

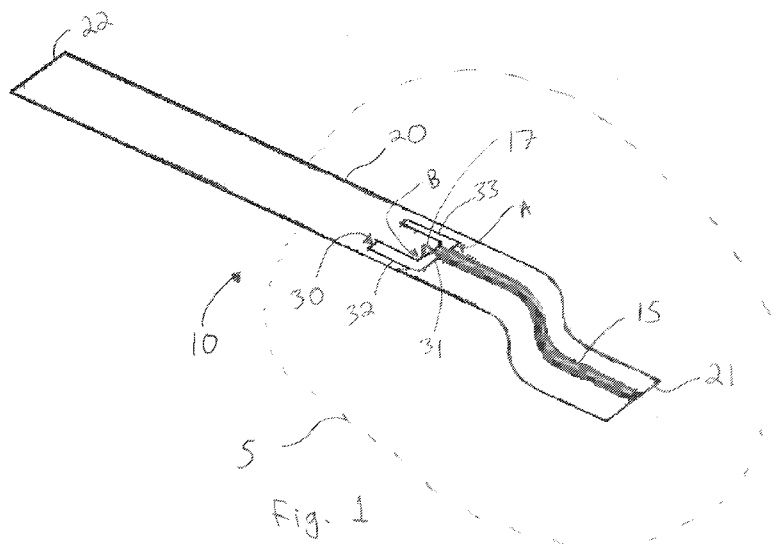


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(54) Title: ON RADIATOR SLOT FED ANTENNA



(57) Abstract: An antenna includes a slot feed on the radiator itself (On Radiator Slot Fed Antenna or ORSFA) instead of the slot feed being a separate element. One of the advantages of having the slot feed integrated onto the radiator is that the antenna is less dependent on the adjacent conductive parts, since the feed is coupling to the radiator rather than to ground (as is done in a standard slot feed antenna concept). The Q of the radiator can also be reduced for a given volume, since the coupler is removed from the antenna volume. In an embodiment the antenna can include a transmission line and an impedance match circuit directly on the radiator.



## On Radiator Slot Fed Antenna

### RELATED APPLICATIONS

[0001] This application claims priority to United States Provisional Application No. 61/598,549, filed February 14, 2012, which is incorporated herein by reference in its entirety.

### FIELD OF THE INVENTION

[0002] The present invention relates to the field of antennas, more specifically to the field of antennas suitable for use in compact devices.

### DESCRIPTION OF RELATED ART

[0003] Antennas are a challenging element to provide in a communication system. On the one hand it is desirable to make the antenna very small. On the other hand, for resonance of the antenna is related to the size and there are limits to how small an antenna can be and still provide acceptable performance.

[0004] Slot fed antennas are known and an embodiment of a slot-fed antenna is described in in PCT Application No. PCT/US10/47978, which is incorporated herein by reference in its entirety. The slot-fed antenna attempts to address some of the problems with prior antenna designs by providing more bandwidth for a given volume of antenna. While the slot-fed antenna design has certain advantages, it is somewhat dependent on adjacent conductive parts and the ground plane is used as part of the circuit. Certain applications and package configurations are less suitable to such a design but still would benefit from improved bandwidth for a given radiator size. Thus, certain individuals would appreciate further improvements in antenna design.

### BRIEF SUMMARY

[0005] This disclosure demonstrates a very compact antenna designs which can be used in highly capacitive loaded environment like devices with metal covers. The concept can be used as a single resonance antenna for GPS and Bluetooth applications or as multi resonance antennas like WiFi and cellular systems by combining several ORSFA elements.

[0006] In an embodiment, a radiating element is coupled to ground on a first end and a second end is separated from ground. The radiating element includes a slot with a first side and a second side, the slot positioned between the first and second end with the first side

facing the first end and the second side facing the second end. A feed is coupled to the slot on the second side.

#### BRIEF DESCRIPTION OF THE DRAWINGS

[0007] The present invention is illustrated by way of example and not limited in the accompanying figures in which like reference numerals indicate similar elements and in which:

[0008] Fig. 1 illustrates a perspective view of an embodiment of an antenna configuration.

[0009] Fig. 2 illustrates an impedance plot of an antenna on a Smith chart.

[0010] Fig. 3 illustrates an impedance plot of an antenna on a Smith chart.

[0011] Fig. 4 illustrates an impedance plot of an antenna on a Smith chart.

[0012] Fig. 5 illustrates an impedance plot of an antenna on a Smith chart.

[0013] Fig. 6 illustrates a perspective view of an embodiment of an antenna configuration.

[0014] Fig. 7 illustrates a perspective view of an embodiment of an antenna configuration.

[0015] Fig. 8 illustrates a perspective view of an embodiment of an antenna configuration.

[0016] Fig. 9 illustrates a perspective view of an embodiment of an antenna configuration.

[0017] Fig. 10 illustrates a perspective view of an embodiment of an antenna configuration.

[0018] Fig. 11 illustrates a perspective view of an embodiment of an antenna configuration.

[0019] Fig. 12 illustrates a perspective view of an embodiment of an antenna configuration.

#### DETAILED DESCRIPTION

[0020] The detailed description that follows describes exemplary embodiments and is not intended to be limited to the expressly disclosed combination(s). Therefore, unless otherwise noted, features disclosed herein may be combined together to form additional combinations that were not otherwise shown for purposes of brevity.

[0021] The description that follows illustrates novel techniques for integrating a slot feed on an antenna onto the radiator itself (On Radiator Slot Fed Antenna or ORSFA), and not as a separate element as described in PCT Application No. PCT/US10/47978, which is incorporated herein by reference in its entirety. One of the advantages of having the slot feed integrated onto the radiator is that the antenna is less dependent on the adjacent conductive

parts, since the feed is only coupling to the radiator and not also to the ground as in the standard slot feed antenna concept. The Q of the radiator is also reduced for a given volume, since the coupler is removed from the antenna volume, so that the capacitive coupling of the radiator can be reduced. In an embodiment the antenna can include a transmission line and an impedance match on the radiator itself.

**[0022]** Fig. 1 illustrates an embodiment of an antenna 10 extending from a ground plane 5. The antenna 10 includes a radiator 20 with a first end 21 and a second end 22. The first end 21 is connected to the ground plane 5 and the second end is not electrically connected to the ground plane. A slot 30 is provided that includes a first side A (facing the first end 21) and a second side B (facing the second end 22). As depicted, the slot 30 has a base 31 and a first leg 32 and a second leg 33. The length of the legs allows the distance around the slot 30 to be tuned as desired. A feed is directly connected to the second side B of the slot by a conductor 17 that extends from a coax cable 15. Thus, the on-radiator feed can be provided as depicted in Fig. 1, where a coax cable is used to feed across a slot on the radiator (indirect feed). The radiator 20 itself can be design in a conventional manner so as to be in resonance at the desired frequency and the indirect slot feed is used to create a Chebyshev-like match so that the available impedance bandwidth is increased. The position, size and shape of the slot are used to define the additional Chebyshev match, as is further described below. Thus, the antenna depicted in Fig. 1 illustrates an on-radiator, slot-fed antenna (hereinafter an “ORSFA”).

**[0023]** As depicted, the radiator 20 is positioned on an infinite ground plane (illustrated by ground plane 5) and has a well-defined connection between the radiator 20 and the ground plane 5. However, in practice the ground plane 5 could have any size and shape, and the radiator 20 could be positioned anywhere on the ground plane 5.

**[0024]** The unmatched complex impedance of the basic ORSFA is shown in Fig. 2. As depicted, the Smith chart 50 includes a curl 52. The small curl 52 is the Chebychev like match created by the indirect slot feed. The size of the curl 52 is controlled by the physical size and shape of the slot. A higher coupling (larger curl) is achieved by moving the slot closer to the first end of the radiator (e.g., closer to the ground connection of the radiator) or by increasing the size of the slot. The phase delay of the curl (the position in the Smith chart) is also an important factor, since this determines the topology of the needed matching circuit and the values of the components. In order to maximize the antenna impedance bandwidth it is desired to keep the phase delay as small as possible, which is somewhat contradictory with

keeping the matching circuit simple. An acceptable compromise for the ORSFA depicted in Fig.1 is to design for a phase delay, allowing for a 50 Ω match, by using a parallel capacitor. The result of using a parallel capacitor are shown in Fig. 3. As can be appreciated, the phase delay is primarily controlled by the size and shape of the slot or by discrete components. The adjustment of the resonance depicted in Fig. 3 was done with a series capacitor for convenience rather than using a different size slot; however, the phase optimization can also be done by adjusting the slot. If possible, adjustment by varying the slot is preferred because it will reduce the number of discrete components used and thereby reduce the complexity and bill of material. The final step is to match the curl to 50 Ω using a parallel capacitor, the result of which are shown in Fig. 5, where impedance curve 62a has a first frequency 63 and a second frequency 64 that are about 98 MHz apart (the two frequencies representing the entrance and exit of the standing wave reflection (SWR) circle = 3:1. This compares with the impedance curve 62b in Fig. 5, where the impedance curve 62b has a frequency 65 and a frequency 66 (the two are about 40 MHz apart) representing when the impedance curve enters and exits the SWR = 3 circle. These values are provided below in Table 1.

[0025] It can be appreciated that the impedance characteristic of the matched ORSFA is very similar to that of a Chebyshev match, which helps contribute to the improved impedance bandwidth. The impedance of the same element, but fed with a standard direct feed, is shown in Fig. 5. In that example, the match was provided by a series inductor, followed by a parallel inductor. The obtained impedances between the slot-fed feeding technique and the standard direct feed technique is summarized in Table 1:

	Bandwidth Frequencies at SWR=3			
	Start	Stop	Bandwidth	Bandwidth
<b>High impedance slot feed</b>	820 MHz	990 MHz	98 MHz	10.7 %
<b>Standard direct feed</b>	893 MHz	933 MHz	40 MHz	4.4 %
<b>Improvement</b>			58 MHz	143 %

Table 1

[0026] The available impedance bandwidth is increased from 40 MHz to 98 MHz using the same element on identical ground planes, but feeding them differently. An increase in impedance bandwidth of 143 % is observed for this configuration in a lossless environment. A similar result is expected for a lossy environment, since the Q of the element is identical

and the coupling slot is not radiating at the element resonance frequency but instead is a very high Q 2<sup>nd</sup> order matching circuit.

[0027] While providing acceptable performance, feeding the radiator with a coax cable may not always be a practical solution from a packaging standpoint. This is because the coax cable occupies space and could be difficult to mount in certain applications. An easier to package solution is to combine a microwave transmission line on the radiator with a coax cable, as depicted in Fig 6. In this configuration a coax cable 115 with a conductor 117 is connected at the first end of a flex PCB 120 with the conductor electrically connected to a microwave transmission line 118 that is used to feed across the slot 130 via line end 119 (which as depicted in Fig. 6 is a direct coupling).

[0028] One disadvantage of using a transmission line on the radiator is that a double side flex PCB with vias is best suited for such a design (which may tend to increase the cost of the solution). However, having a double side Flex PCB makes it possible to substitute the discrete matching component with microwave stubs, low impedance transmission lines and on PCB capacitors as shown in Figs. 7 and 8. It should be noted that the transmission line is depicted as being implemented with a microstrip line. However, if the flex PCB has more than 2 layers, it is also possible to use a stripline instead of a microstrip line.

[0029] Specifically, Fig. 7 illustrates a radiator 220 that can be formed of a flex PCB and includes a slot 130 (which is sized as desired). A coax cable 115 includes a conductor 117 that is electrically connected to transmission line 218 which includes an open stub 219 that couples to the radiator (thus providing an indirect coupling rather than having a direct electrical connection as is depicted in Fig. 6). A parallel capacitor 216 is used to help match the impedance of the transmission line to the desired 50 ohms.

[0030] The  $\lambda/4$  wave open stub is equivalent to a series capacitor and is used control the position and size of the curl. Increasing the length of the open stub to more than a  $\lambda/4$  wave will shift the curl clockwise in the smith chart, while reducing the length will shift it counter clockwise. The width of the  $\lambda/4$  wave open stub can be used to tune the size of the curl without affecting the phase delay and a wider open stub will increase the size of the curl.

[0031] Fig. 8 illustrates an embodiment of antenna that has a radiating element 320 that supports a transmission line 318 that is connected at one end to the conductor 117 of the coax cable 115. The transmission line 318 includes a stub 319 that couples indirectly to the radiating element on the second side of a slot 330. As discussed above, the dimensions of the stub can be adjusted as appropriate. The transmission line 318 further includes a low

impedance area 316 that emulates a parallel capacitor. As can be appreciated, the use of the open stub controls phase delay while the low impedance area can provide the desired 50 ohms match.

**[0032]** The above illustrated slot feeds configurations are all closed slot Low Impedance Slot Feed (LISF) embodiments, similar to what is described in PCT Application No. PCT/US10/47978. However, an open slot LISF configuration could also be used, as is depicted in Fig. 9. The open slot LISF's can have any shape and be placed anywhere on the radiator, the size and position having the affects discussed above. As can be appreciated, therefore, a radiator could include any combination of an open or closed slot and a directly or indirectly coupled transmission line.

**[0033]** As is known, the resonance frequency of the radiator is determined by its length, which could be a problem for certain applications, particularly where the space allocated for the antenna is too small to allow a resonance at a desired frequency. The resonance frequency of the resonator can be changed/tuned by adding a tuning circuit, as shown in Fig. 10. The radiator 520 includes a slot 530 with a conductor 117 from a coax cable 115 connected to a transmission line 518 that is directly coupled across the slot (as opposed to using the stub depicted in Fig. 7). A tuning circuit, as depicted, consists of a cutout 545 and a capacitor 540 that is positioned in the gap formed in the radiator 520.

**[0034]** The depicted tuning circuit consists of a capacitor across a cutout in the radiator, forming a parallel resonance circuit. In such a configuration, the inductor (determined by the cutout) is fixed, but the characteristics of the parallel resonator can be changed by adjusting the capacitance. The capacitor 540 could be a discrete component or implemented in the flex itself. In addition, using a tunable capacitor 540 (e.g., one that can be varied in response to a signal provided by a controller) will allow for a tunable antenna system which could be operated in either a closed or open feedback loop configuration.

**[0035]** Having majority of the antenna structure and matching circuit implemented on a flex PCB enables the option to move the coax away from the feed area. This leads to an antenna solution where the radiator 520 (which can be the same as in the antenna depicted in Fig. 10) can be mounted on a traditional carrier 560, as show in Fig. 11 or on the inside of a cover/housing 570, as shown in Fig. 12. As can be appreciated, the antenna only needs one connection between the antenna flex PCB and the chassis of the device, thus providing substantial design flexibility. Another advantage of mounting the flex PCB on the inside of a cover or housing part is that the high electromagnetic fields between the radiator and the

chassis ground are coupled through air rather than some potentially more lossy carrier material, thereby improving the radiated performance of the antenna.

**[0036]** The above mention examples are all single resonance antenna configurations. However, it is possible to combine individual ORSFA's to cover multiple frequency ranges, either as a multiple feed or single feed configuration. A multiple feed configuration uses a certain number of ORSFA configurations each fed individually from the RF frontend. Good impedance isolation is desirable between all of the ORSFA's in order to avoid an undesirable coupling loss.

**[0037]** A combining network is useful to implement a single feed multiple frequency range antenna system using ORSFA's. The combining network increases the isolation between the ORSFA's seen from the RF frontend, which is used to maintain the individual impedance bandwidths of the ORSFA's. Coupling loss is not an issue for the single feed configuration and the requirements for the impedance isolation between the individual elements is less than a multiple feed configuration. However, good impedance isolation is still desirable, since it will make the tuning of the ORSFA's easier. The combining network can include a desired combination of discrete components, microwave stubs and transmission lines.

**[0038]** The disclosure provided herein describes features in terms of preferred and exemplary embodiments thereof. Numerous other embodiments, modifications and variations within the scope and spirit of the appended claims will occur to persons of ordinary skill in the art from a review of this disclosure.

We claim:

1. An antenna, comprising:
  - a radiating element having a first end and a second end, the first end configured to be connected to a reference voltage plane and the second end not electrically connected to the reference voltage plane;
  - a slot in the radiating element, the slot having a first side and a second side and positioned between the first end and the second end, the first side facing the first end and the second side facing the second end; and
  - a feed coupled to the second side of the slot.
2. The antenna of claim 1, wherein the feed is a conductor, the conductor provided by a coax cable that extends along the radiating element from the first end until the slot.
3. The antenna of claim 1, wherein the feed is a transmission line positioned on the radiating element.
4. The antenna of claim 3, wherein the transmission line is coupled to the second side via an open-ended stub, the stub having a length approximately equal to a  $\lambda/4$  wave length.
5. The antenna of claim 4, wherein the transmission line includes a low impedance portion positioned between the first end and the second side of the slot.
6. The antenna of claim 4, wherein the transmission line includes a parallel capacitor formed by a stub extend off the transmission line between the first end and the second side of the slot.

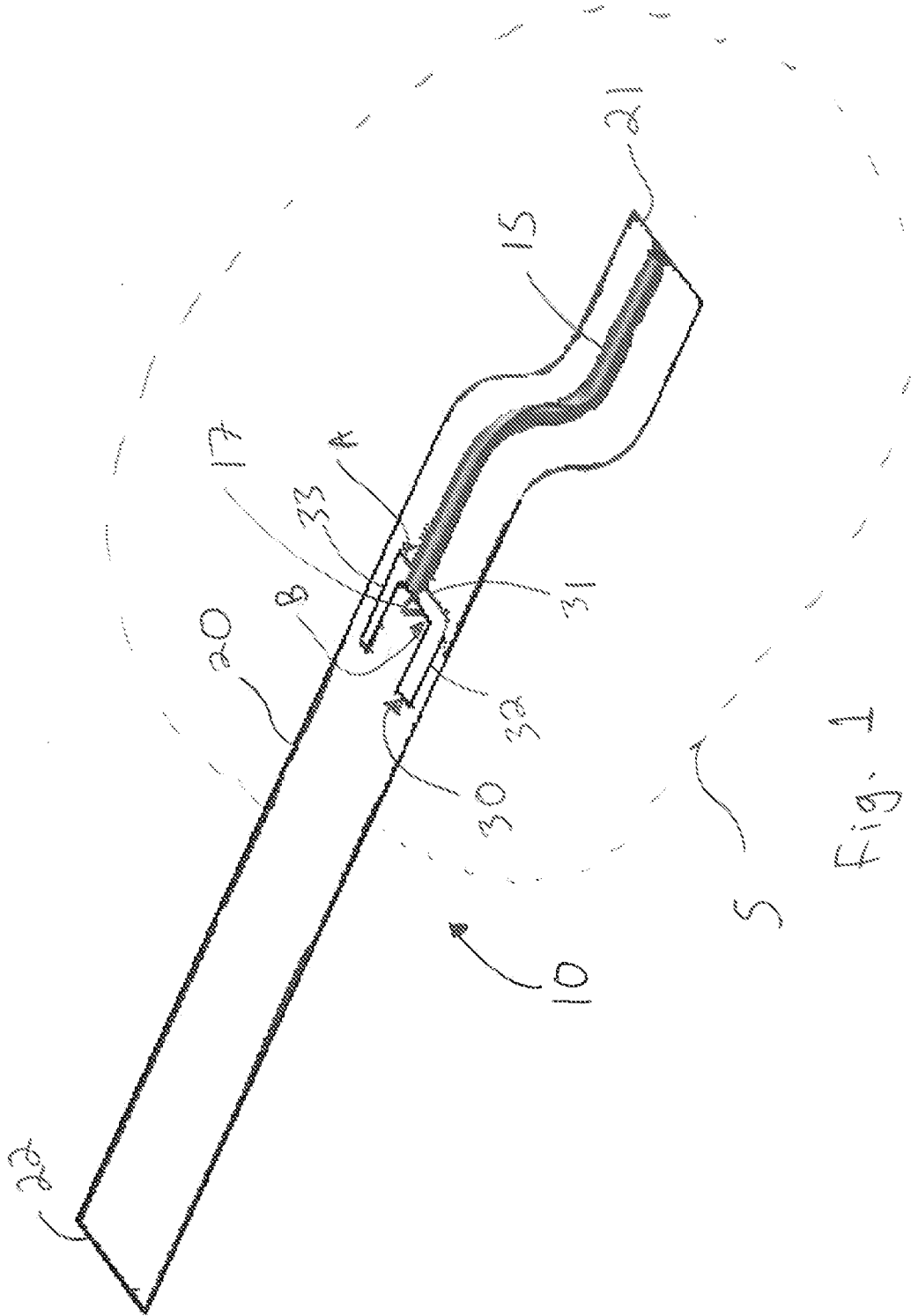


Fig. 1

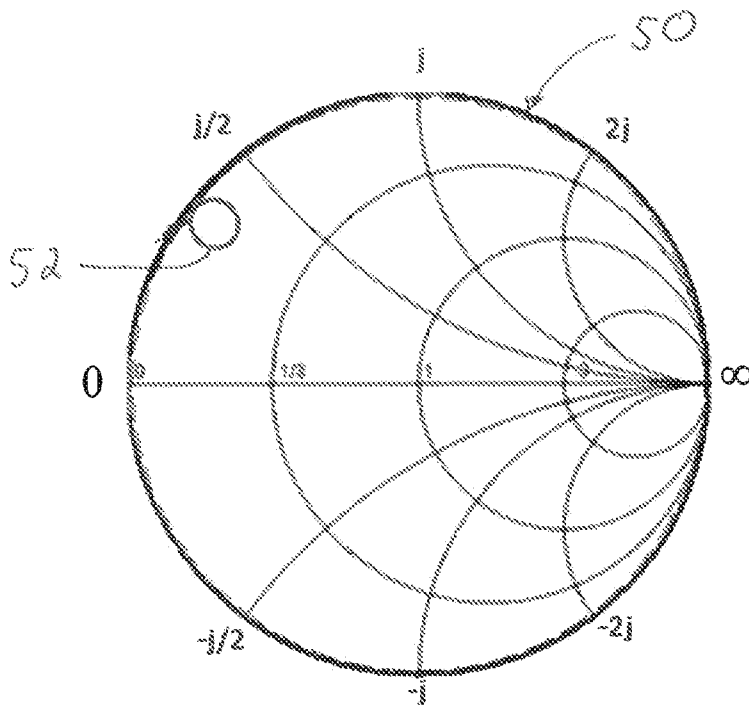


Fig. 2

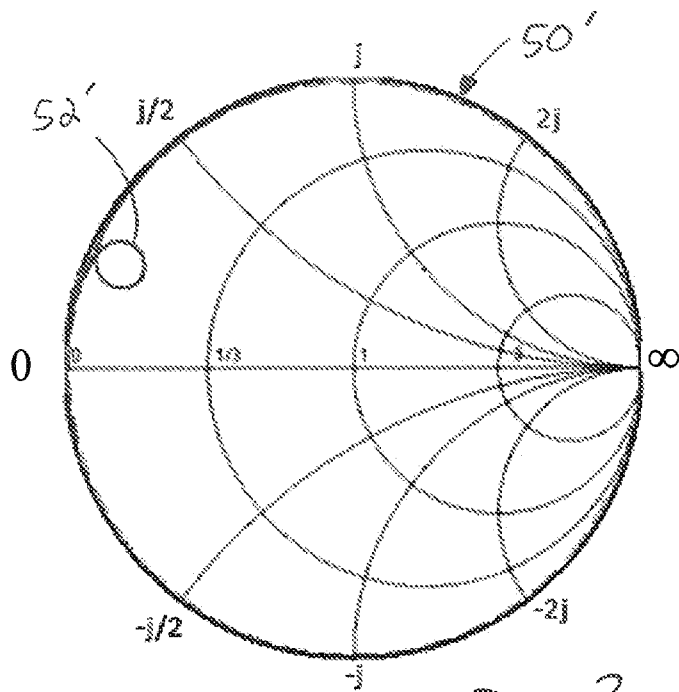
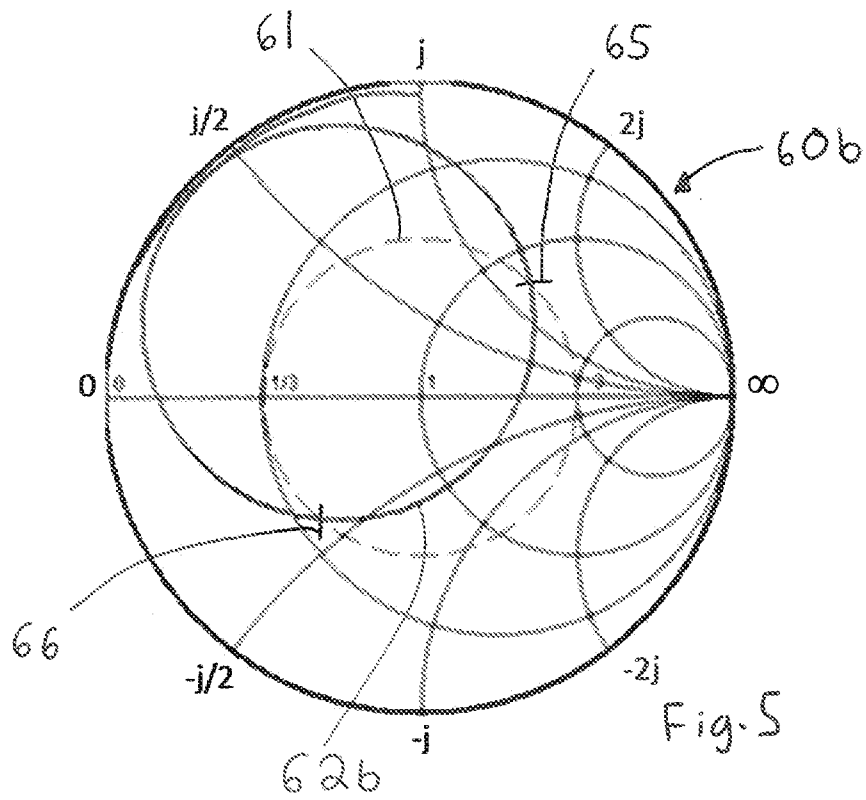
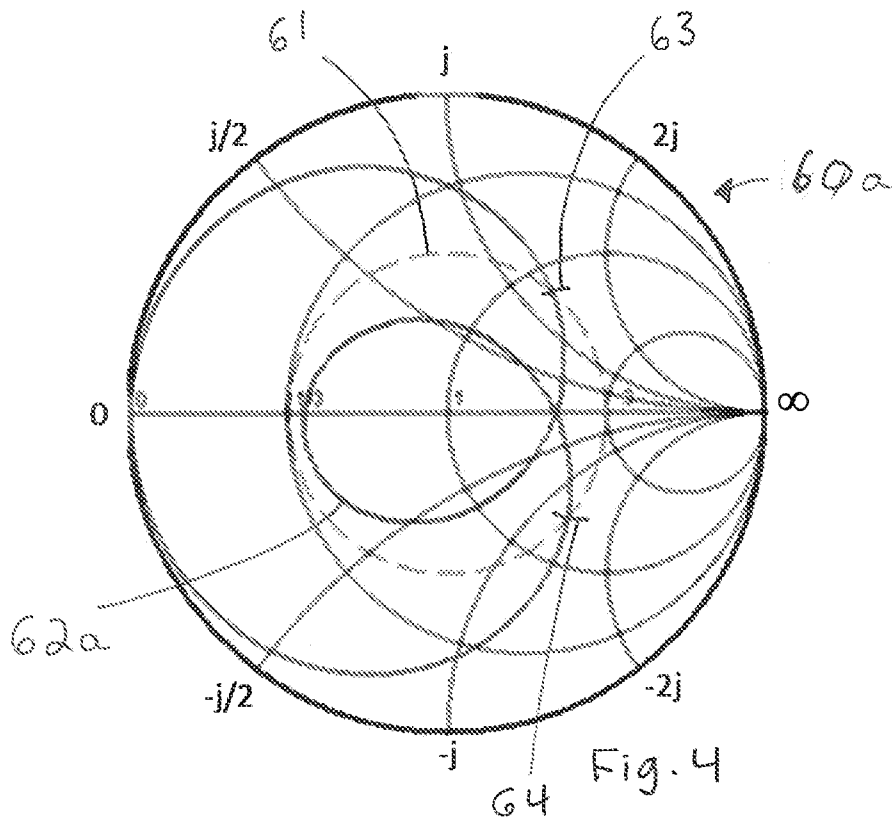
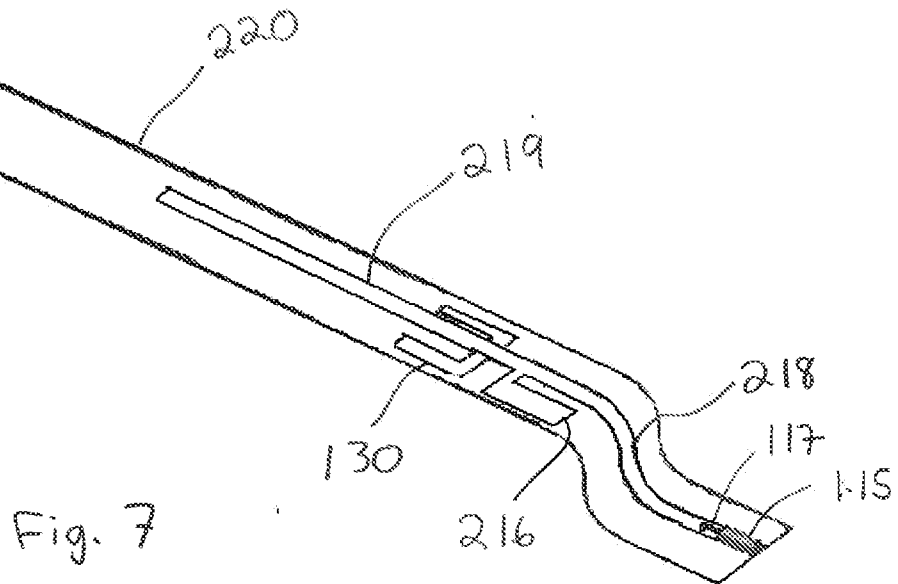
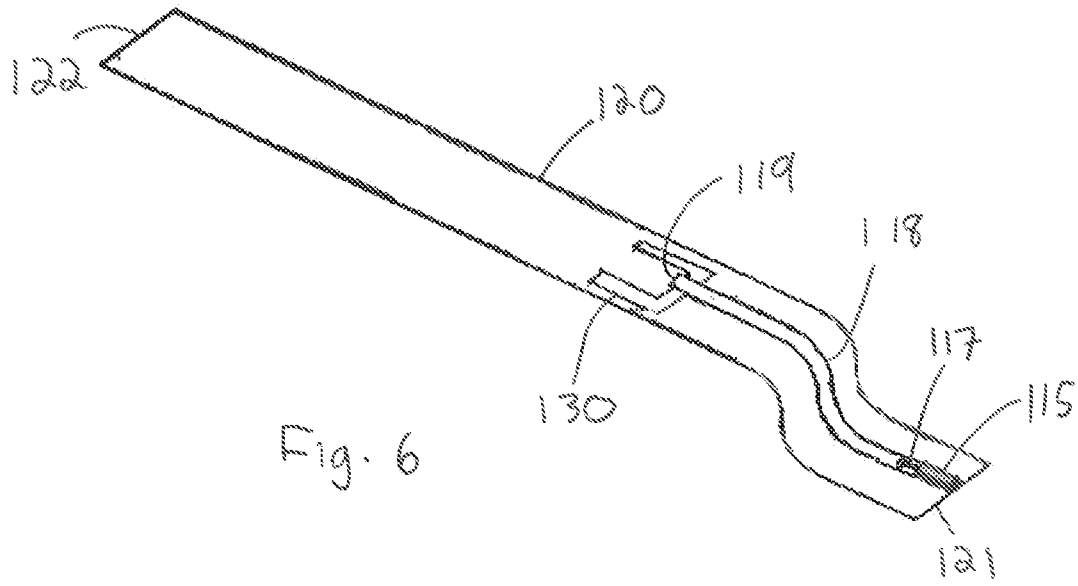


Fig. 3





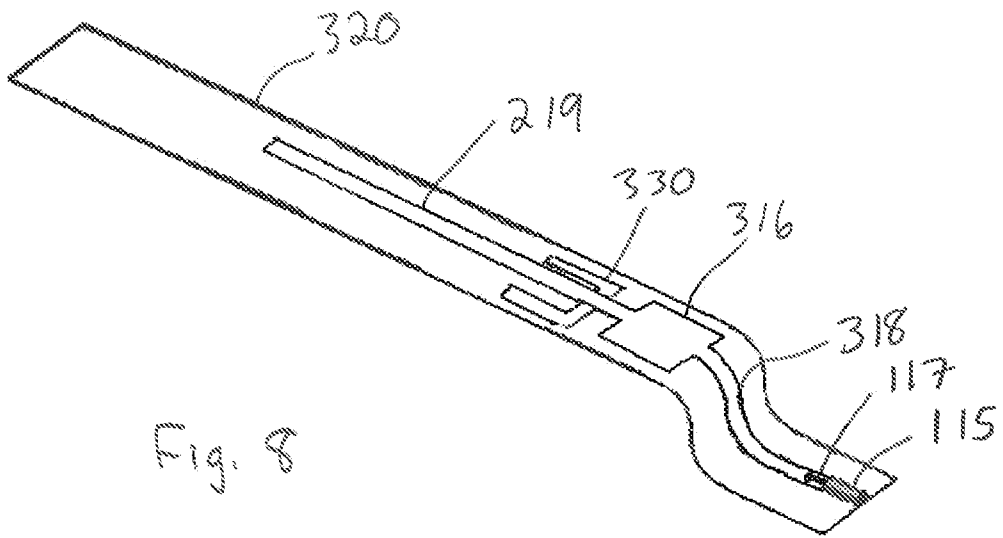


Fig. 8

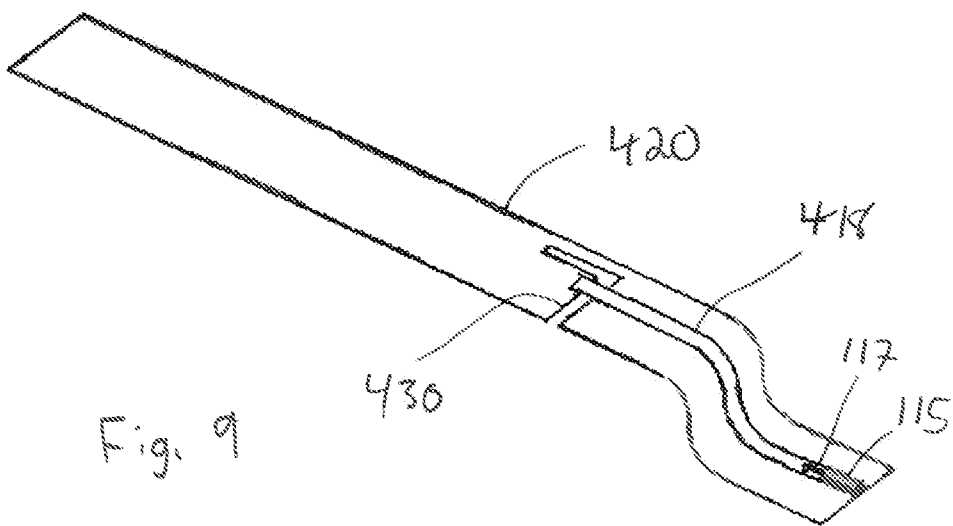


Fig. 9

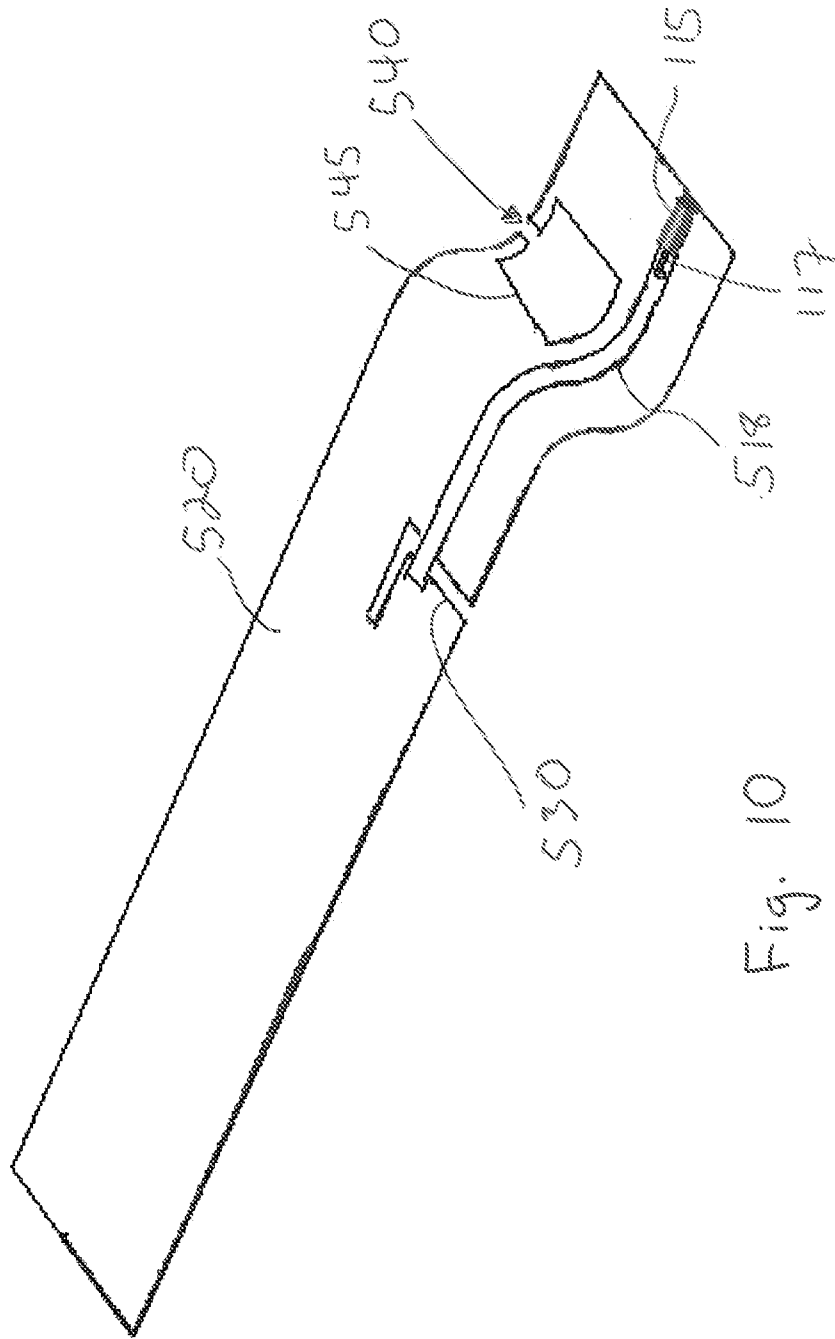


Fig. 10

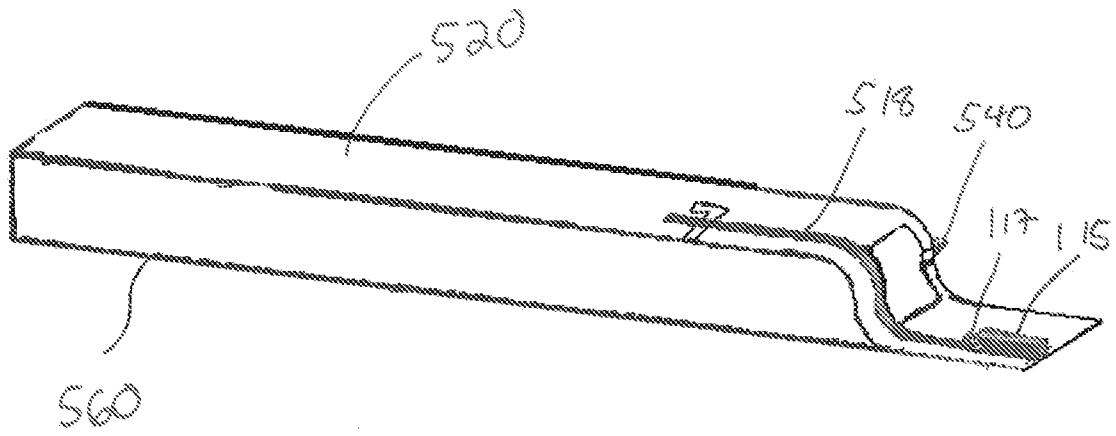


Fig. 11

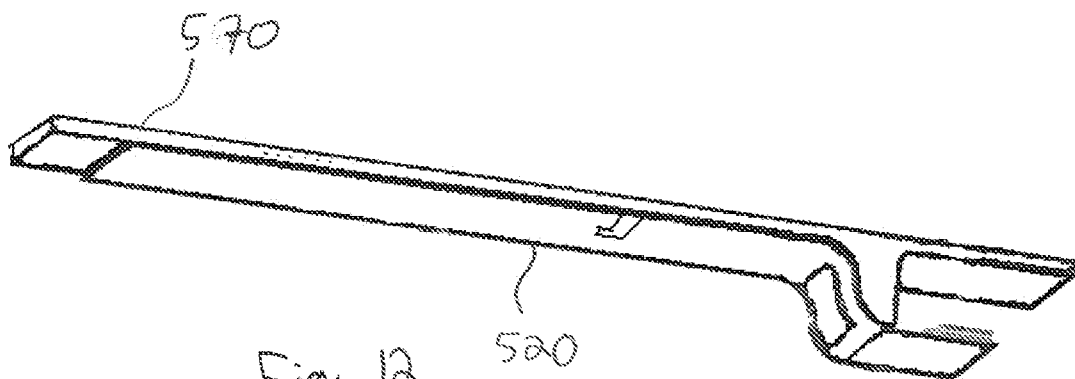


Fig. 12

## INTERNATIONAL SEARCH REPORT

International application No.  
**PCT/US2013/026020****A. CLASSIFICATION OF SUBJECT MATTER****H01Q 13/10(2006.01)i, H01Q 1/24(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 13/10Documentation 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 modelsElectronic data base consulted during the international search (name of data base and, where practicable, search terms used)  
eKOMPASS(KIPO internal) & Keywords: slot, feed, antenna, transmission, coax**C. DOCUMENTS CONSIDERED TO BE RELEVANT**

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 7551142 B1 (ZHANG et al.) 23 June 2009 See column 12-13, claim 1 and figure 8.	1-6
A	US 2010-0085262 A1 (WOLF) 08 April 2010 See paragraph [0076], claim 1 and figures 21-22.	1-6
A	US 7230573 B2 (LIN et al.) 12 June 2007 See column 3, claim 1 and figure 1.	1-6
A	US 2004-0066345 A1 (SCHADLER) 08 April 2004 See paragraphs [0017]-[0018], claim 1 and figure 1.	1-6
A	KR 10-0788284 B1 (LG ELECTRONICS INC.) 27 December 2007 See page 5, lines 18-42, claim 1 and figures 1-2.	1-6

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

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"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

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"&amp;" document member of the same patent family


Date of the actual completion of the international search

28 May 2013 (28.05.2013)

Date of mailing of the international search report

**02 June 2013 (02.06.2013)**

Name and mailing address of the ISA/KR

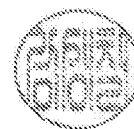

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**INTERNATIONAL SEARCH REPORT**

Information on patent family members

International application No.

**PCT/US2013/026020**

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