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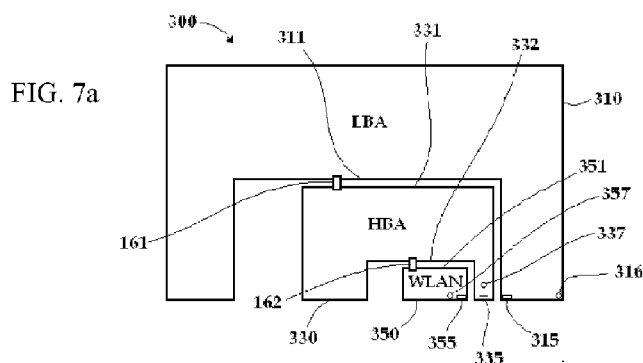
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(54) Title: ADAPTIVE ANTENNA ARRAY



(57) Abstract: An antenna array includes a tunable integrated circuit (TIC) position between two spaced apart edges. The TIC is adjustable over a range of values and can allow the antenna array to provide a desired performance in response to changes in external factors. In certain embodiments, the antenna array may include a second TIC positioned between two other spaced apart edges. The TIC can be adjustable in a closed-loop manner.

Adaptive Antenna Array

BACKGROUND OF THE INVENTION

[001] This application claims priority to United States Provisional Application No. 61/144,721, filed January 14, 2009, which is incorporated herein by reference in its entirety.

FIELD OF THE INVENTION

[002] The present invention relates to the field of antennas, more particularly to the field of antennas in mobile devices.

DESCRIPTION OF RELATED ART

[003] Antenna design in a mobile device, such as a cellular phone, is a complex and challenging task. On the one hand, there is continual pressure to reduce the size of the antenna so as to accommodate smaller form factors and to make space for other components. The reduction in size has a tendency to reduce antenna performance. On the other hand, there is a constant demand for improved antenna performance so as to increase connection reliability and reduce power requirements. In addition, modern cellular phones tend to use a number of bands at different frequencies, which optimally would each have their own antenna so as to optimize performance. However, the use of a larger number of antennas tends to take up more space and often a single antenna must be used for frequencies that extend beyond the desired range of such an antenna.

[004] To address some of the above issues, a planar Inverted-F Antenna (PIFA) has been used. PIFAs tend to allow for improved radiation patterns and with the use of slots and the like can provide the desired resonance frequencies with relatively small areas. The use of parasitic elements can be further used to enhance bandwidth of certain resonant modes. If the feeds and grounds are properly configured, two PIFAs can be mounted closely together, one tuned for a first frequency and one tuned for a second frequency, so as to provide multiple bands of reception performance such as GSM and UMTS.

[005] One issue that remains, however, is that PIFAs still have a relatively narrow bandwidth and thus it would be desirable to further tune the antenna system so that better sensitivity for a desired frequency range could be achieved. In addition, it would be desirable to account for the phantom effects of a user holding the mobile device or placing the mobile device approximate the user's body, e.g., the impedance mismatch and resultant loss in efficiency. While adaptive systems have been proposed to help provide further flexibility and adaptability and address the impedance mismatch caused by the presence of a user's body approximate the antenna, such systems tend to add significant cost to the antenna subsystem. Therefore, an adaptive antenna system that could provide improved performance while minimizing any cost impacts would be appreciated.

BRIEF SUMMARY OF THE INVENTION

[006] A communication system includes an antenna array with a first and second edge being opposite each other. A tunable integrated circuit (TIC) is placed between the first and second edge. A controller module may be used to adjust the value of the TIC. The value of the TIC can be adjusted so as to modify capacitive coupling between the first and second edge. A frequency response of the antenna array can therefore be adjusted based on the value of the TIC. In an embodiment, the controller module may be closed-loop and the value of the TIC can be adjusted based on a detected performance of the communication system. In an embodiment, the antenna array may be a first and second antenna tuned for separate frequencies ranges, wherein the first edge is part of the first antenna and the second edge is part of the second antenna.

BRIEF DESCRIPTION OF THE DRAWINGS

[007] 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:

[008] Figure 1 illustrates a simplified schematic of a mobile device.

[009] Figure 2 illustrates an exemplary embodiment of a schematic of mobile device circuit.

[010] Figure 3 illustrates a simplified schematic an embodiment of a mobile device circuit.

[011] Figure 3a illustrates a simplified schematic of a control

[012] Figure 4 a perspective view of an embodiment of a dual-band antenna array.

[013] Figure 5 illustrates an elevated top view of an embodiment of a dual-band antenna array.

[014] Figure 6 illustrates an elevated top view of an alternative embodiment of a dual-band antenna system.

[015] Figure 7a illustrates an elevated top view of an embodiment of a tri-band antenna array.

[016] Figure 7b illustrates an elevated top of an alternative embodiment of a tri-band antenna array.

[017] Figure 8 illustrates an embodiment of a method that may be used to compensate for impedance mismatch in an antenna array.

[018] Figure 9 illustrates a schematic representation of two edges of an antenna array electrically coupled together.

DETAILED DESCRIPTION OF THE INVENTION

[019] 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.

[020] Multiple band PIFA have been a popular antenna choice for many mobile devices as they provide a relatively beneficial RF capabilities in a compact footprint and can generate multiple bands using single, or multiple feeds. In general, a PIFA is tuned for a particular frequency range based on its size and as the frequency moves outside the tuned frequency range, a voltage standing wave ratio (VSWR) increases (thus indicating more db of power loss). If carefully designed, however, an antenna array (which may be one or more PIFAs suitable for multiple bands such as, but not limited to, GSM and UMTS) can provide a voltage standing wave ratio (VSWR) of about 2:1 to about 3:1 over a desired range. One significant issue is that even for a well designed antenna where the impedance mismatch is relative low over the desired frequency range, environmental factors that affect the impedance of the antenna are constantly changing. Therefore, tuning an antenna to a particular setting, even if it is a good compromise, may not provide a sufficiently optimized antenna system so as to meet desired customer performance.

[021] To address this issue, a tuning circuit, such as but not limited to a series parallel capacitor circuit, that includes adjustable capacitors may be included so as to improve VSWR over the desired range. One method of doing this is to provide an open-loop configuration where the intended frequencies of operation are used to control the capacitive settings on the tuning circuit. However, if the tuning circuit can modify its settings based on detected antenna performance (a closed-loop tuning circuit), the tuning circuit can also be adjusted based on environmental factors and thus better address losses due to phantom hand and the like.

[022] Figure 1 illustrates a mobile device 20 that includes a user interface system 30, a circuitry module 50 and an antenna array 100. The user interface 30 may include any desirable configuration of user input and user output components, such as but not limited to, one or more depressible buttons, switches, displays, touch screens and speakers, as well as connector(s) configured to allow the user (or additional devices) to interface with the mobile device 20. The antenna array 100 allows the mobile device 20 to communicate with remote devices (either positioned near the mobile device or located some distance away) in a

wireless manner. The circuitry module 50 receives and processes inputs from both the user interface and the antenna and then outputs signals in an appropriate manner. Typically the circuitry module 50 will include a processor, transmitters and receivers and a power source that allows the mobile device to function without being connected to an external power source. However, numerous configurations of the circuitry module are possible and well known to persons of skill in the art, depending on the intended purpose of the mobile device, and thus the overall configuration of circuitry module is not intended to be limited.

[023] Figure 2 illustrates a simplified schematic of a portion of the circuitry module, focusing on a wireless communication system. The circuitry module 50 includes a circuit board 52 that includes processor module 54 (which may be a number of known components operating in a conventional manner for the desired circuitry configuration) in communication with a high band transmitter/receiver (HB TX/RX) 56 and further in communication with a low band transmitter/receiver (LB TX/RX) 58. The HB TX/RX 56 feeds an antenna array 100 via a tuning circuit 60. The LB TX/RX feeds the antenna array 100 via tuning circuit 62. As can be appreciated, a separate tuning circuit is used for both the high band and low band, thus even if the tuning circuit 62 is adaptive and thus the wireless communication system provides good performance over a range of conditions, the overall cost of the wireless communication system (which includes the transmitters/ receivers, the tuning circuit and the antenna array) increases significantly.

[024] Figure 3 illustrates an embodiment of a communication system configured to provide a desirable cost/performance trade-off. A processing module 54 is coupled to a LB TX/RX 57a and a HB TX/RX 57b. It should be noted that while schematically depicted as a single component, in operation the transmit/receive function can be performance by different components (e.g., a separate transmitter and receiver). Furthermore, a single transmission/reception circuit could also provide both the high band and the low band function (with, for example, separate outputs for the high and low bands feeds). Thus, the depicted configuration of circuitry is logical rather than physical.

[025] The LB TX/RX 57a and HB TX/RX 57b are respectively coupled to a low band antenna (LBA) 110 and high band antenna (HBA) 130, which form the antenna array. An embodiment of a possible configuration of the antenna array is depicted in Figures 4 and 5. As depicted, the HBA 130 includes feed 135 and ground 140 and the LBA 110 includes feed 115 and ground 120. Coupling the LBA 110 and the HBA 130 is a tunable integrated circuit (TIC) 150, which is controller by controller module 66. As depicted in Figures 4 and 5, the TIC 150 extends between a first edge 111 of the LBA 110 and a second edge 131 of the HBA 130.

[026] It has been determined that by adjusting a capacitance value of the TIC 150, the capacitive coupling between the LBA 110 and the HBA 130 can be adjusted. This in turn, allows the impedance of both the LBA 110 and the HBA 130 to be adjusted. For example, using a TIC, such as a PARATUNE capacitor that is available from PARATEK MICROWAVE, INC., that is adjustable between 0.5-1.5 pF can provide a desirable range of impedance so as to allow VSWR to be desirable over the low band and high band frequencies. Other possible TICs include microelectromechanical systems (MEMS) that are tunable over a desired range. It has been determined that one issue that can create long term durability issues is the voltage that the TIC is exposed to, therefore it is beneficial to use a TIC that is suitable to the environmental factors associated with the application. In an embodiment, increasing the capacitance from 0.5 pF to 1.5 pF causes the frequency response to drop. Thus, if the antenna is tuned for the high end of the frequency band, increasing the capacitive value of the TIC can cause the antenna to be tuned for the lower end of the frequency band, thus allowing the antenna to function desirably over the entire range. This allows the LBA 110 and HBA 130 to perform with a desired VSWR value of a wider range of frequencies. Furthermore, if the value of the TIC 150 is adjusted based on performance feedback (e.g., in a closed-loop), environmental factors such as phantom hand can also be addressed. As can be appreciated, therefore, the configuration depicted in Figures 4 and 5 allows for reduced components versus the separate tuning circuit (such as depicted in Figure 2) and therefore provides a desirable yet cost effective performance improvement. As can be appreciated, for

certain antenna designs and uses, it may be desirable to provide a greater range of adjustability (such as, but not limited to, between 0.5 pF and 3.0 pF).

[027] Figure 3a illustrates an embodiment of the controller module 66 that includes a front end ASIC with a detector and an algorithm that provide input for a controller based on the value detected by the detector so that the controller can adjust a value of the TIC 1. A bidirectional coupler positioned on the feed can be used to provide closed-loop input. Furthermore, a second optional TIC 2 can be positioned between a feed and the antenna array to further improve impedance matching.

[028] It should be noted that the desired range of capacitive tuning will depend on the configuration of the antenna array and the location of the TIC, thus the disclosed range, while beneficial for the depicted antenna array configuration, may be adjusted as desired. If the antenna array is configured as depicted in Figure 5, for example, then moving the TIC 150 so that it couples edge 111 and edge 131 but is positioned further away from edge 152 will modify its performance with respect to the low band and high band (potentially improving high band performance while diminishing low band performance. Therefore, the position of the TIC 150 may vary, depending on how the high band and low band antenna are initially tuned and depending on whether additional impedance matching is needed for a particular band and/or phantom effect. For the depicted configuration, placing the TIC 150 closer to radiating edge (e.g., closer to edge 152) increases antenna tuning sensitivity with the trade off of higher Q. Moving the TIC 150 closer to the ground 140 will results to less sensitive tuning, hence increase the tuning range, potentially beyond a 3:1 range. The depicted position of the TIC 150 is a trade off between the resultant resonance frequency generated, tuning range, and Q of the antenna. As can be appreciated, depending on the configuration of the antenna array, the position of the TIC may also have different tuning impact for different bands. Depending on the antenna array configuration, a particular TIC location may optimize both the low band and the high band performance (thus providing for an optimized TIC location). As can be appreciated however, the improved impedance matching made possible

with the TIC coupled between two opposing edges of the antenna array may improve system performance or allow for the use of reduced power or both.

[029] Figure 6 illustrates a schematic of an embodiment of a dual-band single feed antenna array. A PIFA 200 includes a feed 215 and a ground 220 and further includes a first edge 211 and a second edge 212 that define a slot. A TIC 150 is positioned in the slot and couples the first edge 211 and second edge 212. The TIC can be a passive TIC that is close-loop controlled and may be adjustable over a range of values that may be between about 0.5 pF and about 10 pF. As depicted, the TIC 150 is positioned between end A and end B of the first and second edges 211, 212. The position of the TIC 150 may be adjusted, however, to some other position between the two ends A, B of the edges 211, 212. Positioning the TIC 150 closer to the end A may have a tendency to improve tuning capability of the high band while having a lesser affect on the low band. Conversely, moving the TIC 150 closer to the end B may increase the tuning capability of the low band while decreasing the tuning capability of the high band. In addition, a plurality of TICs could be provided in the slot, at least one near end B and at least one near end A, so as to improve tuning of both the high and low bands to a greater degree.

[030] As can be appreciated, if a tri-band single feed antenna array is provided, a setup similar to that depicted in Figure 6 is possible. A single TIC may couple two edges (such as, but not limited to, edges that form a slot in the antenna array). Depending on the antenna array construction, multiple TICs may be provided, each coupling edges of the antenna array. Furthermore, if a bridge element is used (such as is depicted below in Figure 9), a plurality of bridge elements may be used couple a single TIC to more than two edges. While the use of multiple bridges can be used with different configurations, for many configurations it may be simpler and just as effective effective to couple two opposing edges with a TIC element.

[031] Therefore, as can be appreciated, the number of TICs, the selection of the opposing edges and the position along the selected opposing edges can be modified so as to provide the desired tuning sensitivity in the antenna array. Certain trade-offs, depending on the tuning capabilities of the TIC, may be made in selecting the values that the TIC will provide so as to

provide the most desirable communication system. Thus, the location and desired values of the TIC may be varied depending on factors such as the antenna array configuration and the performance of the TIC.

[032] Figure 7a and 7b illustrates two embodiments of a tri-band antenna array 300, 300a. As can be appreciated, the antenna array may further include additional bands as desired (for example, an additional lower band antenna suitable for a range around about 0.7 GHz could be provided). Furthermore, the antenna array 300 can be configured for desired frequencies in a known manner. As depicted, the antenna array 300 includes a LBA 310 (such as would be suitable for GSM type frequencies), a HBA 330 (such as would be suitable for UMTS type frequencies) and a wireless local area network (WLAN) antenna 350 (such as would be suitable for frequencies used in high-speed wireless communication). Typically the WLAN antenna will be configured for frequencies such as 2.3 GHz, 2.4 GHz, 3.5 GHz or 5 GHz. As can be appreciated, any desired signaling protocol may be provided over such an antenna array. Antenna array 300a is similarly configured but includes a bridge between the HBA 330 and the LBA 310. As can be appreciated, however, the location of the corresponding feed and ground (which could be shared between the LBA and HBA) allows for sufficient separation between the two PIFAs.

[033] As depicted, the LBA 310 includes ground 315 and feed 316 and a first edge 311. The HBA 330 includes a ground 335, a feed 336 and a second edge 331 and a third edge 332. The first edge 311 and second edge 331 oppose each other. The WLAN antenna 350 includes a ground 335, a feed 357 and a fourth edge 351. The third edge 332 and fourth edge 351 oppose each other. Coupling the opposing first and second edge 311, 331 is a TIC 161. Coupling the opposing third and fourth edge 332, 351 is a TIC 162. Thus, more than one TIC may be provided in an antenna array to couple corresponding opposing edges.

[034] In Figure 7b, for example, a TIC 164 is also positioned along the first and second edge 111 and 331. An additional TIC 163 is positioned along opposing edges 312, 333. Each TIC may be controlled separately or as a group, however to conserve costs it may be beneficial to use a single control module with separate outputs (or a single output if the

values of the TIC are determined to be preferably linked) for each TIC that is used. Each TIC may be positioned so as to optimize performance of the portion of the antenna array that is affected by the TIC. For example, if two TIC are used to couple the LBA 310 and HBA 330, one TIC can be positioned at a LBA 310 high impedance spot and one can be positioned at a HBA 330 high impedance spot. As can be appreciated, therefore, as the HBA 330 is coupled to two (or more in Figure 7b) TICs, thus the value of the TICs coupled to the HBA 330 may potentially be adjusted together so as to optimize the performance of the HBA 330. Furthermore, if desired, two or more TICs can be positioned along two opposing edges, with the TICs spaced apart and appropriately configured so as to improve performance in a desired manner. However, such configurations increase cost and for some antenna arrays it may be sufficient to provide a single TIC coupling two opposing edges. However, if packaging constraints impose performance limitations, a desired number of TICs can be used to couple a desired number of edges of the antenna array so as to provide the desired performance.

[035] It should be noted if multiple TICs are used in an antenna array, each TIC may be separately configured so as to be closed-loop or open-loop adjustable. It is expected, however, that maximum flexibility is provided if at least one of the TICs is closed-loop adjustable. If a number of TICs are adjusted as a group, then a single detector can be used to provide a closed-loop system for all those TICs, such as is depicted in Figure 3a.

[036] As can be appreciated, for certain mobile devices it may be desirable to provide more than one antenna array. In such a configuration, each antenna arrays may include a TIC between opposing edges of the antenna array so as to provide adjustability for each antenna array.

[037] Figure 8 illustrates a generalized method for adjusting impedance of at least a portion of an antenna array. In step 810, a TIC that is coupled to two opposing edges of an antenna array is adjusted to provide a desired frequency response in the corresponding portion of the antenna array. As can be appreciated, more than one TIC may be coupled to the same two opposing edges. Similarly, additional TICs may be coupled to other opposing edges. Increasing the number of TICs can be expected, in general, to improve tuning

performance but will also tend to increase cost. For configurations such as depicted in Figure 4 and 5, for example, increasing the capacitance value of the TIC will cause the antenna array to be tuned for lower frequencies. Therefore, the antenna array may be configured for an upper frequency by setting the TIC at a first lowest value (such as, without limitation, 0.5 pF) while adjusting the TIC to its maximum allowable value (such as, without limitation, 1.5 pF) will configure the antenna array for a lower frequency. Thus, an initial tuning of the antenna and predetermined settings of the TIC can be determined for the desired frequency range.

[038] As can be appreciated, for open-loop systems, optional steps 815 and 820 may be omitted. If the system is closed-loop, however, then in step 815 an impedance mismatch is detected. The impedance mismatch may be detected as desired by the controller module and in an embodiment may be detected by a detector in communication with a bidirectional coupler (such as is depicted in Figure 3a). Next, in step 820, the value of the TIC is adjusted to account for the impedance mismatch detected in step 815. As can be appreciated, for example, if a mobile device includes a hands-free headset – then a predetermined value for the TIC will be sufficient for many occasions. However, if the user happens to hold the mobile device then it can be expected that the predetermined TIC value will no longer be optimum. By adjusting the value of the TIC in a closed-loop manner, therefore, the antenna array impedance can be adjusted back towards its free-space condition, thus providing improved efficiency and potentially providing improved reliability as a greater portion of input power can be transmitted. As can be appreciated, therefore, the TIC can be updated in substantially real-time to continuously account for changes in the environmental condition experienced by the mobile device.

[039] As depicted above, an economical and effective method of coupling two edges of an antenna array is to position a TIC so that it couples two opposing edges, typically that also happen to be located relatively close to each other. It should be noted that if an additional element, such as a bridge is included, the coupled edges could be positioned further apart. Figure 9 illustrates an embodiment with a first edge 411 coupled to a second edge 431 via a TIC 450 and a bridge 460. The bridge may be any desirable element such as a conductive

trace that is suitable for extending between the two edges 411, 431. Thus, in certain embodiments the TIC may couple edges on different portions of the antenna array.

[040] The present invention has been described 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. A communication system comprising:
a circuitry module configured to receive and transmit signals;
an antenna array that includes a first edge and a second edge that are spaced apart; and
a tunable integrated circuit (TIC) electrically coupling the first and second edge.
2. The system of claim 1, wherein the TIC is closed-loop controlled.
3. The system of claim 1, wherein the antenna array is configured to provide a first band and a second band and the first and second edges comprises edges of the antenna array configured to provide the respective first and second band.
4. The system of claim 1, wherein the TIC has an adjustable range of at least 1.0 pF.
5. The system of claim 1, wherein the TIC is adjustable over a range that extends at least between 0.5 pF and 1.5 pF.
6. The system of claim 4, wherein the TIC is adjustable to a range that extends up to at least 3.0 pF.
7. The system of claim 1, wherein the TIC is a first TIC and the antenna array further includes a third and fourth edge that are spaced apart and a second TIC, the second TIC electrically coupling the third and fourth edge.
8. An antenna system, comprising:
an antenna array that includes a first edge and a second edge that are spaced apart; and
a tunable integrated circuit (TIC) electrically coupling the first and second edge.
9. The antenna system of claim 8, wherein the TIC is closed-loop controlled.

10. The antenna system of claim 8, wherein the antenna array is configured to provide a first band and a second band and the first and second edges comprises edges of the antenna array configured to provide the respective first and second band.

11. The antenna system of claim 8, wherein the TIC has an adjustable range of at least 1.0 pF.

12. The antenna system of claim 8, wherein the TIC is adjustable at least between about 0.5 pF and about 1.5 pF.

13. The antenna system of claim 8, wherein the TIC is a first TIC and the antenna array further includes a third and fourth edge that are spaced apart and a second TIC, the second TIC electrically coupling the third and fourth edge.

14. A method of tuning an antenna array in a mobile device, comprising:
adjusting a tunable integrated circuit (TIC) that electrically couples a first edge and a second edge of an antenna array so as to modify the frequency response of the antenna array.

15. The method of claim 14, wherein the adjusting modifies a frequency response of the antenna array for two bands simultaneously.

16. The method of claim 14, wherein the adjusting varies a capacitive value of the TIC at least between 0.5 pF and 1.5 pF.

17. The method of claim 14, wherein the adjusting is based on a look-up table that includes predetermined values for the TIC based on a desired operating frequency.

18. The method of claim 14, wherein the adjusting is done in a closed-loop manner in response to detected antenna performance.

19. The method of claim 18, wherein the detected antenna performance is a voltage standing wave ratio.

20. The method of claim 14, wherein the adjusting of the TIC is adjusting a first TIC, the method further comprising adjusting a second TIC the electrically couples a third edge and a fourth edge of the antenna array.

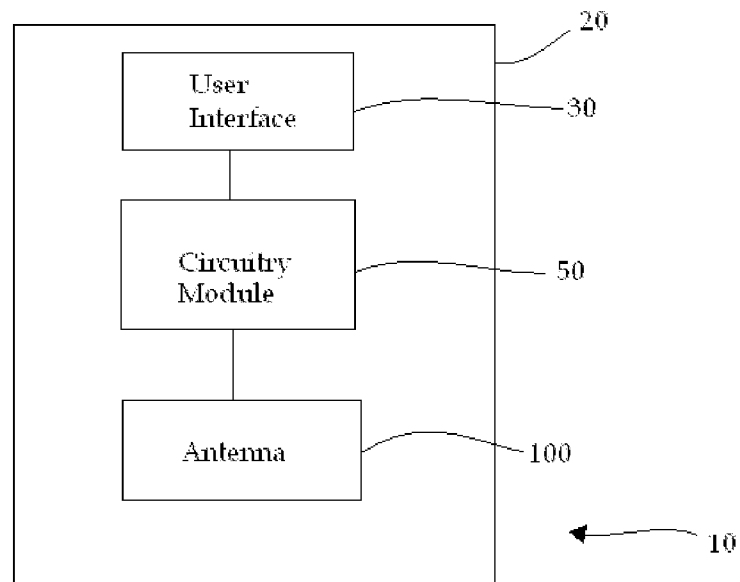


FIG. 1

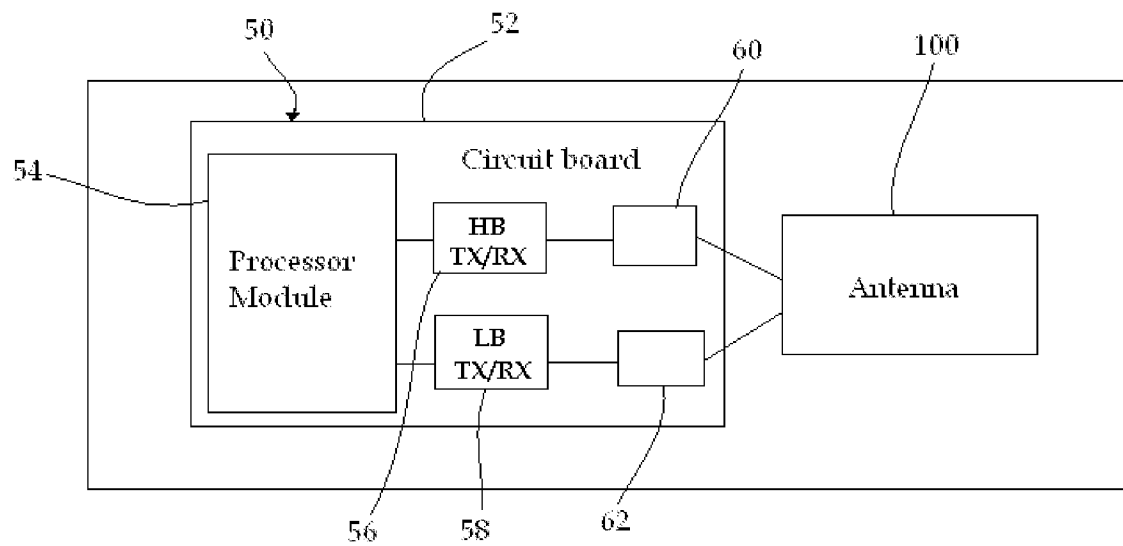


FIG. 2

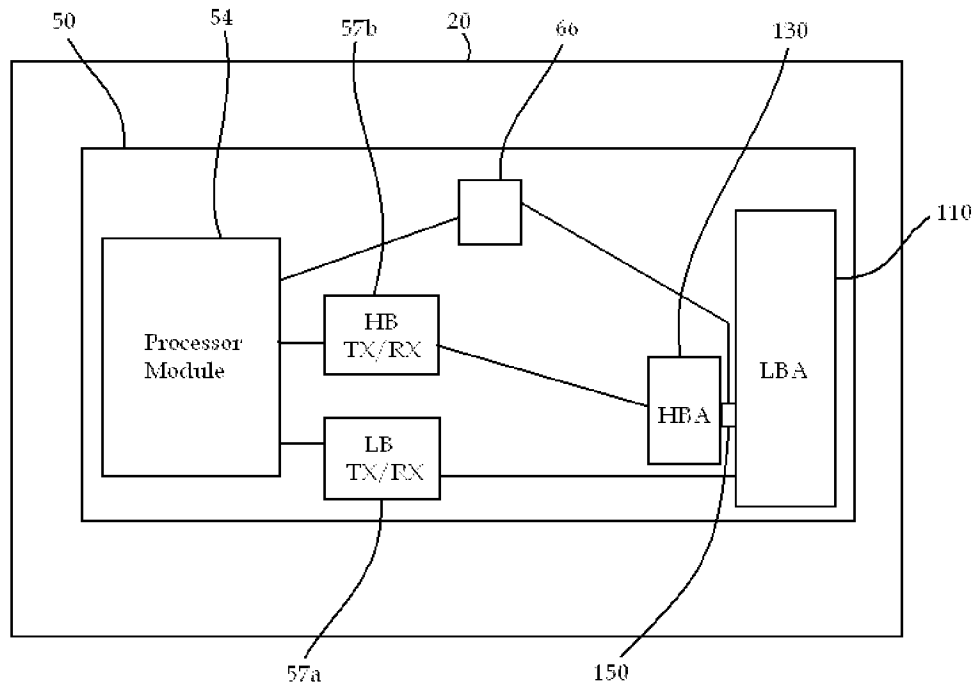


FIG. 3

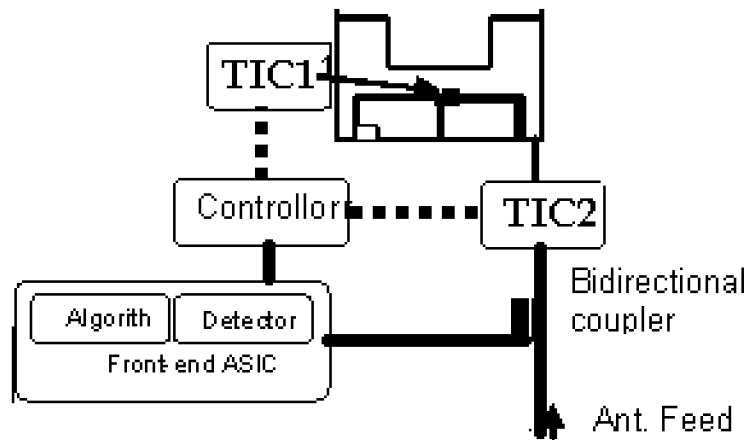


FIG 3a

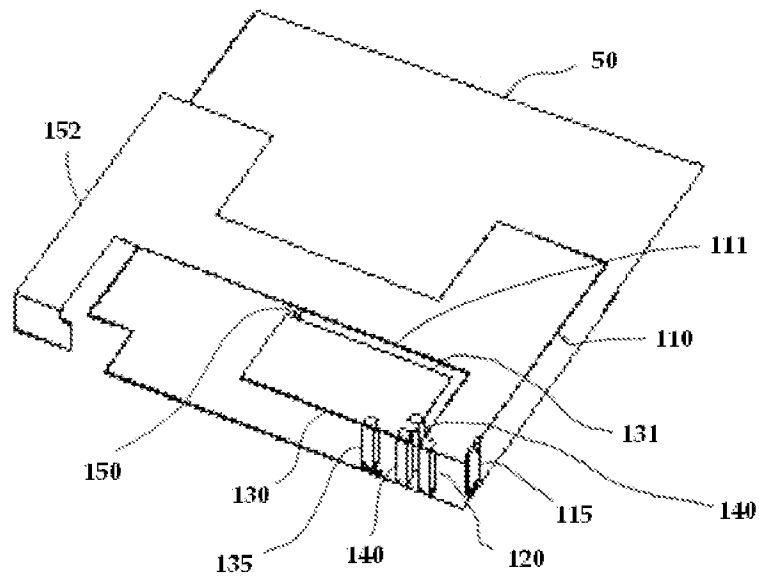


FIG. 4

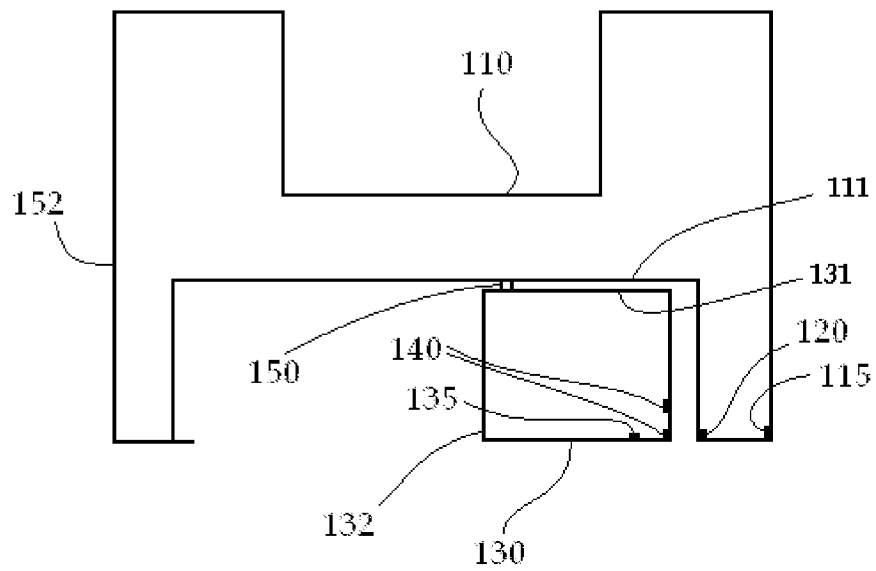


FIG. 5

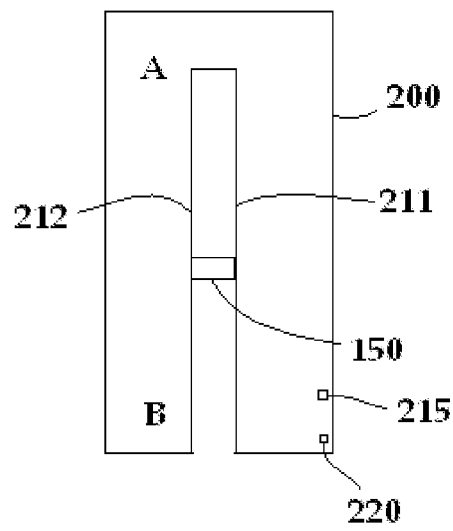


FIG. 6

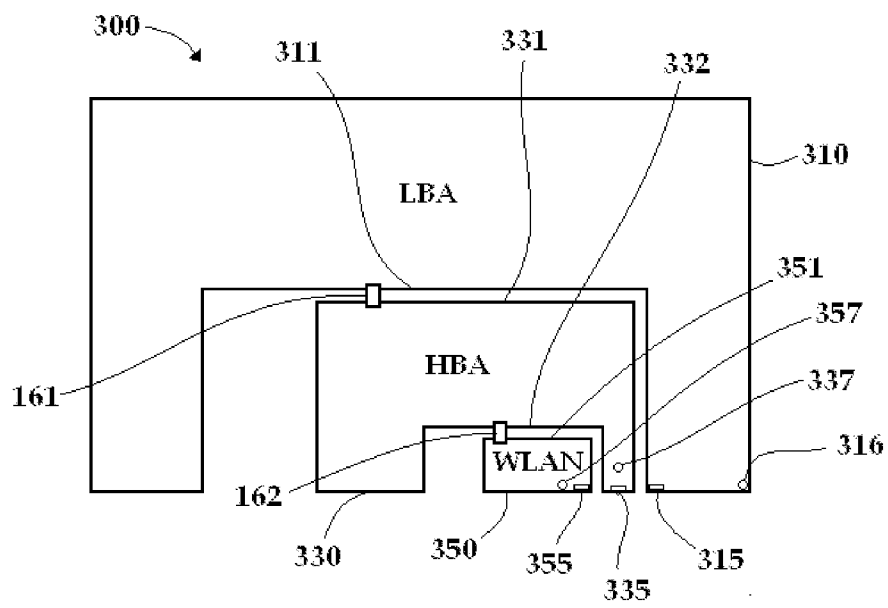


FIG. 7a

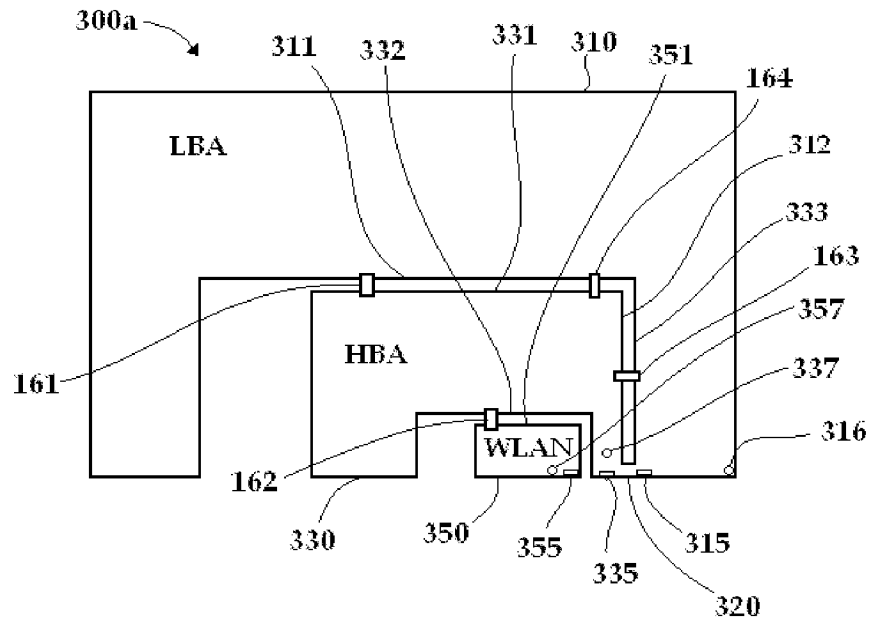


FIG. 7b

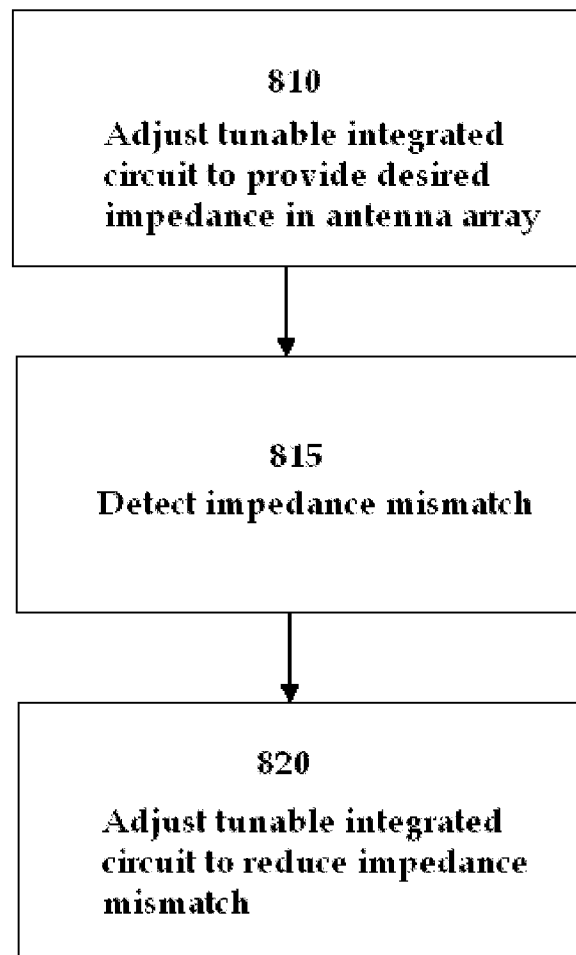


FIG. 8

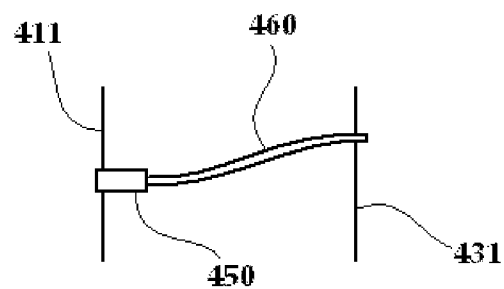


FIG. 9

INTERNATIONAL SEARCH REPORT

International application No
PCT/US2010/021004

A. CLASSIFICATION OF SUBJECT MATTER
INV. H01Q5/00 H01Q9/04
ADD.

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

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

EPO-Internal

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	EP 1 699 108 A1 (SAGEM COMM S A [FR] SAGEM MOBILE [FR]) 6 September 2006 (2006-09-06) abstract page 3, paragraph 10-11 page 5, paragraph 29-31; figures 1-2 page 9, paragraph 76; figure 7	1-20
X	GB 2 335 798 A (NEC TECHNOLOGIES [GB] NEC TECHNOLOGIES [GB]; GLOBALMART LTD [GB]) 29 September 1999 (1999-09-29) abstract page 4; figures 3-4	1-3, 7-10, 13-15, 17-20
A	US 2007/241970 A1 (THORNELL-PERS ANDERS [SE]) 18 October 2007 (2007-10-18) abstract; figures 6-7 page 2, paragraph 30	4-6, 11, 12, 16

☐ Further documents are listed in the continuation of Box C.

☒ See patent family annex.

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Date of the actual completion of the international search

15 April 2010

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INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No

PCT/US2010/021004

Patent document cited in search report		Publication date	Patent family member(s)	Publication date
EP 1699108	A1	06-09-2006	FR 2889360 A1	02-02-2007
GB 2335798	A	29-09-1999	NONE	
US 2007241970	A1	18-10-2007	CN 1879255 A	13-12-2006
			EP 1683232 A1	26-07-2006
			KR 20050045788 A	17-05-2005
			KR 20060115365 A	08-11-2006
			WO 2005048403 A1	26-05-2005