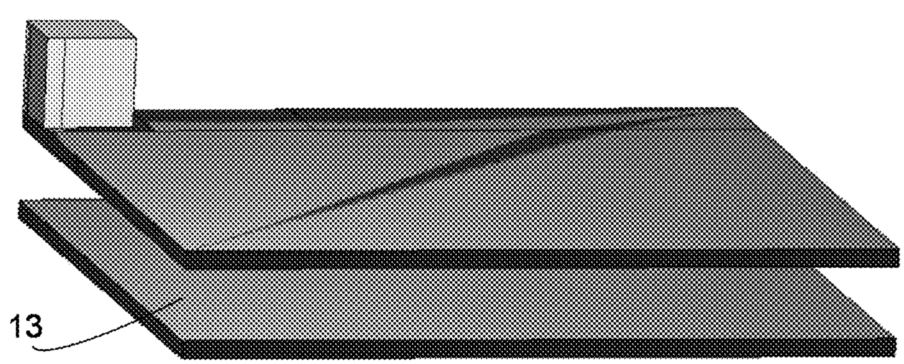


Fig. 10

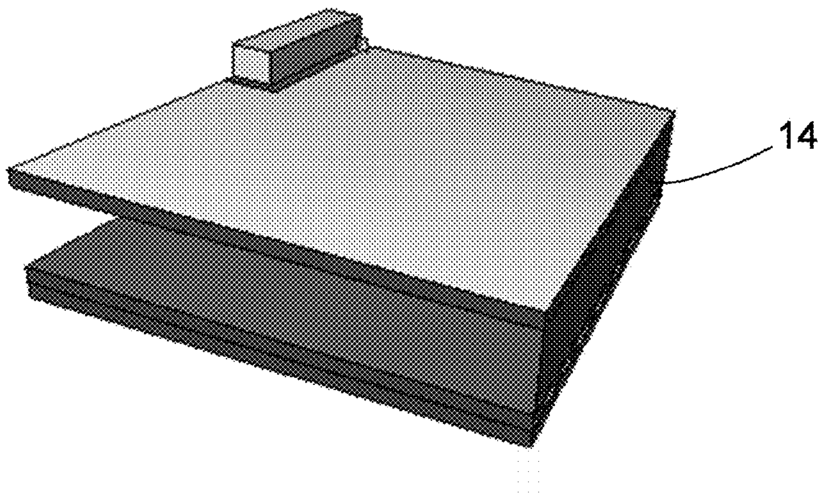


Fig. 11

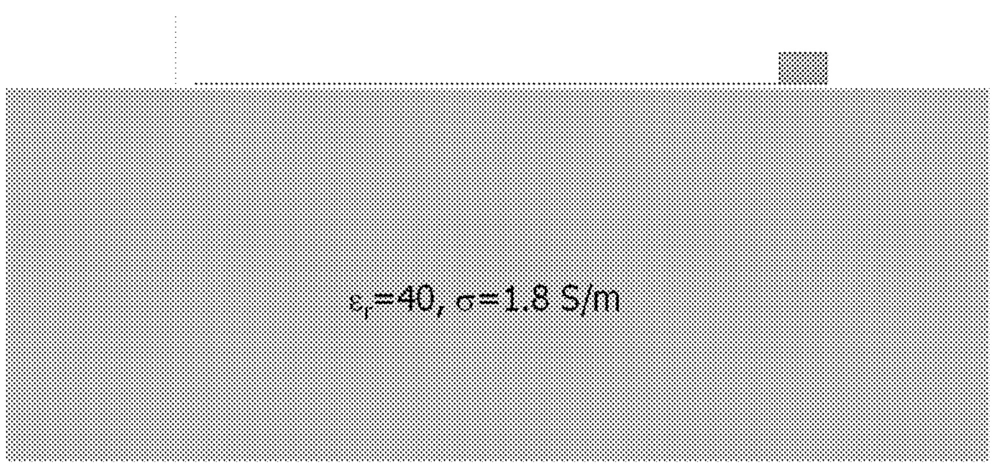


Fig. 12a

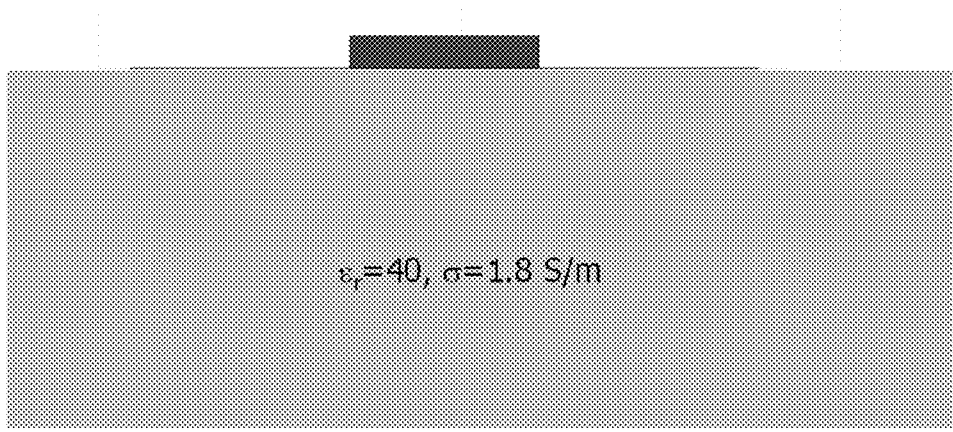


Fig. 12b

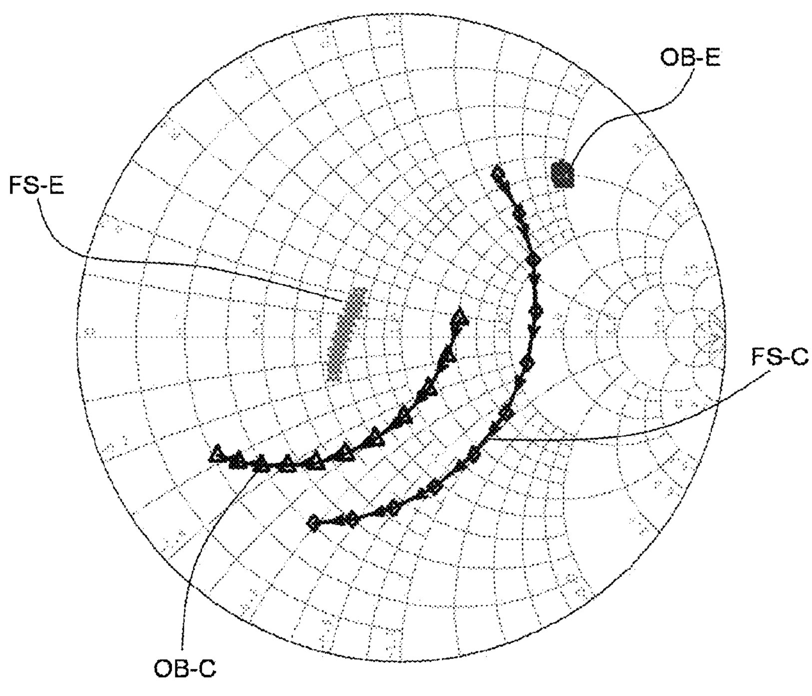


Fig. 13

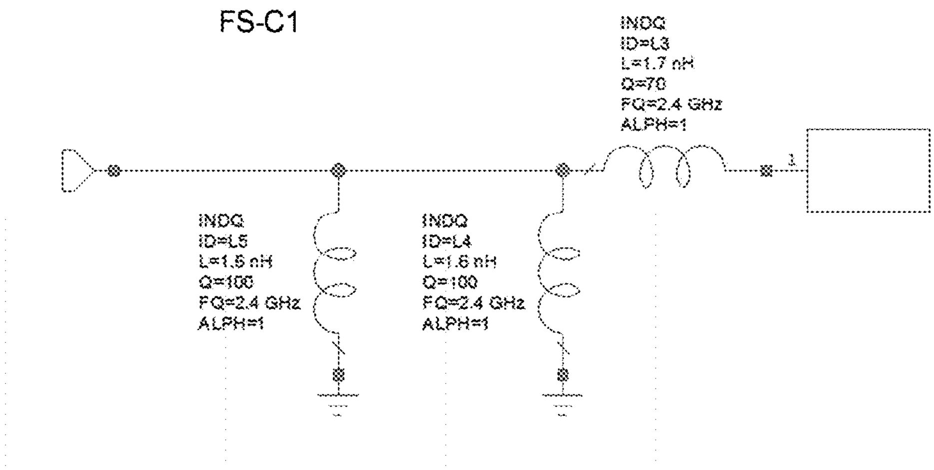


Fig. 14a

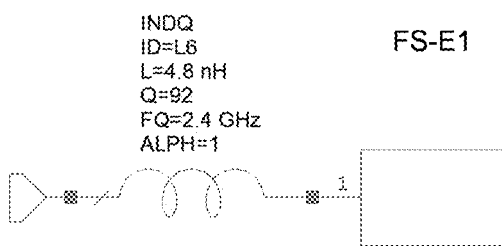


Fig. 14b

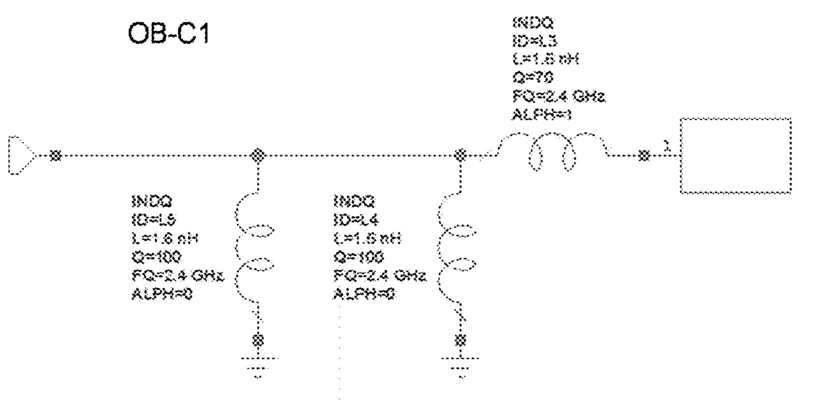


Fig. 14c

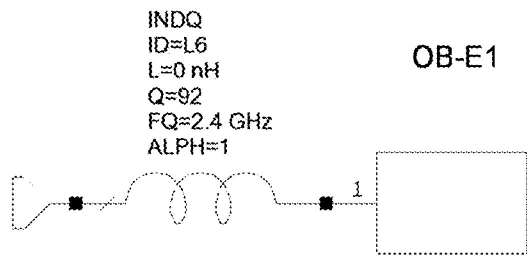


Fig. 14d

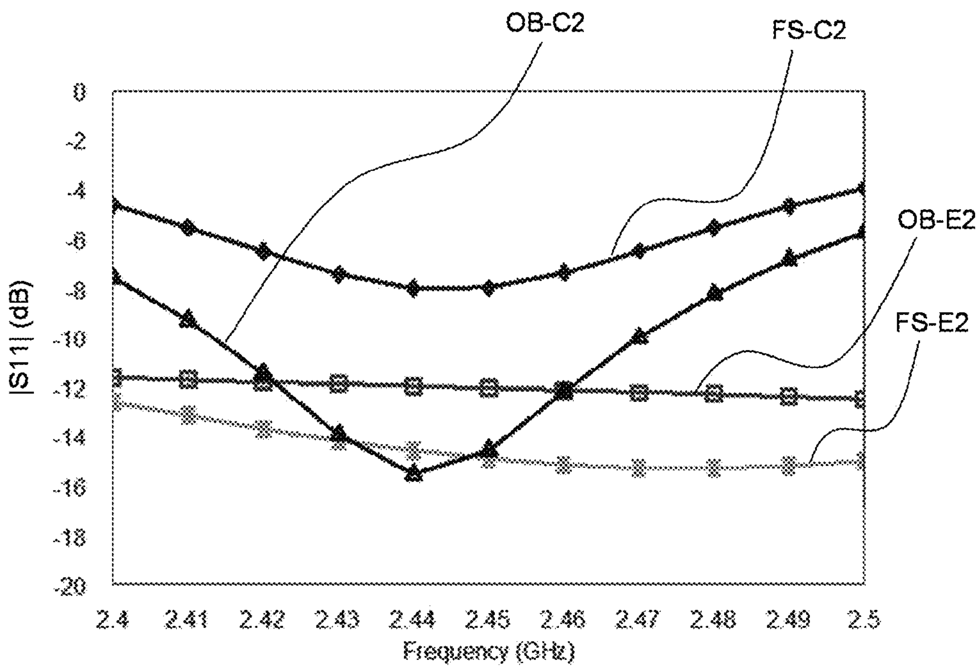


Fig. 15

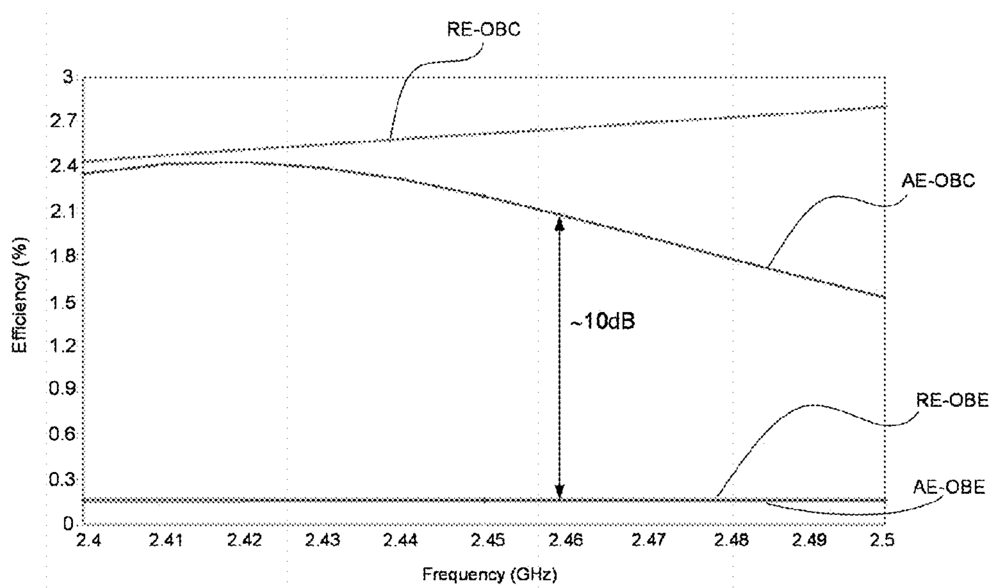

RE-OBC
AE-OBC
RE-OBE
AE-OBE
~10dB
Efficiency (%)
Frequency (GHz)
3
2.7
2.4
2.1
1.8
1.5
1.2
0.9
0.6
0.3
0
2.4
2.41
2.42
2.43
2.44
2.45
2.46
2.47
2.48
2.49
2.5

Fig. 16

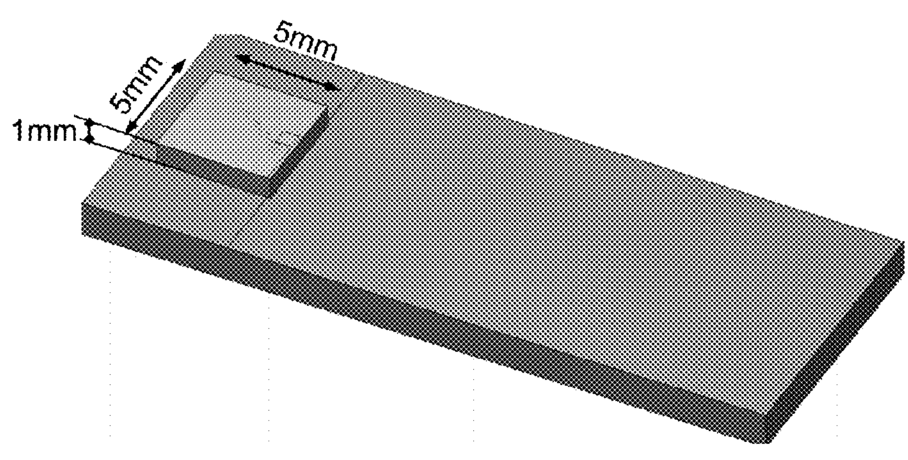

5mm
5mm
1mm

Fig. 17

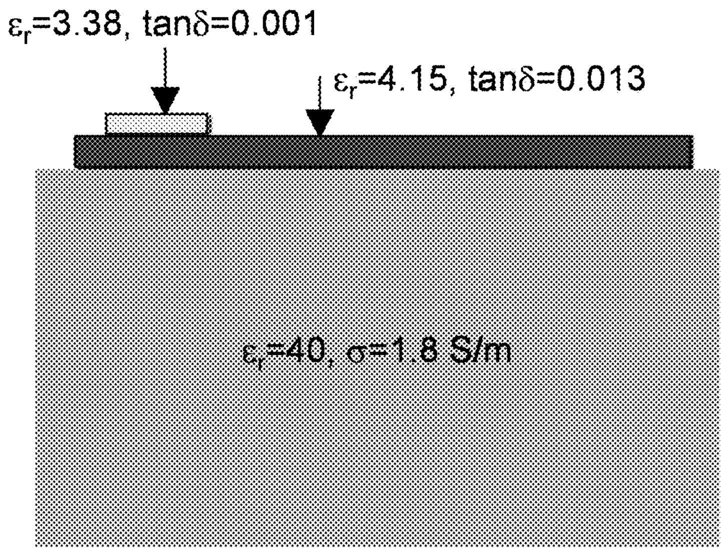

ε_r=3.38, tanδ=0.001
ε_r=4.15, tanδ=0.013
ε_r=40, σ=1.8 S/m

Fig. 18

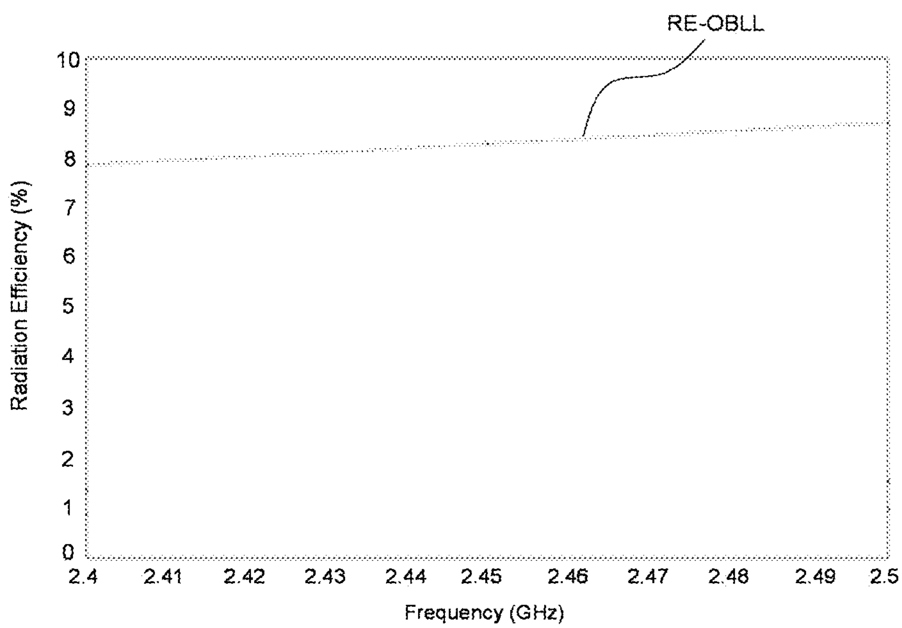

RE-OBLL
Radiation Efficiency (%)
10
9
8
7
6
5
4
3
2
1
0
2.4
2.41
2.42
2.43
2.44
2.45
2.46
2.47
2.48
2.49
2.5
Frequency (GHz)

Fig. 19

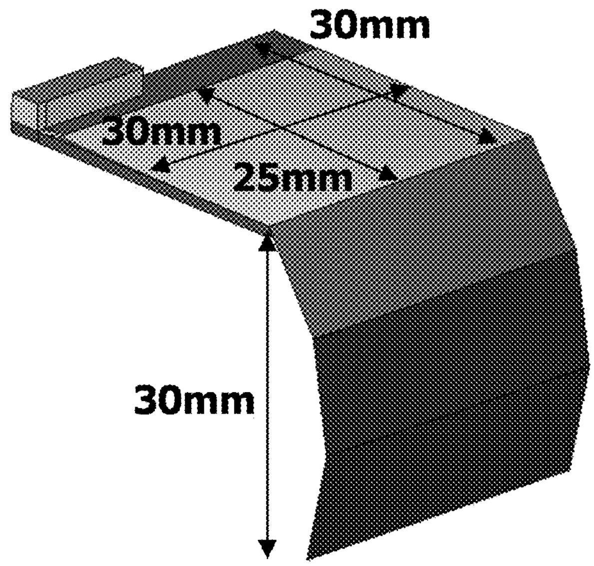


Fig. 20a

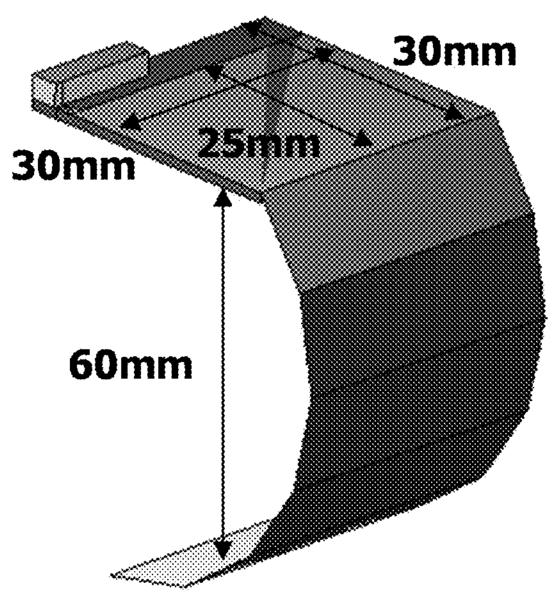


Fig. 20b

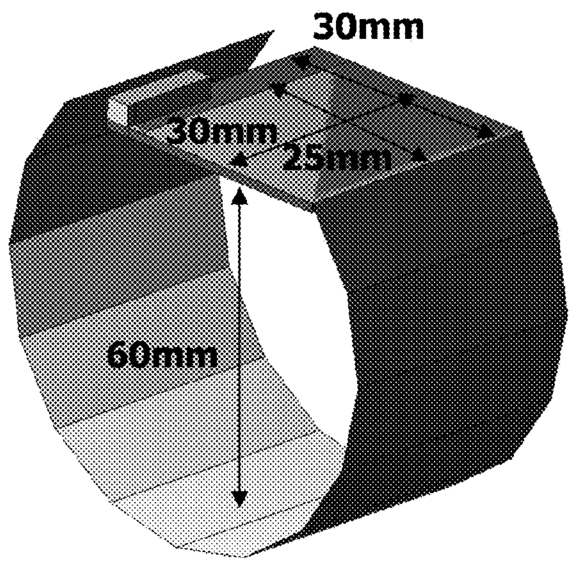


Fig. 20c

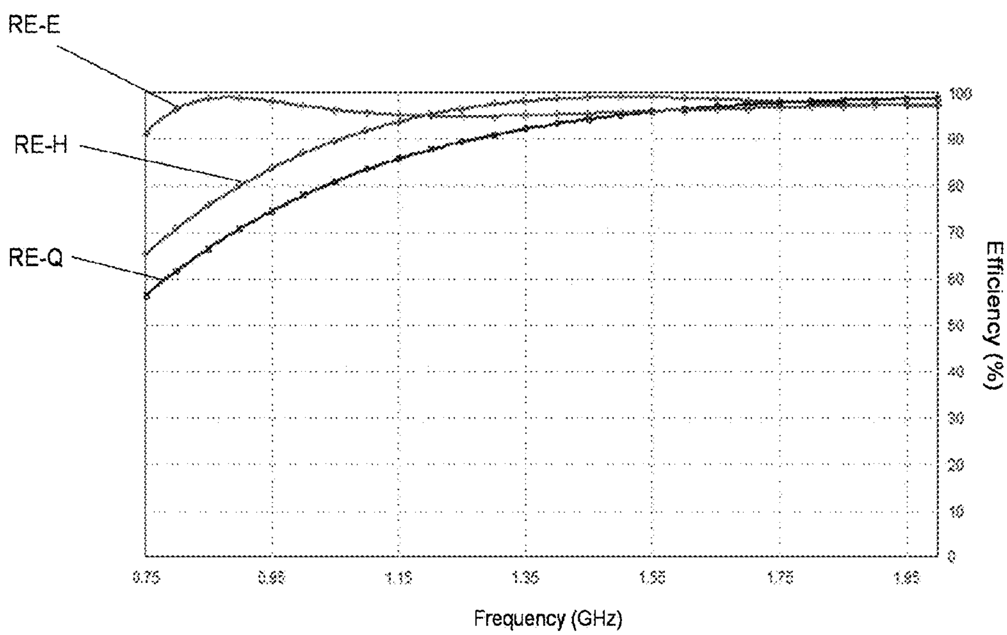


Fig. 21

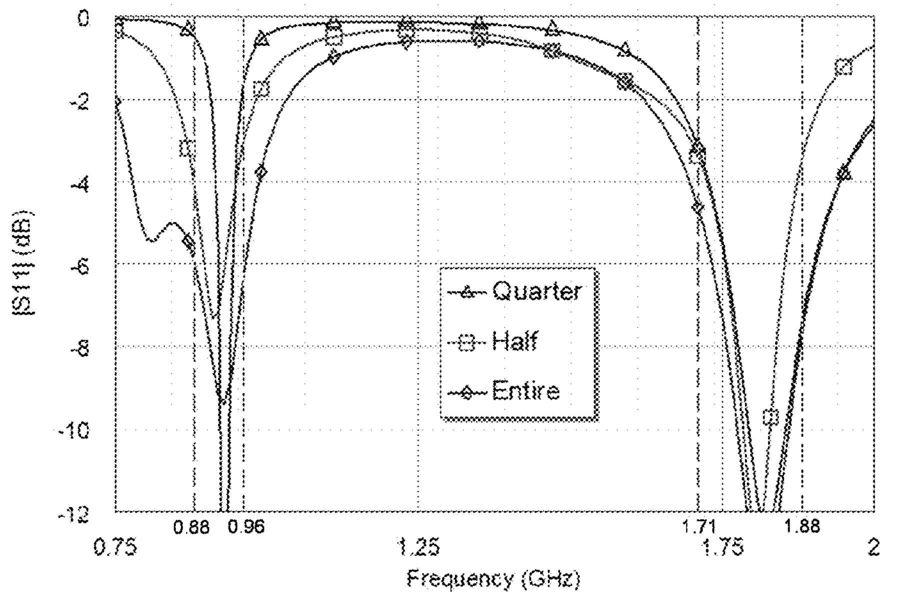

0
-2
-4
-6
-8
-10
-12
|S11| (dB)
Quarter
Half
Entire
0.88
0.96
1.71
1.88
0.75
1.25
1.75
2
Frequency (GHz)

Fig. 22

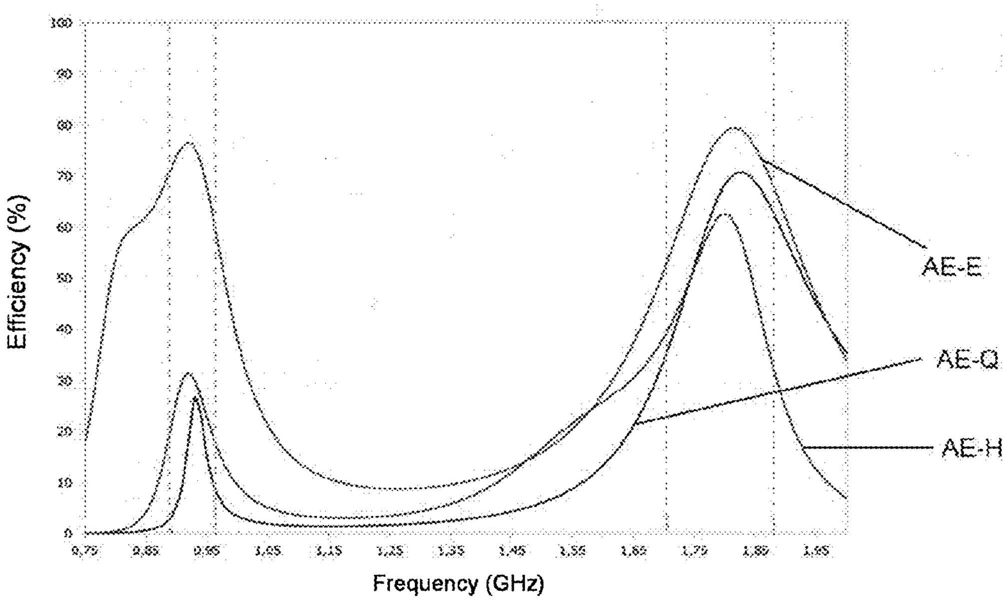

Efficiency (%)
Frequency (GHz)
AE-E
AE-Q
AE-H

Fig. 23

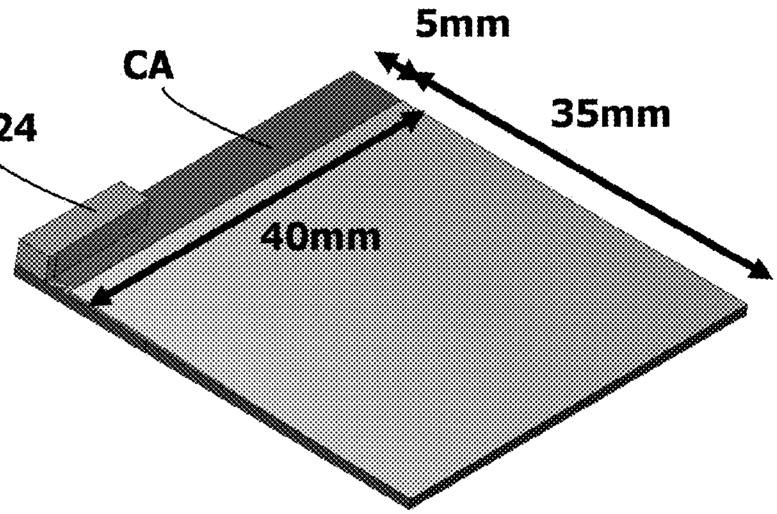


Fig. 24a

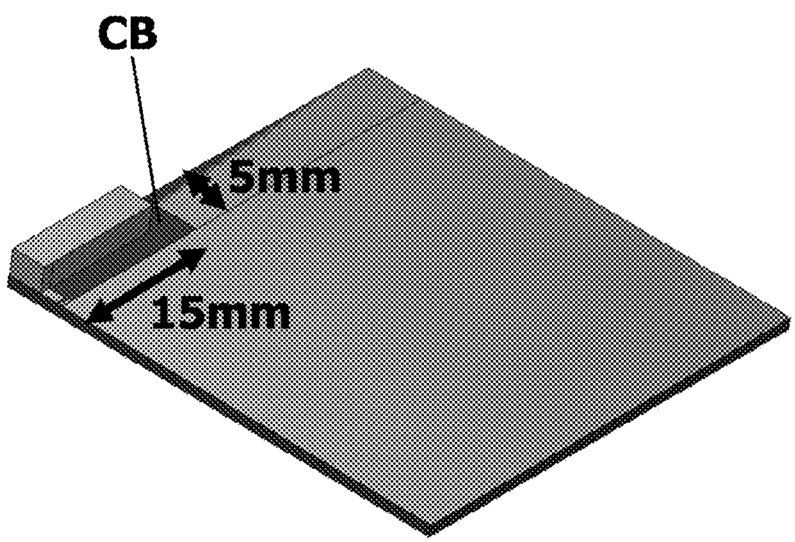


Fig. 24b

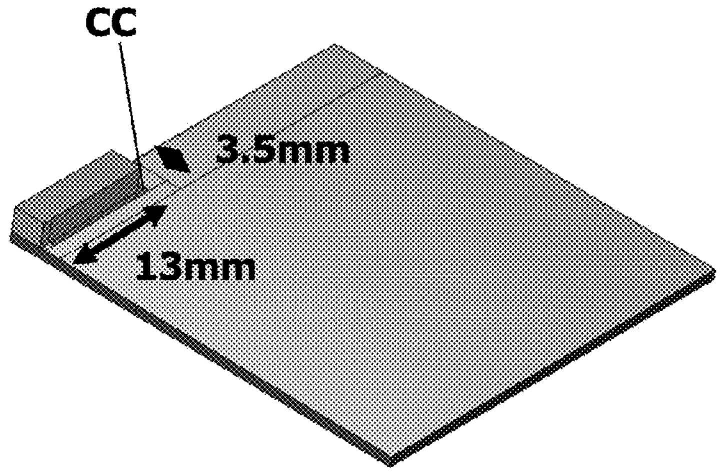


Fig. 24c

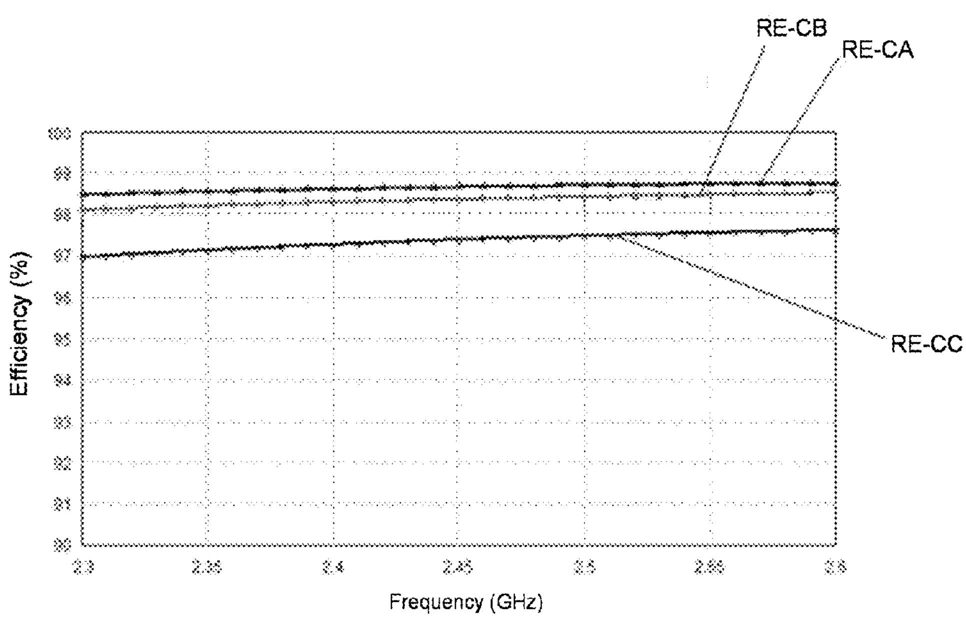
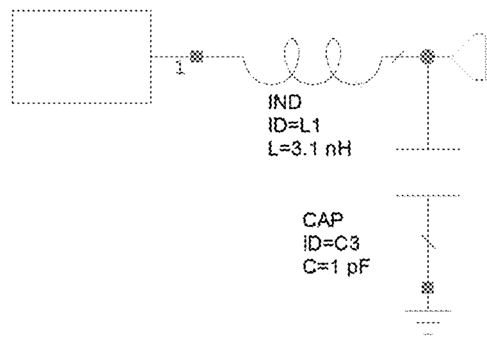
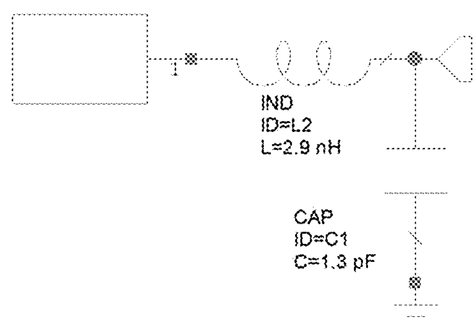


Fig. 25

CA



CB



CC

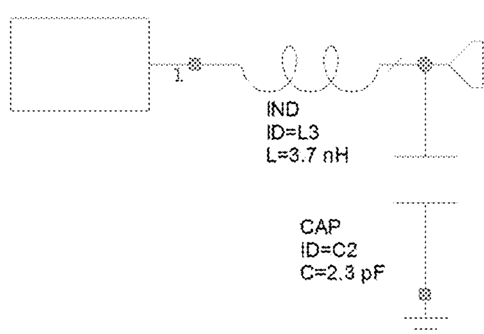


Fig. 26

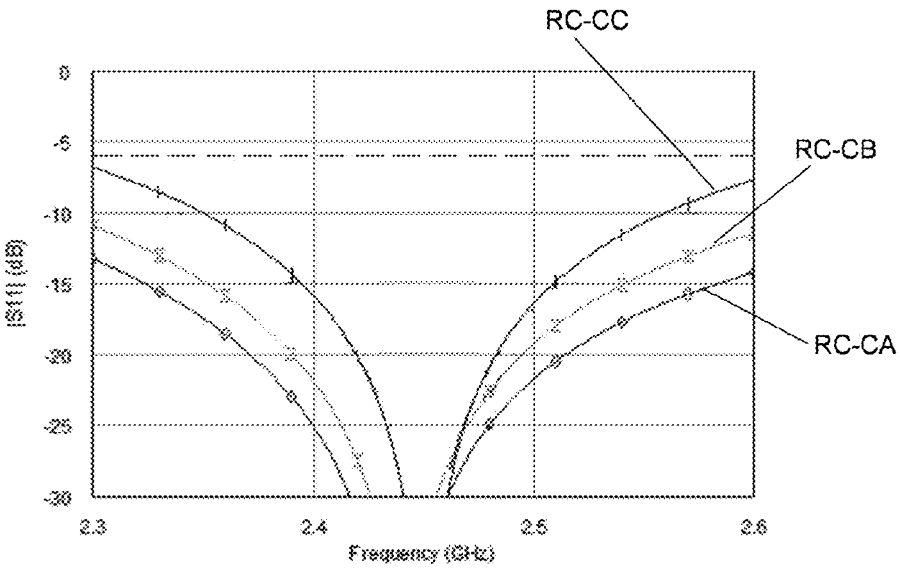

RC-CC
RC-CB
RC-CA
0
-5
-10
-15
-20
-25
-30
|S11| (dB)
2.3
2.4
2.5
2.6
Frequency (GHz)

Fig. 27

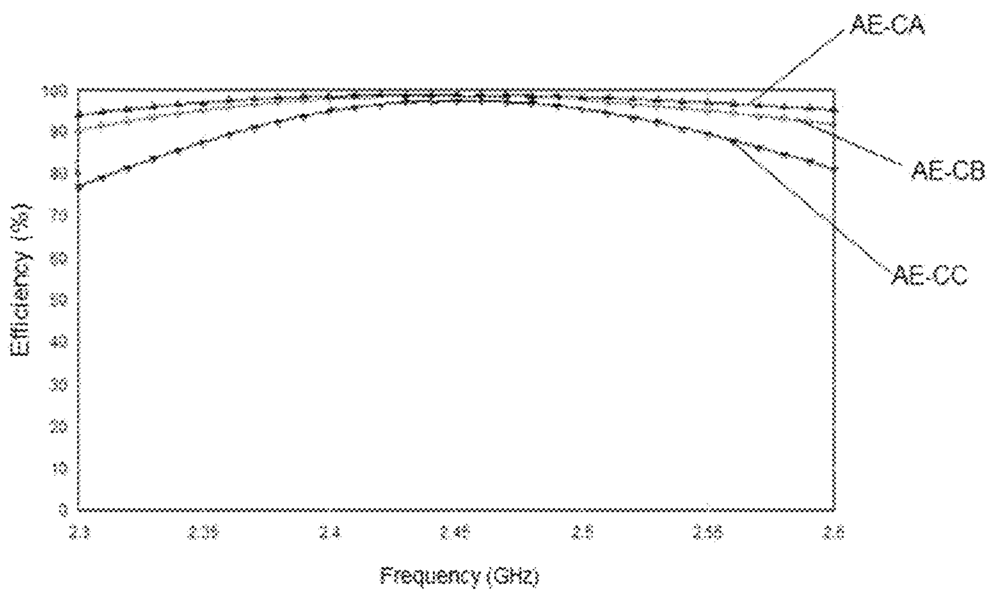

AE-CA
AE-CB
AE-CC
100
90
80
70
60
50
40
30
20
10
0
Efficiency (%)
2.3
2.35
2.4
2.45
2.5
2.55
2.6
Frequency (GHz)

Fig. 28

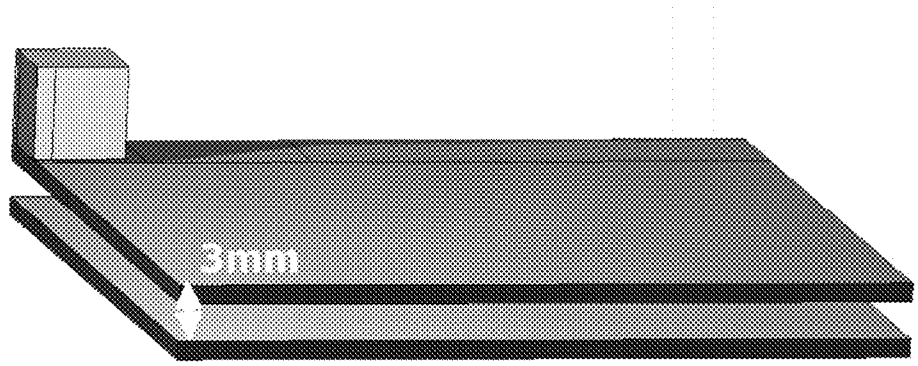


Fig. 29a

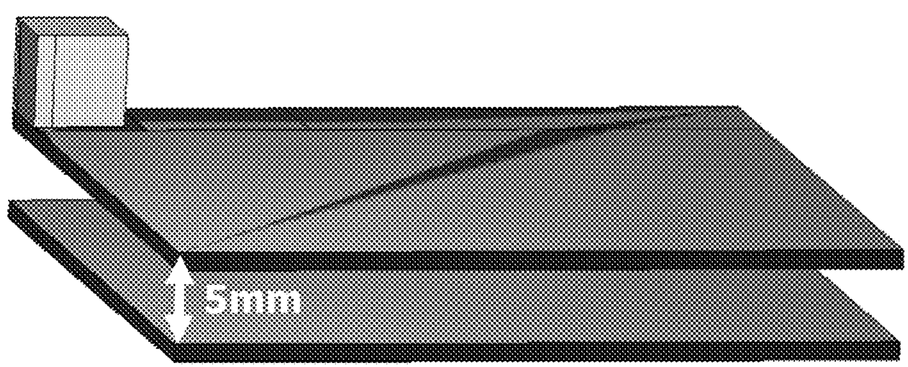


Fig. 29b

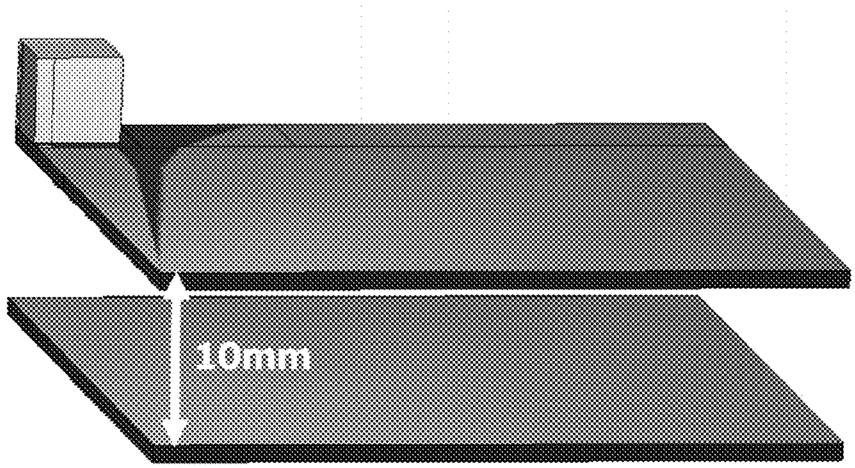


Fig. 29c

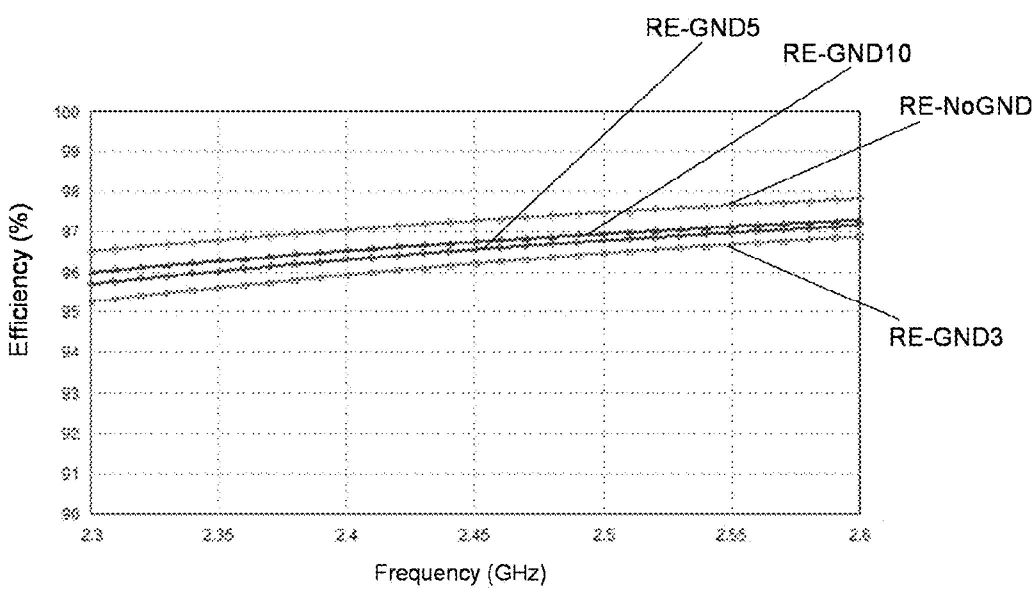


Fig. 30

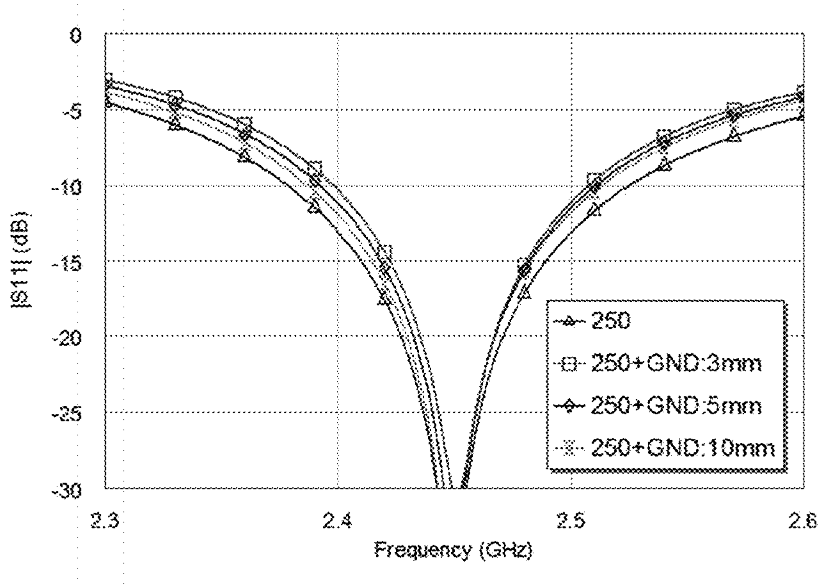

0
-5
-10
-15
-20
-25
-30
|S11| (dB)
2.3
2.4
2.5
2.6
Frequency (GHz)
250
250+GND:3mm
250+GND:5mm
250+GND:10mm

Fig. 31

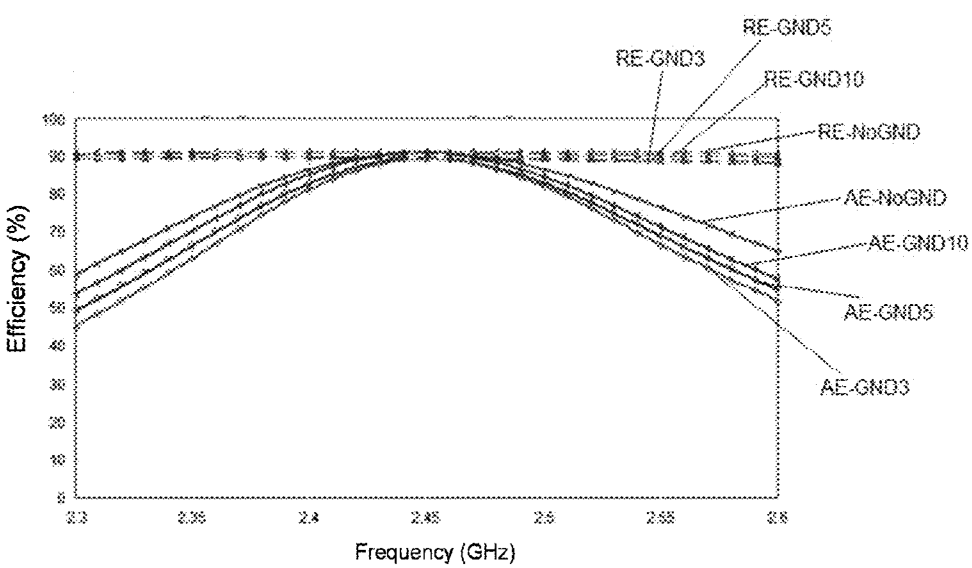

RE-GND3
RE-GND5
RE-GND10
RE-NoGND
AE-NoGND
AE-GND10
AE-GND5
AE-GND3
Efficiency (%)
Frequency (GHz)

Fig. 32

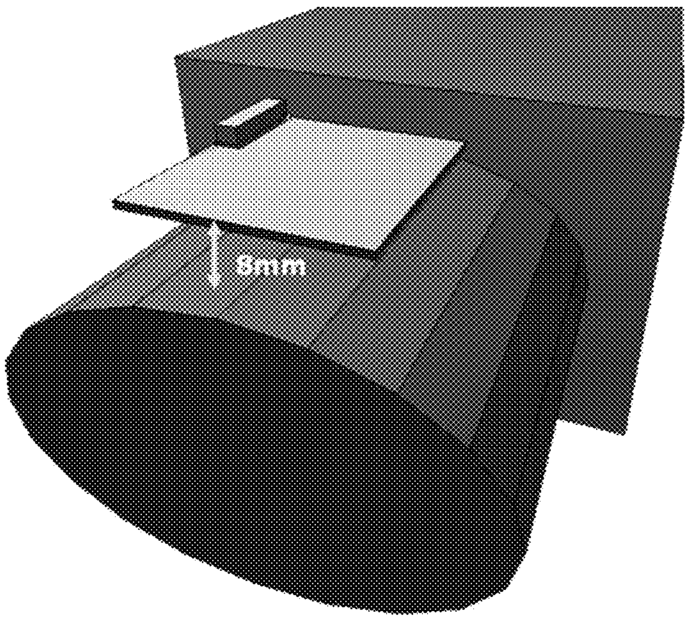


Fig. 33a

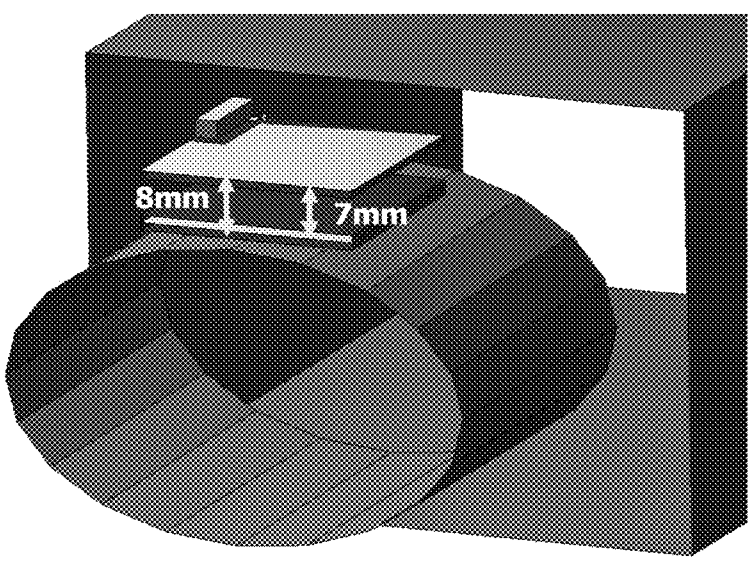


Fig. 33b

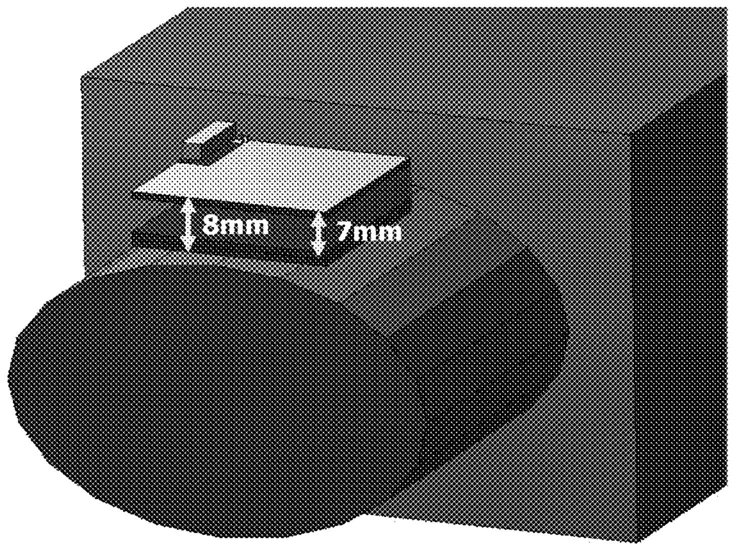


Fig. 33c

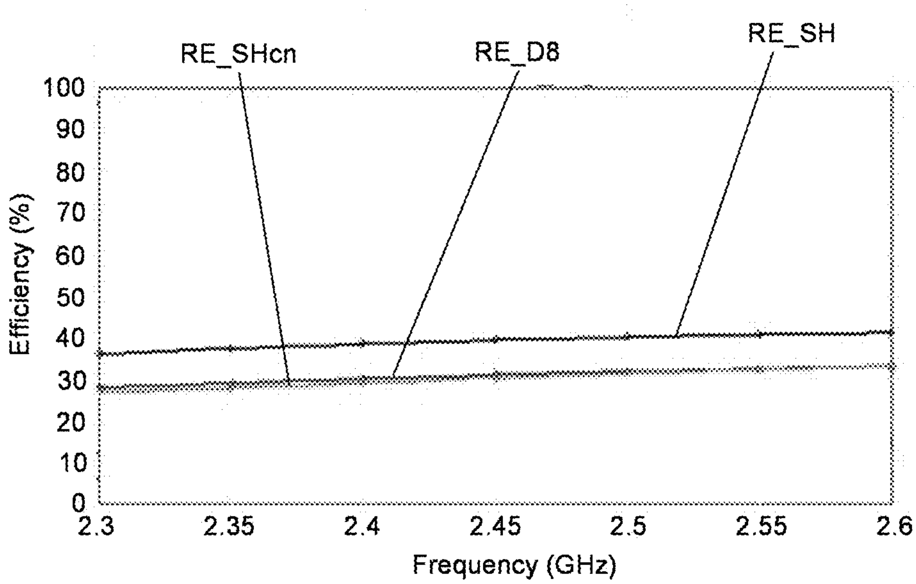


Fig. 34

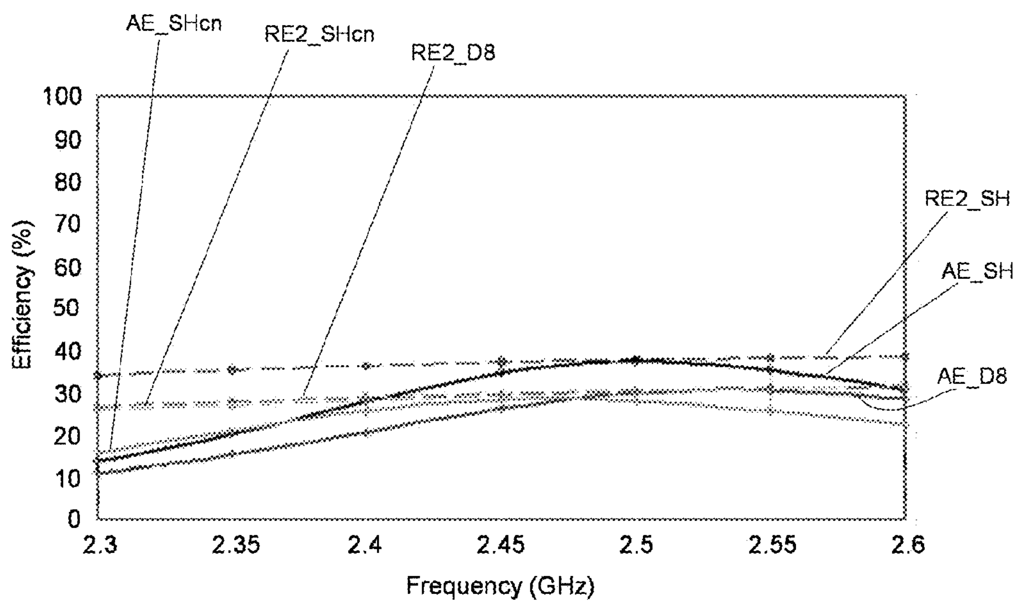

AE_SHcn
RE2_SHcn
RE2_D8
RE2_SH
AE_SH
AE_D8
Efficiency (%)
100
90
80
70
60
50
40
30
20
10
0
2.3
2.35
2.4
2.45
2.5
2.55
2.6
Frequency (GHz)

Fig. 35

GROUND PLANE BOOSTER ANTENNA TECHNOLOGY FOR WEARABLE DEVICES

CROSS REFERENCE TO RELATED APPLICATIONS

[0001] This application claims priority under 35 U.S.C. §119(e) from U.S. Provisional Patent Application Ser. No. 62/328,073, filed Apr. 27, 2016, the entire contents of which are hereby incorporated by reference.

TECHNICAL FIELD

[0002] The present disclosure relates to a wireless wearable device comprising a radiating system that contains at least a non-resonant element disposed in different arrangements within a radiating structure in the radiating system, featuring compact dimensions and an adequate performance when operating on a carrier living body.

BACKGROUND

[0003] The present disclosure relates to the field of wireless devices, and more concretely wearable devices. Typically, a radiating system for a wireless wearable device requires a radiating structure of reduced dimensions that fits in small available spaces, with a robust radio-electric performance resistant to the interaction effect that exists with the carrier living body. More concretely, some of the challenges related to the performance robustness required for these radiating systems are adequate radiation and efficiency performances along with a matched input impedance in the target operation bands, in presence of a living body, to achieve good wireless connections when operating on the carrier body. Additionally, wearable devices provide operation in one or more frequency regions and/or bands of the electromagnetic spectrum, typically Bluetooth bands and/or Wifi and/or GPS and/or mobile bands. So, depending on the coverage bands, if the device needs to cover low bands, such for example LTE700 and/or GSM850 and/or GSM900, an additional challenge is providing enough bandwidth and efficiency at the bands, since normally the platforms of wearable devices are small to host ground planes of sizes that allow operation at low frequencies.

[0004] As mentioned before, one of the main challenges of an antenna technology used for creating wearable devices is to avoid the loss of radiation produced by the nearby carrier body. The contact or proximity of the device to the carrier body causes a loading effect and an energy loss that affect the radio-electric performance of the device when it is mounted on the carrier living body. At present, wearable solutions usually use IFA-PIFA antennas, typically for Wifi, Bluetooth or GPS applications. More recent antenna technologies, also used for designing devices for those applications, are found in the state-of-the-art, like metal-frame antennas or antennas based on HIS-PMC surfaces. In general, the dimensions of the designs found are suitable to fit in real wearable devices, but they feature poor efficiencies when operating on the carrier living body. Optimized solutions can improve the antenna efficiencies reached, but normally, those antennas are customized designs. One also finds solutions that cover mobile communications, including low-frequency bands like GSM850 and/or LTE700. The use of mobile communications is more common in smartwatch applications and the antenna solutions found to cover those communications usually use the strap as a dipole or monopole; the main limitation of these solutions is their poor efficiency when they operate on the wrist. A device related to the present disclosure comprises a radiating system of reduced dimensions that features good impedance bandwidth and an adequate antenna efficiency when placed on a carrier living body. An embodiment according to the present disclosure reduces the interaction between the device and the lossy living body. Additionally, the embodiments related to the present disclosure preserve the maximum available space to allocate other electronic components and also benefit from other advantages like for example the ease of implementation and integration of the radiating structures related to the present disclosure in different device platforms.

SUMMARY

[0005] It is an object to provide a wireless wearable device that overcomes the main drawbacks of current technologies applied to wearable devices, as described in the previous section. A wearable device totally or partially immune to the carrier body effects would be an advantageous solution when creating a device able to operate on living bodies. The configurations related to a wireless wearable device according to the present disclosure reduce the electromagnetic interaction with the carrier living body and are robust solutions with adequate efficiency performance in on-body conditions taking into account the dimensions one handles when creating a wearable device.

[0006] The present disclosure relates generally to wireless wearable devices that comprise a radiating system featuring a radiating structure that contains at least a non-resonant element instead of antenna elements to contribute to the electrical and radiation behavior of the device. The disclosure relates to several ways of arranging the at least one non-resonant element within the radiating structure, which further comprises a first ground plane layer. The radiating structure is included in the wearable device. Some features of the described devices are:

[0007] the small size of the radiating system comprised in the wearable device;

[0008] the small size of the non-resonant element, which allows the integration of the radiating system in the wearable device with minimum volume;

[0009] the arrangements of the radiating structure in the wearable device, which enable a reduction of the electromagnetic interaction between the radiating system comprised in the wearable device and the carrier living body;

[0010] the performance robustness of the radiating structure arrangements to the loading effect produced by the nearby living body and to the wearable device platform dimensions; and

[0011] the radiating system arrangements are simple and ease the integration of the radiating system in the host device.

[0012] A wearable device normally features small dimensions. Such dimensions can range from the dimensions of a ring or bracelet to the dimensions of a smartwatch or a metria wearable sensor. Depending on the device platform and application, which determines the operation frequencies of the device, the available space for integrating the radiating system in the wearable device can be quite reduced. Among the most common smart wearable devices one finds devices devoted to health care applications, normally used for monitoring and prevent diseases of different nature. Also one finds smart wearable devices that cover sport and fitness applications, and devices that cover applications dedicated to attend to elderly. Other wearable devices that often include intelligence are smartwatches, which normally include operation at mobile communication bands. Other examples of wearable devices that can include wireless connectivity to become intelligent devices are jewels. Examples of jewelry susceptible to become smart wearable devices are rings, bracelets, necklaces and alike, whose dimensions can be very small relative to their connectivity operation frequencies. The arrangements of a radiating system that characterize the disclosed device fulfill the space requirements of wearable devices, as for instance but not limited to the ones mentioned before, and, particularly, of quite small devices like for example bracelets or pendants. Additionally, the small volume that the non-resonant element occupies in the radiating structure integrated in the wearable device enables reduced volumes of the smart device. Generally, the described device has reduced dimensions, meaning a maximum radiating structure length preferably smaller than 0.8 times the free-space wavelength corresponding to the highest frequency of operation of the device, or preferably smaller than 0.4 times, or preferably smaller than 0.3 times, or even preferably smaller than 0.16 times or even preferably smaller than 0.125 times the wavelength, which comprises a radiating system that includes a radiating structure that comprises at least a non-resonant element and at least a ground plane layer arranged between them in different configurations that feature adequate performance in on-body conditions.

[0013] A wireless wearable device that features a robust configuration is also an advantageous solution when an operative wearable device is sought. The robustness of a wearable device is normally evaluated by the impact of the nearby carrier-living body on the performance of the device. The impact of the loading effect of the carrier living body to the described device does not prevent the device from operating correctly in the frequency bands of interest. Additionally, the device performance does not strongly depend on its lateral dimensions.

[0014] Concerning the connectivity of smart wearable devices, these devices normally communicate to smartphones, preferably via Bluetooth because of connectivity and battery life reasons. But these devices can also connect via Wifi or mobile communications or other wireless communications. Typically, the described device covers at least a Bluetooth band or a Wifi band or a GPS band or a mobile band. In the context of this document, a frequency band or band preferably refers to a range of frequencies used by a particular communication standard, like for instance GPS standards, Wifi standards, Bluetooth standards, GSM 850, GSM 900, GSM 1800, GSM 1900, UMTS, CDMA, etc. The frequency bands are contained within at least one frequency region, a frequency region referring to a continuum of frequencies of the electromagnetic spectrum.

[0015] Some embodiments described herein refer to smart wearable devices of reduced dimensions featured by a compact radiating system configuration that comprises at least a non-resonant element disposed in an arrangement that does not include ground plane clearance, the ground plane clearance or clearance being a piece or, more concretely, an area of ground plane layer where the ground plane is removed. For those wireless wearable devices where the size is quite critical, like for instance jewels, a radiating structure arrangement without ground plane clearance is a suitable solution to fit the limitations of size. Smart wearable devices like jewels normally need to cover short-range communications that reach short distances near the carrier body. In some of the embodiments whose ground plane arrangement does not include clearance, the at least one non-resonant element is placed on the ground plane layer. The arrangement minimizes the loading effect produced by the carrier living body on the device and the electromagnetic interaction that appears between the radiating system included in the wearable device and the living body.

[0016] Other described embodiments refer to wearable devices also of reduced dimensions that cover short-range communications, which comprise at least a non-resonant element included in a radiating system arrangement that comprises a ground plane clearance that contains the non-resonant element. Typical wearable devices among those are for instance, but not limited to, health care devices, sport and fitness devices or devices dedicated to improve life to elderly. Some of the arrangements whose radiating structure includes at least a ground plane clearance comprise at least a non-resonant element placed at a distance from an edge of the ground plane layer, the distance being one of the parameters that determines the performance of these embodiments. Furthermore, in some of these examples, the clearance is minimized so that the performance achieved reaches at least a minimum target performance, for example, in terms of bandwidth and antenna efficiency.

[0017] As already mentioned, the solution proposed in the context of the present disclosure is a standard solution that does not require customization in function of the platform that allocates a radiating system as described. A device comprising a radiating structure arranged as described aforementioned requires minimum adjustments to implement the solution in different wearable devices. Additionally, the described configurations are simple and ease the integration of the solution in the host device.

[0018] Generally, in some of the embodiments the non-resonant elements are volumetric conducting pieces, used as booster or boosting elements. Examples of booster elements are described in U.S. Pat. No. 9,331,389B2, the entire disclosure of which is incorporated herein by reference, or found at http://www.fractusantennas.com/products as commercial products included in the mXTEND range of products of different sizes. Such non-resonant volumetric conductive elements comprise, in some embodiments, a top conductive surface, supported by a dielectric material piece, which is connected by at least a via to at least one additional bottom conducting surface.

[0019] Other embodiments contain non-resonant elements that comprises a top conducting surface supported by a dielectric material piece, the conducting surface connected to a feeding element.

[0020] Some embodiments comprise a radiating system integrated in a wearable device that includes a radiating structure comprising at least a non-resonant element and a first ground plane layer extended by a conductive element, usually a strip element, which normally is integrated in the device belt or strap or chain or alike. So, the wearable devices that host such a solution typically are smartwatches or, in general, devices that normally require operation at mobile communications including low-frequency bands, as for instance GSM850 or LTE700. Normally, the length of the conductive element is adjusted so that the device operates at the target frequency bands. When operation at low-frequency mobile bands is required, as for instance GSM850 (from 824 MHz to 894 MHz) or LTE700 (from 698 MHz to 746 MHz), an additional challenge appears at the lowest frequencies for achieving an adequate radio-electric performance at the frequencies.

[0021] Some embodiments further comprise a shielding element, which in some of those embodiments the shielding element includes an additional ground plane layer placed between the carrier body and the radiating structure comprised in the wearable device and located at a certain distance from a first ground plane layer comprised in the radiating structure. In some other embodiments, the shielding is connected to the first ground plane layer included in the radiating structure by a conductive element. Some of the shielded embodiments comprise at least a strip connection, like for example an element between the shielding ground plane and the first ground plane layer included in the radiating structure. Additionally, the first ground plane layer or layers comprised in some embodiments, shielded or not, is elongated by a conductive element, typically a strip.

BRIEF DESCRIPTION OF THE DRAWINGS

[0022] FIG. **1** shows a wireless wearable device of reduced dimensions like a smart ring, comprising a non-resonant element **1'** in its radiating structure.

[0023] FIG. **2** provides an example of another smart jewel, a wireless pendant device comprising a non-resonant element **1'** configuration similar to the one shown in FIG. **1**.

[0024] FIG. **3** provides another example of a wireless pendant device that comprises a non-resonant element **1"** configuration different from the one illustrated in FIG. **2**.

[0025] FIG. **4** shows an example of wireless wearable device as for instance a health care device, a sport or fitness device, etc., comprising a non-resonant element arranged in two possible configurations.

[0026] FIG. **5** shows an example of a smartwatch device that includes a non-resonant element arranged again in two possible configurations.

[0027] FIGS. **6***a* and **6***b* present different embodiments where at least a non-resonant element is disposed in different arrangements.

[0028] FIG. **7** provides a non-resonant element that comprises a top conducting surface supported by a dielectric piece, the conducting surface connected to a feeding element.

[0029] FIGS. **8***a* and **8***b* show examples of different commercial boosters. FIG. **8***a* presents a BAR mXTEND booster. FIG. **8***b* shows a RUN mXTEND booster.

[0030] FIG. **9** illustrates an embodiment that comprises an additional ground plane layer used as a shielding element.

[0031] FIG. **10** illustrates an embodiment which comprises a shielding ground plane that is connected to the ground plane layer of the radiating structure.

[0032] FIG. **11** shows an example that comprises an extended ground plane layer by a conductive element.

[0033] FIGS. **12***a* and **12***b* provide examples of the embodiments provided in FIGS. **6***a* and **6***b* placed on a dielectric material that plays the role of an on-body tissue.

[0034] FIG. **13** shows the input reflection coefficients related to free-space 'FE' and on-body 'OB' examples configured as provided in FIGS. **6***a*, **6***b*, **12***a*, and **12***b*.

[0035] FIGS. **14***a*-**14***d* provide the matching networks used to match the examples shown in FIGS. **6***a*, **6***b*, **12***a*, and **12***b*, whose input reflection coefficients are shown in FIG. **13**.

[0036] FIG. **15** provides the modules of the input reflection coefficients provided in FIG. **13**, related to the free-space and on-body examples illustrated in FIGS. **6***a*, **6***b*, **12***a*, and **12***b*.

[0037] FIG. **16** provides both the radiation and the antenna efficiencies related to the on-body examples presented in FIGS. **12***a* and **12***b*.

[0038] FIG. **17** includes an arrangement that comprises a non-resonant element also containing a top conducting surface supported on a dielectric substrate, the top conducting surface connected to a feeding element. The non-resonant element is placed at a non-centered position on a ground plane layer also supported by a dielectric material.

[0039] FIG. **18** shows an on-body configuration including the embodiment provided in FIG. **17**. The dielectric properties of the dielectric materials used are included in the picture.

[0040] FIG. **19** presents the radiation efficiency related to the on-body configuration provided in FIG. **18**.

[0041] FIGS. **20***a*-**20***c* present three embodiments that comprise an extended ground plane layer. FIGS. **20***a* presents an example with a ground plane layer extended by a conductive belt of about 30 mm length. FIG. **20***b* presents an example with a ground plane layer extended by a 60 mm-diameter conductive belt of half a length. FIG. **20***c* presents an example with a ground plane layer extended by a 60 mm-diameter conductive belt of whole length.

[0042] FIG. **21** provides the radiation efficiency related to the three embodiments presented in FIG. **20**, which contain an extended ground plane layer of different lengths.

[0043] FIG. **22** represents the input reflection coefficients that correspond to the three embodiments presented in FIGS. **20***a*-**20***c*.

[0044] FIG. **23** represents the antenna efficiency related to the three embodiments presented in FIGS. **20***a*-**20***c*. The frequency bands that correspond to the bands shown in FIG. **22** are shown in the present figure with dashed lines.

[0045] FIGS. **24***a*-**24***c* show three embodiments of dimensions 40 mm×40 mm containing a RUN mXTend antenna booster. FIG. **24***a* provides an embodiment featured by a clearance area CA of length 40 mm. FIG. **24***b* shows an embodiment featured by a clearance area CB of length 15 mm. FIG. **24***c* provides an embodiment featured by a clearance area CC of length 13 mm.

[0046] FIG. **25** represents the radiation efficiencies related to the embodiments presented in FIGS. **24***a*-**24***c*.

[0047] FIG. **26** provides the matching networks used to match the embodiments provided in FIGS. **24***a*-**24***c*. Each matching network is labeled as the clearance area related to each embodiment respectively.

[0048] FIG. **27** represents the input reflection coefficients related to the embodiments included in FIGS. **24***a*-**24***c* matched with the matching networks included in FIG. **26**.

[0049] FIG. **28** illustrates the antenna efficiencies related to the embodiments presented in FIGS. **24***a*-**24***c* matched with the matching networks included in FIG. **26**.

[0050] FIGS. **29***a*-**29***c* show three different embodiments featured by a radiating structure that contain an additional shielding ground plane placed under a first ground plane layer comprised in the radiating structure comprised in the smart device. FIG. **29***a* provides an example containing an additional ground plane acting as shielding placed at **3** mm from a first ground plane layer comprised in the radiating structure. FIG. **29***b* and FIG. **29***c* provide two examples containing a shielding ground plane layer located at 5 mm and 10 mm, respectively, from a first ground plane layer comprised in the radiating structure.

[0051] FIG. **30** provides the radiation efficiencies related to the examples provided in FIGS. **29***a*-**29** *c*.

[0052] FIG. **31** illustrates the input reflection coefficients related to the examples provided in FIGS. **29***a*-**29***c*.

[0053] FIG. **32** provides both the radiation and the antenna efficiencies related to matched examples configured as the embodiments shown in FIGS. **29***a*-**29***c*.

[0054] FIGS. **33***a*-**33***c* illustrate examples positioned on a simulated phantom hand at 7 mm distance, with a total height of 8 mm from a first ground plane layer contained in the radiating structure to the phantom hand. FIG. **33***a* shows an example without shielding. FIG. **33***b* provides an example that comprises a shielding ground plane in the radiating structure. FIG. **33***c* provides an example that comprises a shielding ground plane connected to the first ground plane layer contained in the radiating structure.

[0055] FIG. **34** provides the radiation efficiencies related to the embodiments presented in FIGS. **33***a*-**33***c*.

[0056] FIG. **35** presents both the radiation and the antenna efficiencies related to the embodiment configurations shown in FIGS. **33***a*-**33***c* once matched.

DETAILED DESCRIPTION

[0057] Some specific examples of smart wireless wearable devices comprising a radiating system arranged according to the present disclosure, together with some performance results related to those specific examples, are provided in this section. The embodiments and results described herein are provided as examples but never with limiting purposes. A wireless wearable device according to the present disclosure contains at least a non-resonant element arranged within a radiating structure comprised in the wearable device. The non-resonant element arrangements are characterized by reduced dimensions that fit in small wearable devices. Some of those arrangements fit in very small wearable devices like for instance smart jewels, whose communication distances requirements normally are not very demanding. Other arrangements feature bigger platforms, which still remain small, suitable to be fitted in wearable devices that normally cover longer communications distances than the even smaller devices, like for example, but not limited to, health care devices, sport and fitness devices or wearable devices that cover applications dedicated to attend to elderly.

[0058] Referring to FIGS. **1-5**, examples of wireless wearable devices are shown that comprise a radiating system featuring a radiating structure that contains at least a non-resonant element instead of antenna elements to contribute to the electrical and radiation behavior of the device. These examples demonstrate several ways of arranging the at least one non-resonant element **1'** or **1"** within a radiating structure **3**, which further comprises a first ground plane layer **2**, where the radiating structure is included in the wearable device **4**. More specifically, FIG. **36** shows a wireless wearable device of reduced dimensions like a smart ring, comprising a non-resonant element **1'** in its radiating structure. FIG. **37** provides an example of another smart jewel, a wireless pendant device comprising a non-resonant element **1'** configuration similar to the one shown in FIG. **1**. FIG. **38** provides another example of a wireless pendant device that comprises a non-resonant element **1"** configuration different from the one illustrated in FIG. **2**. FIG. **39** shows an example of wireless wearable device as for instance a health care device, a sport or fitness device, etc., comprising a non-resonant element arranged in two possible configurations. FIG. **40** shows an example of a smartwatch device that includes a non-resonant element arranged again in two possible configurations.

[0059] Some features of the described devices are: the small size of the radiating system comprised in the wearable device; the small size of the non-resonant element, which allows the integration of the radiating system in the wearable device with minimum volume; the arrangements of the radiating structure in the wearable device, which enable a reduction of the electromagnetic interaction between the radiating system comprised in the wearable device and the carrier living body; the performance robustness of the radiating structure arrangements to the loading effect produced by the nearby living body and to the wearable device platform dimensions; and the radiating system arrangements being simple and the ease of integration of the radiating system in the host device.

[0060] FIGS. **6***a* and **6***b* show different arrangements of the non-resonant element in combination with at least a ground plane layer, both comprised in the radiating structure. FIG. **6***a* provides an arrangement without ground plane clearance, wherein the non-resonant element **1'** is located on the ground plane layer **2**. A non-resonant element comprised in an arrangement like the one shown in FIG. **6***a* comprises a top conducting surface **5** supported by a dielectric piece **6**, the conducting surface connected to a feeding element **7**, typically a coaxial-probe as the one shown in FIG. **7**. One of the functionalities of the ground plane layer is to reduce the electromagnetic interaction between the carrier body and the device. Such an arrangement is preferably used in very small wearable devices, featuring a maximum radiating structure length preferably smaller than 0.16 times the free-space wavelength corresponding to the highest frequency of operation of the device, or preferably smaller than 0.125 times the wavelength, such for instance rings, necklaces, bracelets, which operate at short-range communications that cover small distances near the carrier body.

[0061] FIG. **6***b* shows an arrangement with ground plane clearance, wherein the non-resonant element **1"** is located at a distance from an edge of the ground plane layer **2**. Such an arrangement is preferably used in small wearable devices featuring a maximum radiating structure length preferably smaller than 0.8 times the free-space wavelength corresponding to the highest frequency of operation of the wearable device, or preferably smaller than 0.4 times, or even preferably smaller than 0.3 times the wavelength. A non-resonant element included in an arrangement like the one provided in FIG. **6***b* typically is a volumetric conducting piece, used as booster or boosting element. In some embodiments the non-resonant element comprises a top conductive surface **8**, supported by a dielectric material piece **9**, which is connected by at least a via **10** to at least one additional bottom conducting surface **11** (FIGS. **8***a* and **8***b*). The boosting element serves to excite at least a radiation mode into the ground plane layer included in a radiating structure like the one described in FIG. **6***b*. The boosters examples provided in FIGS. **8***a* and **8***b* correspond to commercial mXTEND boosters, used in some of the embodiments. FIG. **8***a* shows a BAR mXTEND example and FIG. **8***b* provides a RUN mXTEND booster, which features a smaller volume than the BAR mXTEND, both boosters of the mXTEND range of products. A ground plane layer comprised in a radiating structure like the one described in FIG. **6***b* contributes to the radiation of the device. The arrangement enables to cover longer distances than the configuration shown in FIG. **6***a*, providing a solution for short-range wireless communications and for longer range wireless communications normally including mobile communications.

[0062] FIGS. **12***a* and **12***b* illustrate examples of the wearable device structures shown in FIGS. **6***a* and **6***b* placed on a dielectric material that plays the role of an on-body tissue. Some of the parameters that characterize the dielectric material, chosen so that it simulates the on-body tissue, are detailed in FIGS. **12***a* and **12***b*. FIG. **13** provides the input reflection coefficients related to the free-space and on-body embodiments provided in FIGS. **6***a*, **6***b*, **12***a*, and **12***b*, respectively. Such input reflection coefficients show that an arrangement like the one provided in FIG. **6***a*, whose corresponding input reflection coefficients curves are labeled as FS-C (free-space example) and OB-C (on-body example) in FIG. **13**, is more robust to the effect of a nearby living body in terms of input-impedance matching performance. A free-space embodiment that contains a booster located to a distance from an edge of a ground plane layer like the one shown in FIG. **6***b* experiments a considerable mismatch when it is characterized in on-body conditions, as shown in FIG. **13** by curves FS-E and OB-E. The input reflection curves aforementioned correspond to embodiments that do not include a matching network to achieve matched examples.

[0063] Next, four matching networks used to match the embodiments shown in FIGS. **6***a*, **6***b*, **12***a*, and **12***b* are provided in FIGS. **14***a*-**14***d*. The labels used for each matching network are chosen accordingly to the labels used for referring to each of the corresponding examples, shown in FIGS. **6***a*, **6***b*, **12***a*, and **12***b*. The modules of the input reflection coefficients related to the specific matched examples are provided in FIG. **15** and, in FIG. **16**, their corresponding radiation and antenna efficiencies. The radiation and antenna efficiencies are higher for the arrangement where the non-radiating element is placed on the ground plane layer comprised in the radiating system as shown in FIG. **6***a*. In the particular examples provided and described before, a 10 dB difference in the antenna efficiency obtained for the on-body cases is evidenced between both examples.

[0064] In FIG. **17**, another embodiment that comprises a non-resonant element also containing a top conducting surface supported on a dielectric substrate and the top conducting surface connected to a feeding element, is provided. The non-resonant element is placed at a non-centered position on a ground plane layer also supported by a dielectric material. In this particular embodiment, the non-resonant element is square, as shown in FIG. **17**, and features a height equal to 1 mm. The ground plane layer below the non-resonant element is supported by a piece of dielectric material placed underneath. The example is characterized in on-body conditions, as shown in FIG. **18**, and the radiation efficiency related to this specific example is provided in FIG. **19**. The dielectric material used to support the top conducting surface is featured by low losses. The other dielectric properties used are provided in FIG. **18**. The radiation efficiency related to such embodiment is improved by using a low-losses supporting dielectric material.

[0065] Other embodiments refer to wearable devices that usually require operation at mobile communications including low-frequency bands, devices like for instance smartwatches. Such devices comprise a radiating system, the radiating system comprising a radiating structure that comprises at least a non-resonant element **1"** and at least a ground plane layer **2** extended by a conductive element **12** (FIG. **9**). More concretely, FIGS. **20***a*-**20***c* provide some embodiments able to operate at low-frequency mobile bands, as for example GSM900, which comprise a conductive strip that extends the ground plane layer contained in the radiating structure that is included in the wearable device, typically a smartwatch or alike, the conductive strip normally contained in the device strap. The length of the conductive strip determines the performance of the embodiments especially at low-frequencies. More specifically, FIG. **20***a* shows an embodiment wherein the conductive element is a conductive strip that measures a quarter length of the length related to a 60 mm-diameter conductive strap with a round-shape. FIG. **20***b* shows an embodiment including a conductive strip that measures half a length of the length related to a 60 mm-diameter round conductive strap. Finally, FIG. **20***c* provides an example containing a conductive element that extends the ground plane layer included in the radiating structure that features the smart device, whose length corresponds to the entire length of a 60 mm-diameter round conductive strip. The platform and ground plane layer dimensions related to the particular aforementioned examples are provided in FIG. **20** and the booster contained in those examples is a RUN mXTEND booster, shown in FIG. **8***b*.

[0066] FIG. **21** shows the radiation efficiencies that correspond to the examples described previously and presented in FIGS. **20***a*-**20***c*. The radiation efficiency obtained when the conductive strip length corresponds to the entire length of a 60 mm-diameter round strip, labeled RE-E in FIG. **21**, is higher, especially at low-frequencies smaller than 1 GHz, than the radiation efficiency achieved when such conductive strip is shorter than the aforementioned length. The curve RE-H shows that better radiation efficiencies are achievable when the conductive strip is half a length of the length related to a 60 mm-diameter round strap than when it is a quarter length, the corresponding radiation efficiency curve labeled RE-Q in FIG. **21**.

[0067] The input reflection coefficients related to the embodiments presented in FIGS. **20***a*-**20***c* are provided in FIG. **22** and the related antenna efficiencies are plotted in FIG. **23**. Those embodiments are matched at both low frequencies and high frequencies allocated in mobile frequency ranges. The impedance bandwidth achieved at low frequencies around 900 MHz is enlarged when the conductive strip extension features an optimum length that corresponds to the entire length of a 60 mm-diameter round strip. In general, the input reflection coefficient criteria used in the described context to consider that a solution is well matched is an input reflection coefficient below −6 dB or below −4.5 dB in the target frequency band. The antenna efficiency related to the embodiments is considerably improved around 900 MHz for this particular example, and the antenna-efficiency bandwidth is enlarged at those frequencies, adding bands to the device operation like GSM850.

[0068] Other embodiments correspond to wearable devices focused on covering diverse applications as for instance health applications, sport applications, elderly-care applications, which normally cover short-range communications. FIGS. **24***a*-**24***c* show three different embodiments that include a radiating system arranged as described in FIG. **6***b*. These embodiments improve the space available for placing additional components, by reducing the ground plane clearance, labeled CA, CB and CC in FIGS. **24***a*-**24***c* for each of the examples shown, which contains a RUN mXTEND booster B-224, the one illustrated in FIG. **8***b*. The dimensions of the clearances are included in FIGS. **24***a*-**24***c*. The radiation efficiencies related to the mentioned embodiments are provided in FIG. **25** and curves RE-CA, RE-CB and RE-CC evidence that the degradation related to the reduction of the clearance is not relevant for this particular configuration and the operation frequencies of operation (plotted in FIG. **25**).

[0069] Next, three matching networks used for matching the embodiments provided in FIGS. **24***a*-**24***c* are presented in FIG. **26**. The matching network topology used for all the examples is the same but the component values used are different. The module of the input reflection coefficients related to the matched embodiments are plotted in FIG. **27**. All the embodiments are full well matched below −6 dB in the target frequency bands of operation, for this particular example Bluetooth bands and/or Wifi bands for instance, covering frequency ranges that include 2.45 GHz. In FIG. **28**, the antenna efficiencies related to those embodiments are provided. The antenna efficiency performance related to the embodiments featured by the different clearance areas described in FIGS. **24***a*-**24***c* remains stable in the target frequency bands, like Bluetooth or Wifi bands, despite the reduction of the ground plane clearance.

[0070] Other embodiments comprise an additional ground plane **13** as shown in FIG. **10** used as shielding. The shielding ground plane is placed at a certain distance from a first ground plane layer included in the radiating structure comprised in the smart wearable device, the first ground plane layer supported by a dielectric material of a certain thickness, which in the particular examples provided in FIGS. **29***a*-**29***c* measures 1 mm. In FIGS. **29***a*-**29***c*, three embodiments comprising a shielding ground plane in the radiating structure are provided, the additional shielding ground plane placed at 3 mm, at 5 mm or at 10 mm in each example shown in FIG. **29***a*, FIG. **29***b* and FIG. **29***c*, respectively. The booster element included in the embodiments is a CUBE mXTEND booster, with dimensions 5 mm×5 mm×5 mm, included in the mXTEND range of commercial boosters described in http://www.fractusantennas.com/products. The ground plane clearance comprised in the first ground plane layer included in the radiating structure comprised in the embodiments is minimized as shown in FIGS. **29***a*-**29***c*.

[0071] The radiation efficiencies related to the embodiments presented in FIGS. **29***a*-**29***c* are provided in FIG. **30**. For comparison purposes, FIG. **30** also contains a curve that represents the radiation efficiency related to an example with the same configuration characteristics and dimensions than the embodiments from FIG. **30** but without shielding ground plane. Such curves show that the radiation efficiency performance remains stable when the shielding ground plane is added to the radiating structure that features the smart wearable device. Next, the input reflection coefficients related to the aforementioned embodiments, once matched, are plotted in FIG. **31** and their corresponding radiation and antenna efficiencies in FIG. **32**. The performance in terms of bandwidth and efficiencies achieved at the operation bands of the embodiments, more concretely Bluetooth bands and/or Wifi bands for instance, which cover frequency ranges that comprise the frequency 2.45 GHz, is stable when the shielding ground plane distance is increased, however a slight improvement is evidenced.

[0072] FIGS. **33***a*-**33***c* provides examples of configurations placed above a dielectric structure that reproduces a phantom hand. FIG. **33***a* shows an embodiment placed at a certain distance above the dielectric phantom hand. FIG. **33***b* provides a shielded embodiment placed directly above the dielectric phantom hand and FIG. **33***c* shows another shielded embodiment on a dielectric phantom hand wherein the shielding ground plane is connected to the original radiating structure ground plane. FIG. **35** presents the radiation and antenna efficiencies related to the configurations provided in FIG. **33**.

[0073] Some embodiments further comprise a shielding element **13**, which in some of those embodiments the shielding element includes an additional ground plane layer placed between the carrier body and the radiating structure comprised in the wearable device and located at a certain distance from a first ground plane layer comprised in the radiating structure. In some other embodiments, the shielding is connected to the first ground plane layer included in the radiating structure (FIG. **11**) by a conductive element. Some of the shielded embodiments comprise at least a strip connection, like for example element **14** shown in FIG. **11**, between the shielding ground plane and the first ground plane layer included in the radiating structure. Additionally, the first ground plane layer or layers comprised in some embodiments, shielded or not, is elongated by a conductive element, typically a strip.

[0074] Next, some examples of different configurations placed on a dielectric material block that simulates a phantom hand are described. All those embodiments are located at 8 mm from the phantom block. The configuration shown in FIG. **33***a* comprises an arrangement like the one in FIG. **6***b* featured by a minimized ground plane clearance of dimensions 5×14 mm^2 that hosts a RUN mXTEND booster (FIG. **8***b*). The dimensions of the ground plane layer contained in the radiating structure are 30 mm width and the maximum length is also 30 mm. In FIG. **33***b*, an arrangement containing a shielding ground plane of 1 mm thickness placed at 7 mm underneath a first ground plane layer contained in the radiating structure that characterizes the smart wearable device is provided. The configuration shown in FIG. **33***c* placed above the dielectric phantom is similar to the one provided in the previous Figure, but the shielding ground plane is connected to the first ground plane layer by a conducting strip.

[0075] In FIG. **34**, the radiation efficiencies related to the specific embodiments presented in FIGS. **33***a*-**33***c* are provided. The distance between the device structure and the phantom hand has an impact on the input impedance and the radiation efficiency. The smaller the distance the lower the radiation efficiency. The radiation efficiency related to the on-body arrangement shown in FIG. **33***a* is improved when a shielding ground plane is added to the radiating structure include in the wearable device. However, the radiation performance related to an arrangement wherein the shielding ground plane is connected to the ground plane layer included in the device radiating structure by a conductive strip is similar to the radiation efficiency related to the configuration presented in FIG. **34**, in which the radiating structure is placed at the same distance from the phantom dielectric but does not include a shielding ground plane between them.

[0076] FIG. **35** shows the radiation and the antenna efficiencies related to the embodiments presented in FIGS. **33***a*-**33***c*, once matched. The radiation efficiencies are plotted with dashed lines and the corresponding antenna efficiencies with solid lines. Among the configurations compared in FIG. **35**, the arrangement that includes a shielding ground plane under the original structure, which comprises a first ground plane layer in the radiating structure that is included in the wearable device, is the one that features better antenna efficiency values in the target frequency range or ranges, comprising Bluetooth bands and/or Wifi bands for example. However, the other embodiments are also good solutions for operating on a carrier living body, providing also adequate antenna efficiencies in such operation environments as shown in FIG. **35**.

[0077] Although some examples of smart wearable devices featuring a radiating system arrangement that comprises at least a non-resonant element, such as for instance those described herein are provided, other non-resonant element arrangements could have been constructed.

What is claimed is:

1. A wireless wearable device comprising:

a radiating system configured to operate in at least one operating frequency band contained within at least one frequency region, the radiating system comprising:

a radiating structure which comprises:

at least a non-resonant element; and

a first ground plane layer,

wherein the at least one non-resonant element and the at least one ground plane layer are disposed in an arrangement having a maximum radiating structure length less than 0.8 times a free-space wavelength corresponding to a highest frequency of operation.

2. The wireless wearable device according to claim **1**, wherein the radiating structure has a maximum length less than 0.3 times the free-space wavelength corresponding to the highest frequency of operation.

3. The wireless wearable device according to claim **1**, wherein the radiating structure has a maximum length less than 0.125 times the free-space wavelength corresponding to the highest frequency of operation.

4. The wireless wearable device according to claim **1**, wherein the first ground plane layer of the radiating structure comprises at least a ground plane clearance that contains the at least one non-resonant element.

5. The wireless wearable device according to claim **4**, wherein the non-resonant element is a volumetric conducting piece.

6. The wireless wearable device according to claim **4**, wherein the radiating structure further comprises a shielding ground plane layer.

7. The wireless wearable device according to claim **1**, wherein the first ground plane layer of the radiating structure does not contain ground plane clearance.

8. The wireless wearable device according to claim **7**, wherein the at least one non-resonant element comprises a top conducting surface supported by a dielectric material piece, the conducting surface being connected to a feeding element.

9. The wireless wearable device according to claim **1**, wherein the at least one non-resonant element comprises a top conducting surface supported by a dielectric material piece, the conducting surface being connected to a feeding element.

10. The wireless wearable device according to claim **1**, wherein the non-resonant element is a volumetric conducting piece.

11. The wireless wearable device according to claim **1**, wherein the radiating structure further comprises a shielding ground plane layer.

12. A wireless wearable device according to claim **1**, wherein the first ground plane layer of the radiating structure is extended by a conductive element.

13. A wireless wearable device comprising:

a radiating system configured to operate in at least one low-frequency mobile band within the 880 MHz to 960 MHz frequency range, the radiating system comprising:

a radiating structure which comprises:

at least one non-resonant element; and

a ground plane layer extended by a conductive element,

wherein the at least one non-resonant element and the ground plane layer are disposed in an arrangement having a maximum radiating structure length less than 0.8 times a free-space wavelength corresponding to a highest frequency of operation.

14. The wireless wearable device according to claim **13**, wherein the non-resonant element is a volumetric conducting piece.

15. The wireless wearable device according to claim **14**, wherein the non-resonant element comprises a top conductive surface, supported by a dielectric material piece, which is connected by at least a via element to at least one additional bottom conducting surface.

16. The wireless wearable device according to claim **15**, wherein the radiating structure further comprises a shielding ground plane layer.

17. The wireless wearable device according to claim **14**, wherein the radiating structure further comprises a shielding ground plane layer.

18. The wireless wearable device according to claim **17**, wherein the shielding ground plane is connected to the first ground plane layer of the radiating structure by a conductive element.

19. The wireless wearable device according to claim **18**, wherein the conductive element comprises at least a conducting strip element.

20. A wireless wearable device according to claim **17**, wherein the first ground plane layer of the radiating structure is extended by a conductive element.

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