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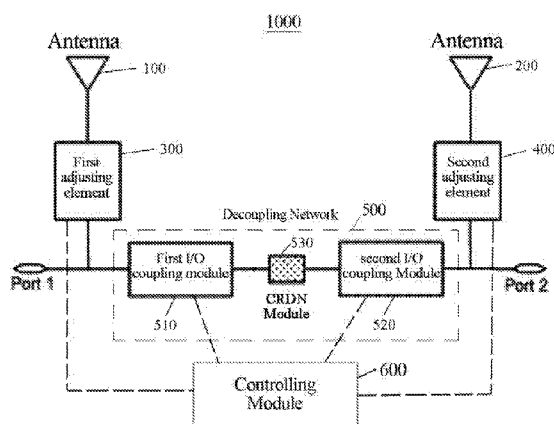


Figure 1

(57) Abstract: Disclosed is an apparatus for decoupling two antennas in an antenna array, in which the two antennas transmit and receive signals via a first input/output port and a second input/output port of the apparatus. The device may comprise a first adjusting device connected between a first antenna of the two antennas and the first input/output port, a second adjusting device connected between a second antenna of the two antennas and the second input/output port, and one or more decoupling networks connected between the first input/output port and the second input/output port. The first adjusting device and the second adjusting device are configured to have admittance adjustable to compensate an admittance of the decoupling networks such that an isolation coefficient between the two input/output ports approaches zero as well as reflection coefficients of each input/output port are minimized.

A METHOD AND AN APPARATUS FOR DECOUPLING MULTIPLE ANTENNAS IN A COMPACT ANTENNA ARRAY

Technical Field

[0001] The present application relates to an antenna decoupling technology, in particular, to an apparatus and a method for decoupling multiple antennas in a compact antenna array.

Background

[0002] To satisfy the fast growing demands from mobile internet market for higher data rate on wireless communication systems, many advanced technologies for increasing the data throughput have been put into use. Among them, Multiple Input Multiple Output (MIMO) data accessing scheme, a proven technology to effectively use the multi path environment, has been becoming a compulsory option in today's wireless communication systems both in base stations and mobile terminals.

[0003] Due to an inevitable strong electromagnetic wave mutual coupling between closely spaced antennas in a MIMO wireless terminal, such as a 4G LTE smart phone, the mutual coupling and spatial correlation between antennas are severely high, which lowers the channel capacity gain due to a strong signal correlation. Therefore, how to reduce the unwanted mutual couplings of coupled antennas is a very important issue.

[0004] US 13/691,227 by *Wu et al.* proposed a new technique named Coupled Resonator Decoupling Network (CRDN) for decoupling two coupled antennas. The basic principle underlying is to design a second or higher order coupled resonator network that is connected to the two coupled antennas in parallel and is with its mutual admittance opposite to that of the two coupled antennas such that the unwanted mutual coupling of two antennas can be canceled in a relatively wide frequency band.

[0005] However, to apply the new technology in a mobile terminal, a small form factor integrated decoupling apparatus that is independent to the form factors of the antennas is highly desirable. In addition, the circuitry of using the integrated CRDN

is also critical in applying the unique technology.

Summary

[0006] The present application proposes an apparatus for decoupling two antennas in a compact antenna array and a method for decoupling two antennas in a compact antenna array.

[0007] According to an embodiment of the present application, disclosed is an apparatus for decoupling two antennas in an antenna array, in which the two antennas transmit and receive signals via a first input/output port and a second input/output port of the apparatus. The device may comprise a first adjusting device connected between a first antenna of the two antennas and the first input/output port, a second adjusting device connected between a second antenna of the two antennas and the second input/output port, and one or more decoupling networks connected between the first input/output port and the second input/output port. The first adjusting device and the second adjusting device are configured to have admittance adjustable to compensate an admittance of the decoupling networks such that an isolation coefficient between the two input/output ports approaches zero and as well as reflection coefficients of each input/output port are minimized.

[0008] According to another embodiment of the present application, disclosed is an apparatus for decoupling a plurality of antennas in an antenna array, in which the plurality of antennas transmit and receive signals via respective one of a plurality of input/output ports. The device may comprise a plurality of adjusting devices, each of which connected between a respective antenna of the plurality of antennas and a respective one input/output port of the plurality of input/output ports, and one or more decoupling networks connected between the respective input/output ports of the plurality of input/output ports. The plurality of adjusting devices are configured to have an admittance adjustable to compensate an admittance of the decoupling networks such that an isolation coefficient between the input/output ports approach zero as well as reflection coefficients of each input/output port are minimized.

[0009] According to a further embodiment of the present application, disclosed

is a method for decoupling two antennas in a antenna array, in which the two antennas transmit and receive signals via a first input/output port and a second input/output port. The method may comprise: inserting a first adjusting device between a first antenna of the two antennas and the first input/output port; inserting a second adjusting device between a second antenna of the two antennas and the second input/output port; connecting one or more decoupling networks between the first input/output port and the second input/output port; and adjusting an admittance of each of the first and the second adjusting devices to compensate an admittance of the decoupling networks such that an isolation coefficient between the two input/output ports approach zero as well as reflection coefficients of each input/output port are minimized.

Brief Description of the Drawing

[0010] Exemplary non-limiting embodiments of the invention are described below with reference to the attached figures. The drawings are illustrative and generally not to an exact scale.

[0011] Fig. 1 is a schematic diagram illustrating an apparatus for decoupling two antennas in a compact antenna array consistent with an embodiment of the present application.

[0012] Fig. 2 is a schematic circuit diagram of an illustrative example CRDN module consistent with an embodiment of the present application.

[0013] Fig. 3 is a physical layout of an LTCC realization of the illustrative example CRDN module consistent with an embodiment of the present application.

[0014] Fig. 4 is a schematic diagram illustrating an apparatus for decoupling two antennas in a compact antenna array consistent with another embodiment of the present application.

[0015] Fig. 5 is a schematic diagram illustrating an apparatus for decoupling two antennas in a compact antenna array consistent with a further embodiment of the present application.

[0016] Fig. 6(a) is a schematic circuitry diagram illustrating a decoupling scheme for two antennas operating in the same frequency band consistent with an

embodiment of the present application.

[0017] Fig. 6(b) is a schematic circuitry diagram illustrating a decoupling scheme for two antennas operating in the different frequency bands consistent with an embodiment of the present application.

[0018] Fig. 7 is a schematic circuitry diagram illustrating a dual-band decoupling scheme for two antennas for different wireless services consistent with an embodiment of the present application.

[0019] Fig. 8 is a flowchart illustrating a method for decoupling two antennas in a compact antenna array consistent with some disclosed embodiments.

[0020] Fig. 9(a) is a schematic configuration diagram illustrating a testing antenna array with two antennas operating in the same frequency band consistent with some disclosed embodiments.

[0021] Fig. 9(b) shows simulated and measured mutual coupling coefficient of the coupled and decoupled antennas arrays in the testing array of Fig. 9(a).

[0022] Fig. 9(c) shows simulated and measured reflection coefficient of the coupled and decoupled antennas arrays in the testing array of Fig. 9(a).

[0023] Fig. 10(a) is a schematic configuration diagram illustrating a testing antenna array with two antennas operating in the different frequency bands consistent with some disclosed embodiments.

[0024] Fig. 10(b) shows simulated and measured reflection coefficient of the coupled and decoupled antennas arrays in the testing array of Fig. 10(a).

[0025] Fig. 10(c) shows simulated and measured isolation coefficient of the coupled and decoupled antennas arrays in the testing array of Fig. 10(a).

[0026] Fig. 10(d) shows efficiency of the testing array of Fig. 10(a) before and after decoupling by the apparatus according to the present application.

Detailed Description

[0027] References will now be made in detail to exemplary embodiments, examples of which are illustrated in the accompanying drawings. When appropriate, the same reference numbers are used throughout the drawings to refer to the same or

like parts.

[0028] Fig. 1 is a schematic configuration of an apparatus 1000 for decoupling two antennas in an antenna array consistent with an embodiment of the present application. As known, a multi-antenna array comprises a plurality of closely disposed antennas. Hereinafter, a two-antenna array comprising two closely disposed antennas will be taken as an example to explain the application. It will be understood that, for an antenna array comprising more than two antennas, the configuration discussed below could be used for each two of the antennas. It will also be understood that, for an antenna array comprising more than two antennas, an alternative method is to design a multi-port decoupling network. Both of these two methods equivalently generate a second path of controllable mutual coupling to cancel out the existing antenna to antenna mutual coupling in a broadband sense.

[0029] As shown in Fig. 1, the two-antenna array comprises two closely disposed antennas 100, 200. According to the present application, the antennas 100, 200 may be identical or different antennas used for identical or different wireless services, such as 2G(GSM), 3G(UMTS), 4G(LTE), Wi-Fi, GPS and Bluetooth. In an embodiment, one end of the antenna 100 is connected to an input/output port 1 to transmit/receive data to/from the apparatus such as a mobile terminal in which the antenna array is installed. One end of the antenna 200 is connected to an input/output port 2 to transmit/receive data to/from the apparatus in which the antenna array is installed.

[0030] The apparatus 1000 may comprise a first adjusting device 300 and a second adjusting device 400. As shown, the first adjusting device 300 is connected between the first antenna 100 and the first input/output port 1, and the second adjusting device 400 is connected between the second antenna 200 and the second input/output port 2. According to an embodiment, the first adjusting device 300 and the second adjusting device 400 may be made of distributed element circuits, such as a transmission line or stepped impedance resonators circuits. Alternatively, the first adjusting device 300 and the second adjusting device 400 may be made of any form of lumped element circuits, such as a single inductor, a single capacitor, an LC ‘ π ’ network,

an LC 'L' network or combination of them.

[0031] As shown in Fig. 1, the apparatus 1000 may further comprise a decoupling network 500. The decoupling network 500 may be connected between the first input/output port 1 and the second input/output port 2.

[0032] In an embodiment, the first adjusting device 300 and the second adjusting device 400 may be configured to have admittance adjustable to compensate an admittance of the decoupling network 500 such that an isolation coefficient between the two input/output ports approaches zero. According to the embodiment, the first adjusting device 300 and the second adjusting device 400 are configured to have an electrical length and characteristic impedance, both of which are adjustable to compensate the admittance of the decoupling network 500.

[0033] Referring to Fig. 1 again, each of the decoupling network 500 may comprise a first I/O coupling module 510, a second I/O coupling module 520 and a Coupled Resonator Decoupling Network (CRDN) module 530. The first I/O coupling module 510 is connected between the first input/output port 1 and the CRDN module 530, and the second I/O coupling module 520 is connected between the second input/output port 2 and the CRDN module 530. Thus, the first I/O coupling module 510, the second I/O coupling module 520 and the CRDN module 530 are connected with each other in series.

[0034] The CRDN module 530 may be implemented by using different passive integration technologies, including LTCC (Low Temperature Co-fired Ceramic) and multi-layered PCB. An illustrative example of a CRDN module 530 in the form of a LTCC will be given hereinafter.

[0035] A schematic circuit diagram of the illustrative example LTCC CRDN module 530 is shown in Fig. 2. A first resonant loop (L1, C1) in Figure 2 is illustratively composed of a capacitor C1 and an inductor L1, and a second resonant loop (L2, C2) in Figure 2 is illustratively composed of a capacitor C2 and an inductor L2. It is noted that the resonant loops may also be composed in other forms. According to the present application, the specific values of inductors and/or capacitors are unimportant, as long as the resonant frequency of the resonant loop is appropriate with

respect to the coupled antennas and that the desired coupling coefficients are obtained.

[0036] The isolation coefficient between the two ports 1 and 2 is diminished by setting a coupling coefficient between the first resonant loop (L1, C1) and the second resonant loop (L2, C2) based on a constraint that the mutual admittance in the whole network composed of the two antennas, the first adjusting device and the second adjusting device, and the decoupling network approaches zero, while the self-admittances approach to the characteristic admittance of ports 1 and 2, respectively.

[0037] According to another embodiment, the CRDN module 530 may be implemented by using lumped elements or distributed elements or mixture of both as long as desired isolation coefficient is obtained. Fig. 3 shows a physical layout of an LTCC realization, in which the realization of each of the circuit elements in Fig. 2 is marked.

[0038] In an embodiment, the first I/O coupling module 510 and the second I/O coupling module 520 are configured to have adjustable electrical parameters such that the decoupling network 500 has an adjustable working frequency and adjustable decoupling level.

[0039] In an embodiment, the first I/O coupling module 510 and the second I/O coupling module 520 may be made of distributed element circuits, such as a transmission line or stepped impedance resonators circuits. Alternatively, the first I/O coupling module 510 and the second I/O coupling module 520 may be made of any form of lumped element circuits, such as a single inductor, a single capacitor, an LC 'π' network, an LC 'L' network or combination of them.

[0040] According to an embodiment, the apparatus 1000 may further comprise a controlling module 600 (shown in Fig. 1). The controlling module 600 may be coupled with the first adjusting device 300 and the second adjusting device 400, respectively. In addition, the controlling module 600 may further be coupled with the first I/O coupling module 510 and the second I/O coupling module 520, respectively. The controlling module 600 may be configured to control the adjustment of the first adjusting device 300 and the second adjusting device 400, and the adjustment of the first I/O coupling module 510 and the second I/O coupling module 520 so as to shift

their working frequency bands, respectively.

[0041] Fig. 4 is a schematic diagram illustrating an apparatus 1000' for decoupling two antennas 100' and 200' in a compact antenna array consistent with another embodiment of the present application. Similar to the apparatus 1000 illustrated in Fig. 1, the apparatus 1000' comprises a first adjusting device 300', a second adjusting device 400', a decoupling network 500'. The decoupling network 500' may comprise a first I/O coupling module 510', a second I/O coupling module 520' and a CRDN module 530'. The function and connecting relation of the above-mentioned elements in apparatus 1000' are similar to that in the apparatus 1000, and thus the detailed description will be omitted here. The difference between the apparatus 1000' and 1000 will be described in detail hereafter.

[0042] As shown in Fig. 4, the apparatus 1000' further comprises a first matching network 610 and a second matching network 620. The first matching network 610 is located at the port 1 of the apparatus 1000', and the second matching network 620 is added at the other port 2 of the apparatus 1000'. The matching networks 610 and 620 may be implemented by lumped LC elements or transmission line stubs to further broaden the matching bandwidth.

[0043] Fig. 5 is a schematic diagram illustrating an apparatus 1000'' for decoupling two antennas in a compact antenna array consistent with a further embodiment of the present application. Similar to the apparatus 1000 illustrated in Fig. 1 and the apparatus 1000' illustrated in Fig. 4, the apparatus 1000'' comprises a first adjusting device 300'', a second adjusting device 400'', a decoupling network 500''. The decoupling network 500'' may comprise a first I/O coupling module 510'', a second I/O coupling module 520'' and a CRDN module 530''. Similar to the apparatus 1000' illustrated in Fig. 4, the apparatus 1000'' further comprises a first matching network 610' and a second matching network 620'. The function and connecting relation of the above-mentioned elements in the apparatus 1000'' are similar to that in the apparatus 1000', and thus the detailed description will be omitted here. The difference between the apparatus 1000'' and 1000' will be described in detail hereafter

[0044] As shown in Fig. 5, the apparatus 1000'' further comprises a second

decoupling network 700. The second decoupling network 700 may comprise a first I/O coupling module 710, a second I/O coupling module 720 and a CRDN module 730. The first I/O coupling module 710, the second I/O coupling module 720 and the CRDN module 730 are connected with each other in series. According to an embodiment, the CRDN module 730 is configured to have at least one resonator configured to enhance the overall isolation. The first I/O coupling module 710 and the second I/O coupling module 720 are configured to have adjustable electrical parameters such that the decoupling networks 700 have an adjustable working frequency and an adjustable decoupling level.

[0045] According to this embodiment, the decoupling networks 500'' and 700 are connected in parallel and each of the decoupling networks 500'' and 700 may work in different frequency bands such that decoupling of the antennas 100'' and 200'' at different frequency bands are achievable.

[0046] According to the present application, the two antennas 100, 100', 100'' and 200, 200', 200'' may work in the same or different frequency bands. In the case of two antennas working in the same band, the two resonant loops may also be identical with each other. Otherwise, the two resonant loops may be in different resonant frequency from one another. Some illustrative prototype examples are shown in Figures 6(a)-7.

[0047] Fig. 6(a) illustrates a schematic circuitry diagram illustrating a decoupling scheme for two antennas operating in different frequency bands consistent with an embodiment of the present application. In this embodiment, the decoupling network is used for diminishing interferences between antennas for different wireless services. As shown, the example of this mobile phone is an LTE smart phone, in which a 2G/3G antenna and an LTE antenna are provided. As shown in Fig. 6(a), two different lumped element π networks are used for adjusting electrical length of the adjusting devices connecting with the antennas. The first lumped element π network is consisting of lumped capacitors C1 and C2 and a lumped inductance L1, while the second lumped element π network is consisting of lumped capacitors C3 and C4 and a lumped inductance L2.

[0048] In an embodiment, the decoupling network may be used for diminishing mutual couplings of two MIMO antennas working in the same frequency band in a mobile phone.

[0049] Fig. 6(b) illustrates a schematic circuitry diagram of a decoupling scheme with adjustable I/O coupling for two antennas operating in different frequency bands consistent with an embodiment of the present application. In this embodiment, the lumped capacitors C1 and C2 are used to adjust I/O coupling of the decoupling network, respectively, in order to realize different I/O couplings of the decoupling network, thus various levels of decoupling performance can be obtained.

[0050] In another embodiment, the decoupling network may be used for diminishing mutual couplings of adjustable I/O coupling for two antennas operating in the same frequency band. In this embodiment, the lumped capacitor C1 is used to adjust I/O coupling of the decoupling network in order to realize different I/O couplings of the decoupling network, thus various levels of decoupling performance can be obtained.

[0051] Fig. 7 illustrates a schematic circuitry diagram illustrating a multi-band or a wide band decoupling scheme for two antennas for different wireless services consistent with an embodiment of the present application. In this embodiment, the decoupling network is used for diminishing interferences between antennas for different wireless services. As shown, the example of this mobile phone is an LTE smart phone, in which a 2G/3G antenna and an LTE antenna are provided. As shown in Fig. 7(a), two different lumped element π networks are used for adjusting electrical length of the adjusting devices connecting with the antennas. The first lumped element π network is consisting of lumped capacitors C1 and C2 and a lumped inductance L1, while the second lumped element π network is consisting of lumped capacitors C3 and C4 and a lumped inductance L2. Furthermore, the lumped capacitors C5 and C6 are used to adjust I/O coupling of the decoupling network, respectively, in order to realize different I/O couplings of the decoupling network.

[0052] Fig. 8 is a flowchart illustrating method 8000 for decoupling two

antennas in an antenna array consistent with some disclosed embodiments. In an embodiment, the two antennas transmit and receive signals via a first input/output port 1 and a second input/output port 2. As discussed above, the antennas may operate in the same or different frequency bands. One end of the antenna 100 is connected to an input/output port 1 to transmit/receive data to/from the apparatus such as a mobile terminal in which the antenna array is installed. One end of the antenna is connected to an input/output port 2 to transmit/receive data to/from the apparatus in which the antenna array is installed.

[0053] At step S801, inserting a first adjusting device between a first antenna and the first input/output port 1 is proceeded. At step S802, inserting a second adjusting device between a second antenna of the two antennas and the second input/output port is proceeded. According to an embodiment, the first adjusting device and the second adjusting device may be configured to transmission lines. Alternatively, the first adjusting device and the second adjusting device may be configured to lumped element π networks.

[0054] At step S803, connecting one or more decoupling networks between the first input/output port and the second input/output port is proceeded. In an embodiment, the decoupling networks are connected between the first input/output port 1 and the second input/output port 2. As mentioned above, each of the decoupling networks may comprise a first I/O coupling module, a second I/O coupling module and a CRDN module.

[0055] According to an embodiment, the step S803 of connecting may further comprise: inserting the first I/O coupling module between the first input/output port and the CRDN module; inserting the second I/O coupling module between the first input/output port and the CRDN module; and adjusting electrical parameters of the first and second I/O coupling modules such that the decoupling networks have an adjustable working frequency and an adjustable decoupling level.

[0056] According to an embodiment, the first adjusting device and the second adjusting device may be made of distributed element circuits, such as a transmission line or stepped impedance resonators circuits. Alternatively, the first adjusting device

and the second adjusting device may be made of any form of lumped element circuits, such as a single inductor, a single capacitor, an LC ' π ' network, an LC 'L' network or combination of them.

[0057] According to an embodiment, the CRDN module may be composed of two or more resonators or resonant loops having at least one resonator, in which the resonator is configured to cooperate with the adjustable electrical length and characteristic impedance of each of the first and the second adjusting devices so as to isolate the two ports electrically.

[0058] The CRDN module may be implemented by using different passive integration technologies, including LTCC (Low Temperature Co-fired Ceramic) and multi-layered PCB. An illustrative example of a CRDN module in the form of a LTCC will be given hereinafter. In an embodiment, the CRDN module may be implemented by using lumped elements or distributed elements or mixture of both as long as desired isolation coefficient is obtained.

[0059] At step S804, adjusting an admittance of each of the first and the second adjusting devices to compensate an admittance of the decoupling networks such that an isolation coefficient between the two input/output ports approaches zero is proceeded. According to the embodiment, the first adjusting device and the second adjusting device are configured to have an electrical length and characteristic impedance, both of which are adjustable to compensate the admittance of the decoupling network.

[0060] According to another embodiment, the method 8000 may further comprise: connecting a controlling module to the first adjusting device and the second adjusting device, and the first I/O coupling module and the second I/O coupling module, and controlling the adjustment of the first adjusting device and the second adjusting device, and the adjustment of the first I/O coupling module and the second I/O coupling module so as to shift their working frequency bands, respectively.

[0061] According to another embodiment, the method 8000 may further comprise: adding a first matching network at one port of the two ports, adding a second matching network at the other port of the two ports, and adjusting the first matching network and the second matching network to broaden a matching bandwidth of the two

antennas.

[0062] According to a further embodiment, the method 8000 may further comprise: connecting a plurality of the decoupling networks in parallel, each of the decoupling networks having different working frequency band such that decoupling of the antennas in multiple work frequency bands are achievable.

[0063] With the device for decoupling two antennas in a compact antenna array according to the present application, the proposed decoupling scheme can be applied to various antenna arrays. Taking the advantage of the LTCC multilayer technology, the device according to the present application can be made in a compact volume.

[0064] Furthermore, with the device according to the present application, good decoupling and matching conditions can be achieved over a wide frequency range. Besides, a tradeoff between decoupling bandwidths and levels of isolation can also be realized without reconfiguring the device.

[0065] Such effects and advantages will be further verified with reference to the following experimental results shown in Figs. 9(a)-9(c) and Figs. 10(a)-10(c).

[0066] An example configuration of the entire apparatus, the detailed layout of the LTCC CRDN module together with the PCB board to be mounted is illustrated in Fig. 9(a). In the example embodiment, two coupled antennas working at 2.4 GHz band separated by distance D are printed on a FR4 board. The other antenna relevant dimensions are $W2 = 3$ mm, $W3 = 9.8$ mm and $S3 = 19.4$ mm. A section of transmission line of length $S2$ and characteristic impedance of $Z0$ is inserted at each antenna port.

[0067] Fig. 9(b) shows simulated and measured mutual coupling coefficient of the coupled and decoupled antennas arrays in the testing array of Fig. 9(a), and Fig. 9(c) shows simulated and measured reflection coefficient of the coupled and decoupled antennas arrays in the testing array of Fig. 9(a). It can be seen that the decoupling bandwidth with $|S_{21}| \leq -20$ dB is about 14% (360 MHz), while the impedance matching bandwidth with $|S_{11}| \leq -10$ dB is about 15% (370 MHz). For comparison, the same array decoupled by a lumped element has a decoupling bandwidth of about 3.7% for 20 dB isolation.

[0068] Fig. 10(a) shows an example configuration diagram illustrating a testing antenna array with two antennas operating in the different frequency bands according to another embodiment. In the embodiment, two antennas working at 2.35 GHz (TDD LTE band 40) and 2.45 GHz (ISM band) respectively and the corresponding LTCC decoupling network are given. It can be seen that the two antennas and the LTCC CRDN module, which are connected by two ports, are mounted on each side of a $60 \text{ mm} \times 60 \text{ mm}$ FR4 substrate. As shown in Fig. 10(a), the two antennas are coupled at a distance of $d_1 = 17 \text{ mm}$ in the X-direction and $d_2 = 10 \text{ mm}$ in the Y-direction, while the other antenna relevant dimensions are $L_1 = 26 \text{ mm}$, $L_2 = 25 \text{ mm}$, $h = 6.3 \text{ mm}$ and $W_a = 5 \text{ mm}$.

[0069] Figs. 10(b)-10(c) shows simulated and measured reflection and isolation coefficient of the coupled and decoupled antennas arrays in the testing array of Fig. 10(a). As shown, it is obvious that an improvement of at least 13dB in isolation has been achieved after decoupling within the two contiguous frequency bands. Accordingly, the 6dB matching bandwidths of the two antennas decrease from 180 MHz to 135 MHz (TDD LTE band 40) and 212 MHz to 150 MHz (ISM band), respectively. It is because for two coupled antennas, one acts as a lossy load for the other. Thus it is understandable that the matching bandwidth for a lossier antenna is wider. However, despite a slightly narrower matching bandwidth, the radiation efficiencies of the decoupled antennas are greater than those of coupled ones.

[0070] Fig. 10(d) presents the measured efficiencies of the two antennas before and after decoupling to further illustrate the merits of the proposed LTCC CRDN module. It can be seen that an obvious improvement in efficiency can be achieved when the proposed LTCC CRDN module is utilized, which could be very valuable for practical applications of mobile devices.

[0071] Therefore, with this antenna-independent LTCC CRDN module and appropriate adjusting devices and I/O coupling devices, a tradeoff between the decoupling bandwidth and level can be realized without reconfiguring the entire CRDN network. This attractive feature allows a mass production of one LTCC device for various applications as long as the frequency band is right.

[0072] The embodiments of the present invention may be implemented using certain hardware, software, or a combination thereof. In addition, the embodiments of the present invention may be adapted to a computer program product embodied on one or more computer readable storage media (comprising but not limited to disk storage, CD-ROM, optical memory and the like) containing computer program codes.

[0073] In the foregoing descriptions, various aspects, steps, or components are grouped together in a single embodiment for purposes of illustrations. The disclosure is not to be interpreted as requiring all of the disclosed variations for the claimed subject matter. The following claims are incorporated into this Description of the Exemplary Embodiments, with each claim standing on its own as a separate embodiment of the disclosure.

[0074] Moreover, it will be apparent to those skilled in the art from consideration of the specification and practice of the present disclosure that various modifications and variations can be made to the disclosed systems and methods without departing from the scope of the disclosure, as claimed. Thus, it is intended that the specification and examples be considered as exemplary only, with a true scope of the present disclosure being indicated by the following claims and their equivalents.

What is claimed is:

1. An apparatus for decoupling two antennas in an antenna array, wherein the two antennas transmit and receive signals via a first input/output port and a second input/output port of the apparatus, and the apparatus comprises:

a first adjusting device connected between a first antenna of the two antennas and the first input/output port,

a second adjusting device connected between a second antenna of the two antennas and the second input/output port; and

one or more decoupling networks connected between the first input/output port and the second input/output port;

wherein the first adjusting device and the second adjusting device are configured to have an admittance adjustable to compensate an admittance of the decoupling networks such that an isolation coefficient between the two input/output ports approaches zero as well as reflection coefficients of each input/output port are minimized.

2. The apparatus according to claim 1, wherein the first and the second adjusting devices are configured to have an electrical length and characteristic impedance, both of which are adjustable to compensate the admittance of the decoupling networks.

3. The apparatus according to claim 1, wherein each of the decoupling networks comprises a Coupled Resonator Decoupling Network (CRDN) module having at least one resonator,

wherein the resonator is configured to cooperate with the adjustable electrical length and characteristic impedance of each of the first and the second adjusting devices so as to isolate the two ports electrically.

4. The apparatus according to claim 3, wherein the decoupling networks further comprise:

a first I/O coupling module connected between the first input/output port and the CRDN module; and

a second I/O coupling module connected between the second input/output port and the CRDN module;

wherein, the first and second I/O coupling modules have adjustable electrical parameters such that the decoupling networks have an adjustable working frequency and an adjustable decoupling level.

5. The apparatus according to claim 1, further comprising a first matching network added at one input/output port of the two input/output ports and a second matching network added at the other input/output port of the two input/output ports,

wherein the first matching network and the second matching network are configured to broaden a matching bandwidth of the two antennas.

6. The apparatus according to claim 1, wherein when there are plurality of the decoupling networks that connected in parallel, each of the decoupling networks having different working frequency band such that decoupling of the antennas at multiple frequency bands are achievable.

7. The apparatus according to claim 1, wherein the one or more decoupling networks are used for antennas operating in the same frequency band or antennas operating in different frequency bands.

8. The apparatus according to claim 4, further comprising

a controlling module connected with the first adjusting device and the second adjusting device, and the first I/O coupling module and the second I/O coupling module, wherein the controlling module is configured to control the adjustment of the first adjusting device and the second adjusting device, and the adjustment of the first I/O coupling module and the second I/O coupling module so as to shift their working frequency bands, respectively.

9. An apparatus for decoupling a plurality of antennas in an antenna array, wherein the plurality of antennas transmit and receive signals via respective one of a plurality of input/output ports, the device comprises:

a plurality of adjusting devices, each of which connected between a respective antenna of the plurality of antennas and a respective one input/output port of the plurality of input/output ports,

one or more decoupling networks connected between the respective input/output ports of the plurality of input/output ports,

wherein the plurality of adjusting devices are configured to have an admittance adjustable to compensate an admittance of the decoupling networks such that an isolation coefficient between the input/output ports approaches zero as well as reflection coefficients of each input/output port are minimized.

10. A method for decoupling two antennas in an antenna array, wherein the two antennas transmit and receive signals via a first input/output port and a second input/output port, the method comprising:

inserting a first adjusting device between a first antenna of the two antennas and the first input/output port,

inserting a second adjusting device between a second antenna of the two antennas and the second input/output port;

connecting one or more decoupling networks between the first input/output port and the second input/output port; and

adjusting an admittance of each of the first and the second adjusting devices to compensate an admittance of the decoupling networks such that an isolation coefficient between the two input/output ports approaches zero as well as reflection coefficients of each input/output port are minimized.

11. The method according to claim 10, wherein the adjusting comprising:

adjusting an electrical length and a characteristic impedance of each of the first and the second adjusting devices to compensate the admittance of the decoupling networks.

12. The method according to claim 11, wherein each of the decoupling networks comprises a Coupled Resonator Decoupling Network (CRDN) having at least one resonator,

wherein the resonator is configured to cooperate with the adjusted electrical length and characteristic impedance of each of the first and the second adjusting devices so as to isolate the two ports electrically.

13. The method according to claim 12, wherein each of the decoupling networks further comprises a first I/O coupling module and a second I/O coupling module, the method further comprises:

inserting the first I/O coupling module between the first input/output port and the CRDN module; and

inserting the second I/O coupling module between the second input/output port and the CRDN module;

adjusting electrical parameters of the first and second I/O coupling modules such that the decoupling networks have an adjustable working frequency and an adjustable decoupling level.

14. The method according to claim 10, further comprising:

adding a first matching network at one port of the two ports,

adding a second matching network at the other port of the two ports, and

adjusting the first matching network and the second matching network to broaden a matching bandwidth of the two antennas.

15. The method according to claim 10, further comprising:

connecting a plurality of the decoupling networks in parallel, each of the decoupling networks having different working frequency band such that decoupling of the antennas at multiple frequency bands are achievable.

16. The method according to claim 13, further comprising

connecting a controlling module with the first adjusting device and the second adjusting device, and the first I/O coupling module and the second I/O coupling module, and

controlling the adjustment of the first adjusting device and the second adjusting device, and the adjustment of the first I/O coupling module and the second I/O coupling module so as to shift their working frequency bands, respectively.

17. An apparatus for decoupling two antennas in an antenna array, wherein the two antennas transmit and receive signals via a first input/output port and a second input/output port of the apparatus, and the apparatus comprises:

a first adjusting device connected between a first antenna of the two antennas and the first input/output port,

a second adjusting device connected between a second antenna of the two antennas and the second input/output port; and

one or more decoupling networks connected between the first input/output port and the second input/output port, each of which comprises:

a Coupled Resonator Decoupling Network (CRDN) module;

a first I/O coupling module connected between the first input/output port and the CRDN module; and

a second I/O coupling module connected between the second input/output port and the CRDN module;

wherein, the first and second I/O coupling modules have adjustable electrical parameters such that the decoupling networks have an adjustable working frequency and an adjustable decoupling level.

wherein the first and the second adjusting devices are configured to have an electrical length and characteristic impedance, both of which are adjustable to compensate the admittance of the decoupling networks, such that an isolation coefficient between the two input/output ports approaches zero as well as reflection coefficients of each input/output port are minimized.

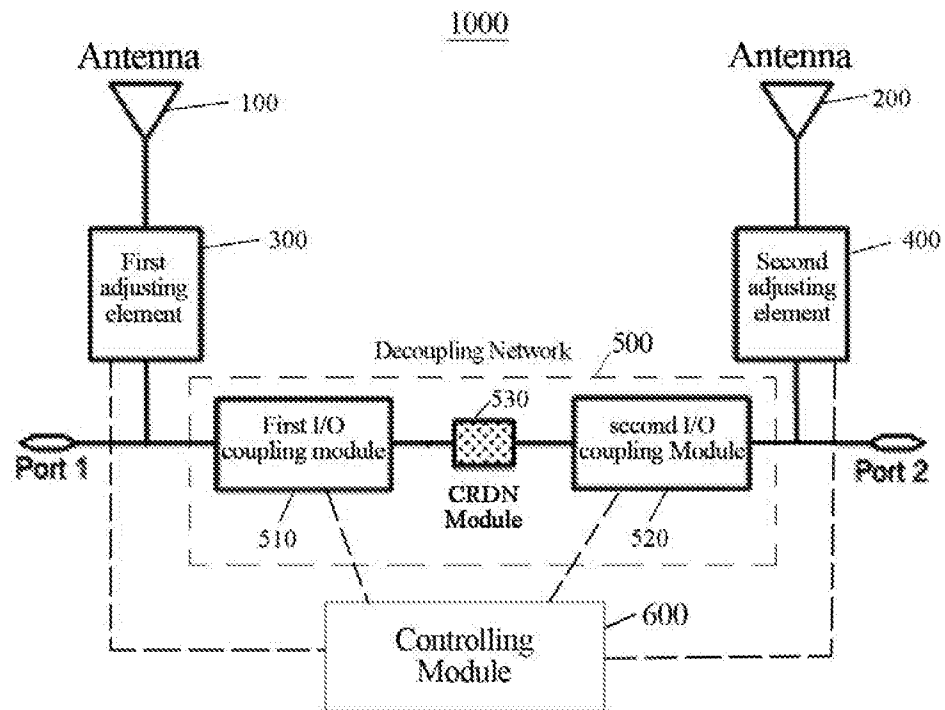


Figure 1

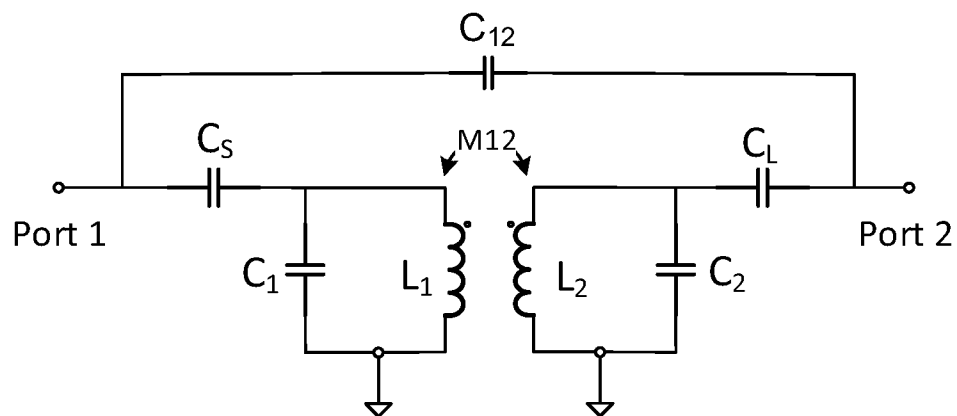


Figure 2

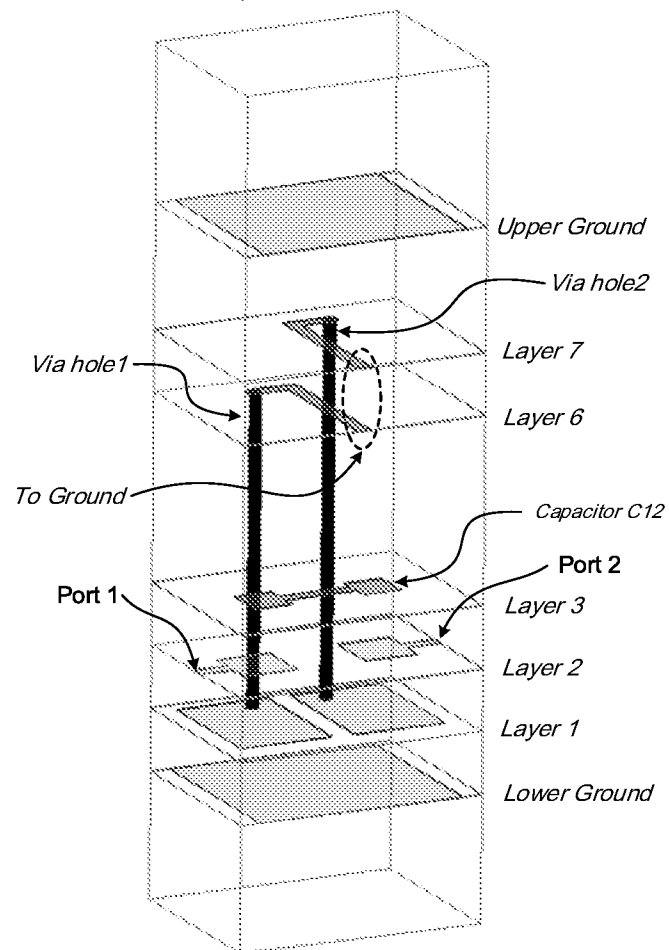


Figure 3

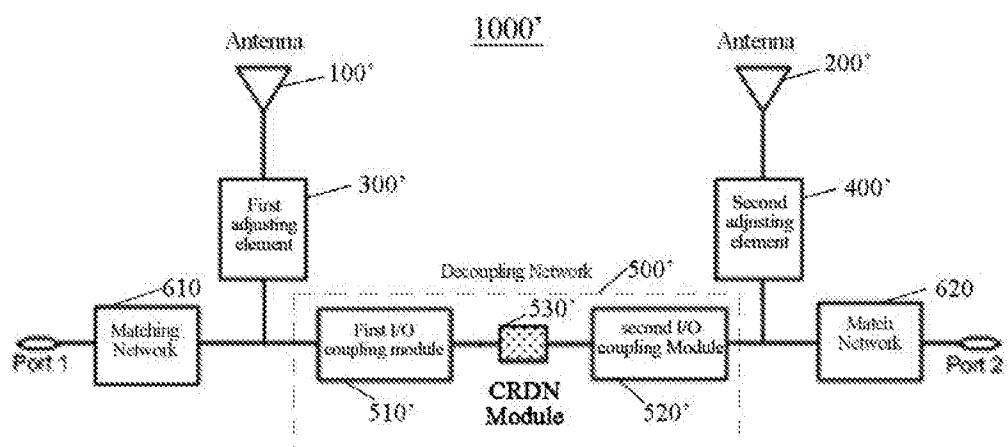


Figure 4

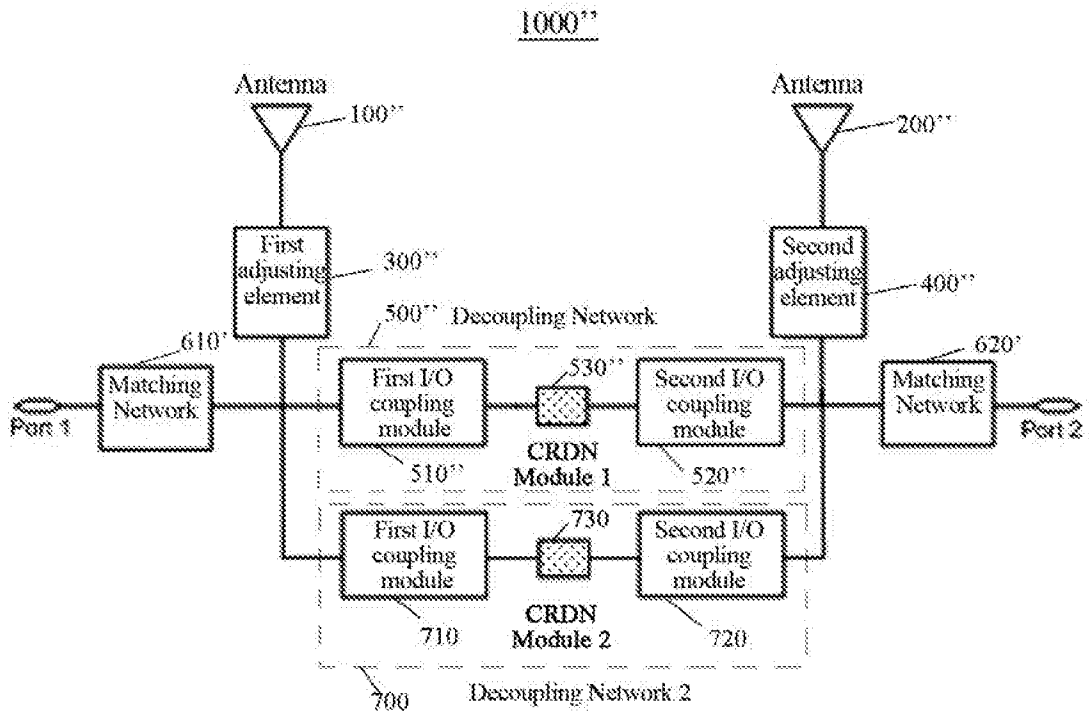


Figure 5

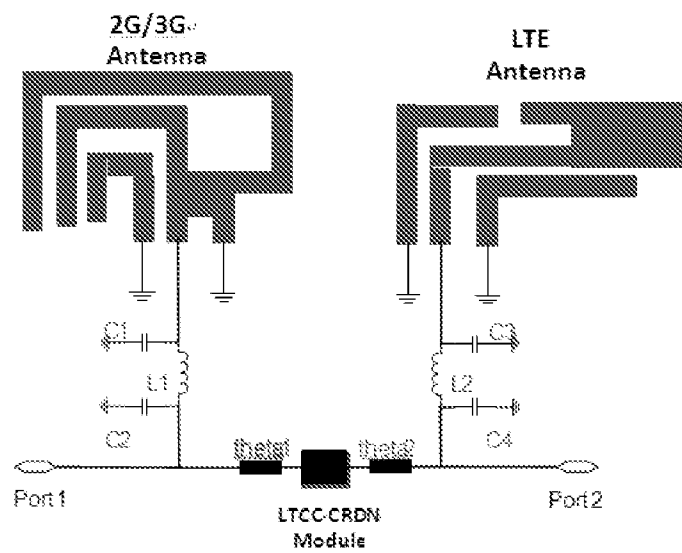


Figure 6(a)

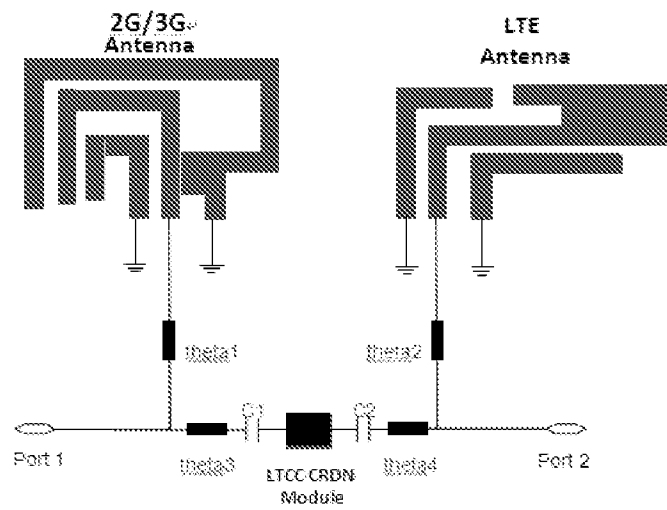


Figure 6(b)

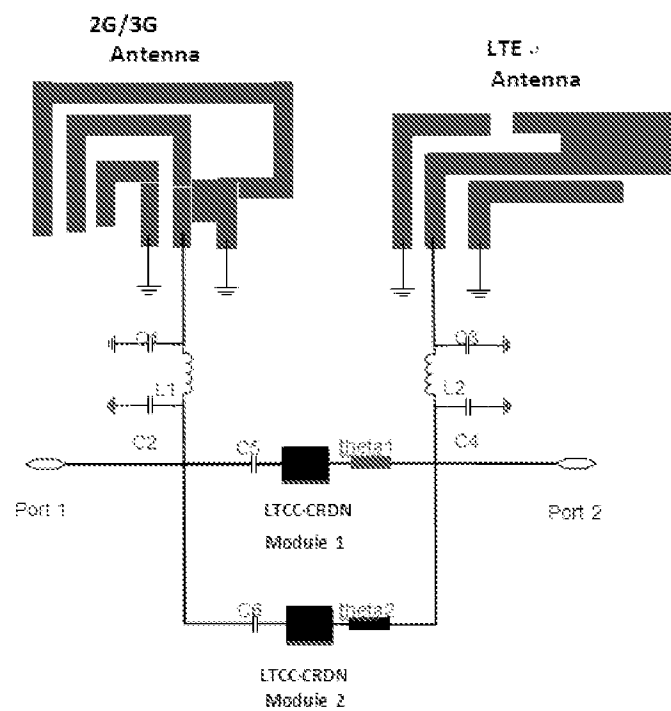


Figure 7

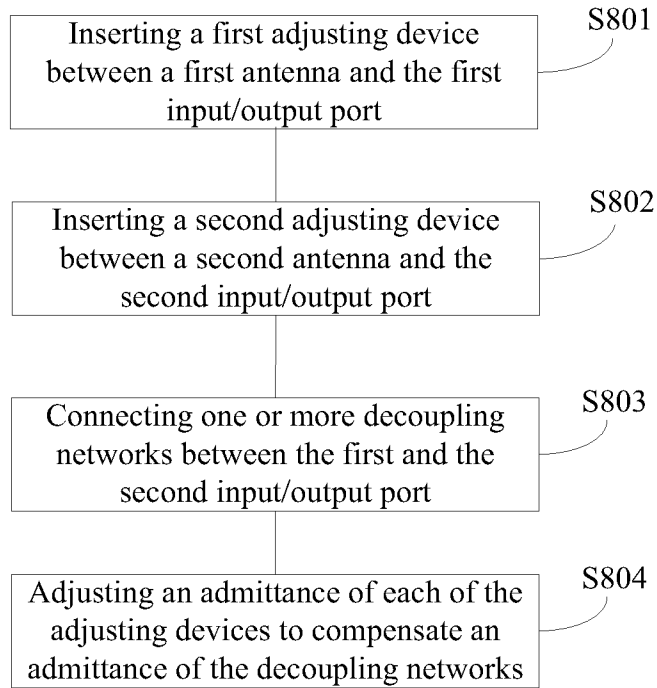
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Figure 8

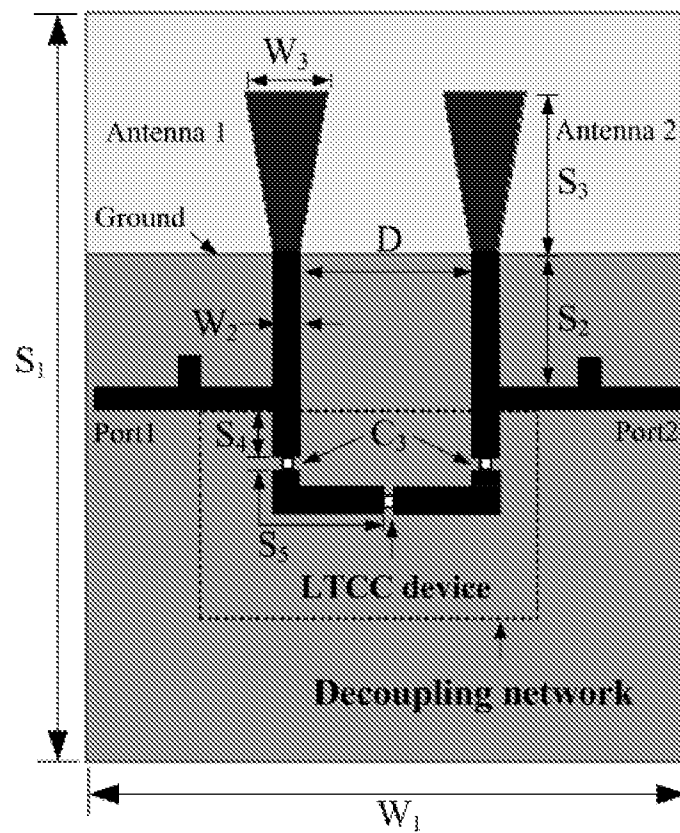


Figure 9(a)

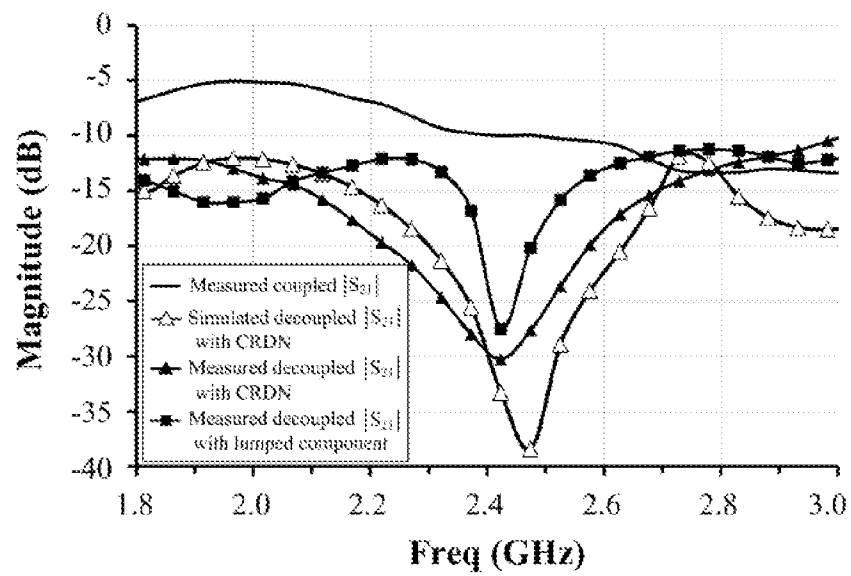


Figure 9(b)

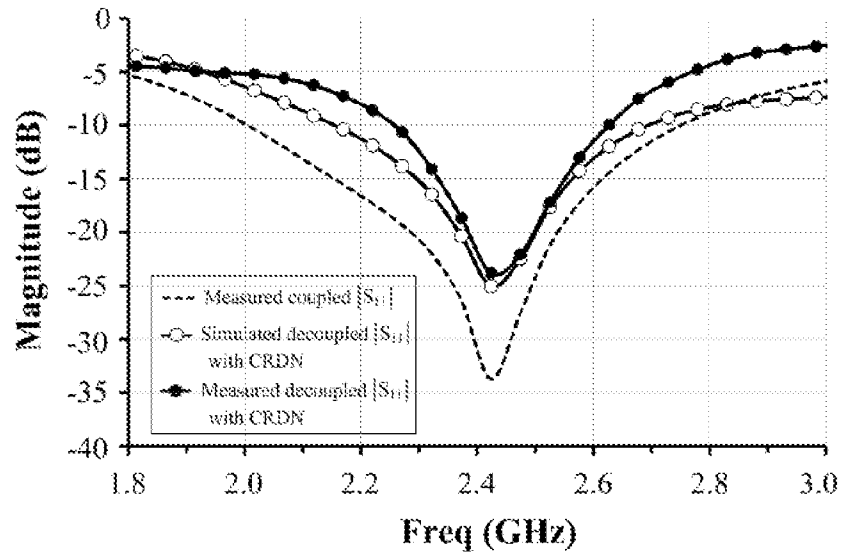


Figure 9(c)

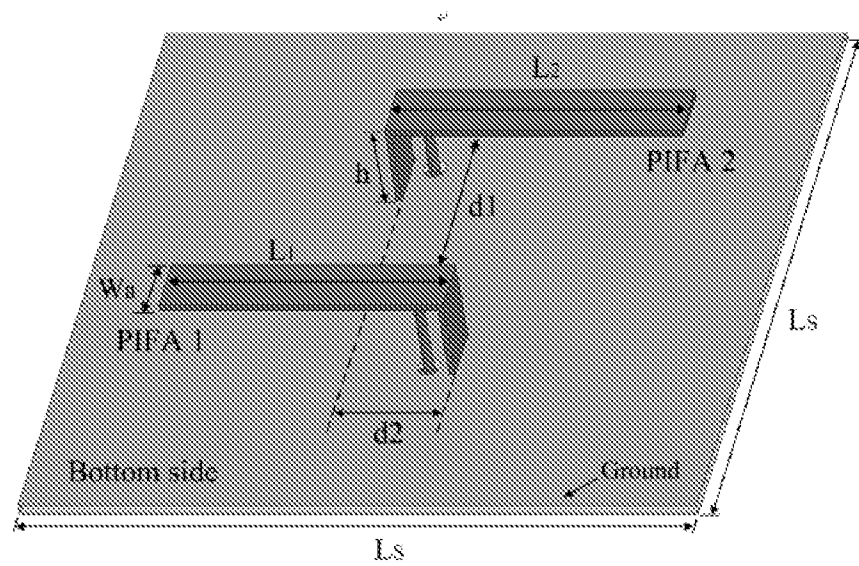


Figure 10(a)

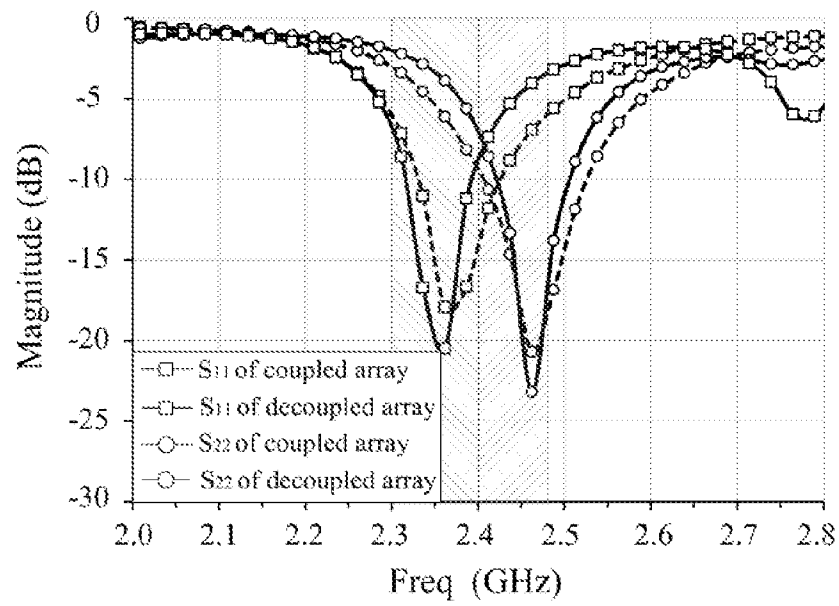


Figure 10(b)

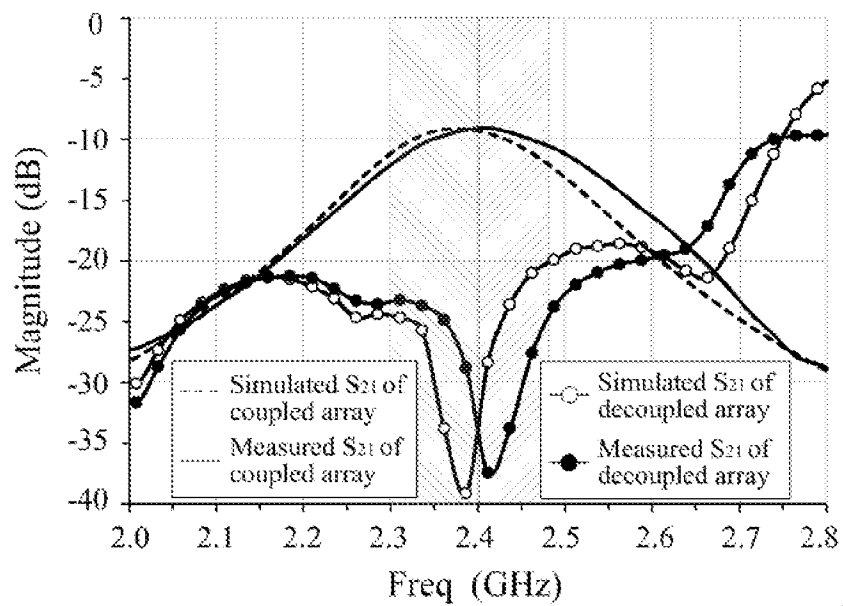


Figure 10(c)

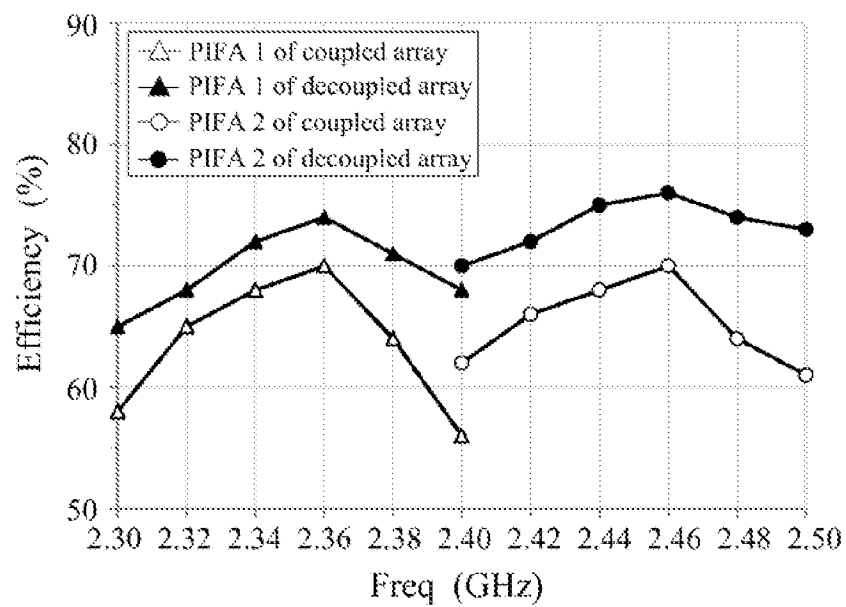


Figure 10(d)

INTERNATIONAL SEARCH REPORT

International application No.

PCT/CN2015/081743

A. CLASSIFICATION OF SUBJECT MATTER

H01Q 1/52(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

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 practicable, search terms used)

CNABS, CNTXT, VEN: antenna, aerial, decouple, couple, resonator, adjust, tunable, change, regulation, port, CRDN

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 2014159986 A1 (MICROSOFT CORP.) 12 June 2014 (2014-06-12) description, paragraphs [0023] to [0058], and figures 1-9	1-17
X	CN 103855469 A (THE CHINESE UNIVERSITY OF HONG KONG) 11 June 2014 (2014-06-11) claims 1-20, description, paragraphs [0037] to [0123], and figures 1-17	1-17
A	CN 102201614 A (BROADCOM CORP.) 28 September 2011 (2011-09-28) the whole document	1-17



Further documents are listed in the continuation of Box C.



See patent family annex.

* Special categories of cited documents:

“A” document defining the general state of the art which is not considered to be of particular relevance

“E” earlier application or patent but published on or after the international filing date

“L” document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

“O” document referring to an oral disclosure, use, exhibition or other means

“P” document published prior to the international filing date but later than the priority date claimed

“T” later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

“X” document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

“Y” document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

“&” document member of the same patent family

Date of the actual completion of the international search

10 September 2015

Date of mailing of the international search report

21 September 2015

Name and mailing address of the ISA/CN

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INTERNATIONAL SEARCH REPORT
Information on patent family members

International application No.

PCT/CN2015/081743

Patent document cited in search report			Publication date (day/month/year)	Patent family member(s)			Publication date (day/month/year)
US	2014159986	A1	12 June 2014	WO	2014089530	A1	12 June 2014
CN	103855469	A	11 June 2014	US	2014152523	A1	05 June 2014
CN	102201614	A	28 September 2011	CN	102201614	B	21 January 2015
				EP	2372843	A3	01 May 2013
				EP	2372843	A2	05 October 2011
				TW	201205957	A	01 February 2012
				US	8958845	B2	17 February 2015
				EP	2372843	B1	31 December 2014
				HK	1161773	A1	31 July 2015
				US	2011228713	A1	22 September 2011