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(54) **SLIM RADIATING SYSTEMS FOR ELECTRONIC DEVICES**

SCHLANKE STRAHLENDE SYSTEME FÜR ELEKTRONISCHE VORRICHTUNGEN

SYSTÈMES DE RAYONNEMENT MINCES POUR DISPOSITIFS ÉLECTRONIQUES

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Description

FIELD OF THE INVENTION

[0001] The present invention relates generally to the field of electronic devices which require the transmission and/or reception of electromagnetic wave signals, and more particularly, to slim radiating structures in wireless electronic devices.

BACKGROUND

[0002] Wireless electronic devices typically handle one or more cellular communication standards, and/or wireless connectivity standards, and/or broadcast standards, each standard being allocated in one or more frequency bands, and the frequency bands being contained within one or more regions of the electromagnetic spectrum.

[0003] For that purpose, a typical wireless electronic device must include a radiating system capable of operating in one or more frequency regions with an acceptable radio-electric performance (in terms of for instance reflection coefficient, standing wave ratio, impedance bandwidth, gain, efficiency, or radiation pattern). The integration of the radiating system within the wireless electronic device must be effective to ensure that the overall device attains good radio-electric performance (such as for example in terms of radiated power, received power, sensitivity) without being disrupted by electronic components and/or human loading.

[0004] Additionally, a space within the wireless electronic device is usually limited and the radiating system has to be included in the available space. The radiating system is expected to be small enough to occupy as little space as possible within the device, which then allows for smaller devices, or for the addition of more specific components and functionalities into the device. At the same time, it is sometimes convenient for the radiating system to be flat since this allows for slim devices. Thus, many of the demands for wireless devices also translate to specific demands for the radiating systems thereof. This is even more critical in the case in which the wireless device is a multifunctional wireless device. Commonly-owned patent applications WO2008/009391 and US2008/0018543 describe a multifunctional wireless device.

[0005] For a good wireless connection, high efficiency is further required. Other more common design demands for radiating systems are the reflection coefficient (or standing-wave ratio, SWR) and the impedance which is supposed to be about 50 ohms. Other demands for radiating systems for wireless handheld or portable devices are competitive cost and a low SAR.

[0006] Furthermore, a radiating system has to be integrated into a device or, in other words, a wireless device has to be constructed such that an appropriate radiating system may be integrated therein which puts additional constraints by consideration of the mechanical fit, the electrical fit, and the assembly fit.

[0007] Of further importance, usually, is the robustness of the radiating system, which means that the radiating system does not change its properties upon smaller shocks to the device and the human loading.

[0008] Besides radio-frequency performance, small size and reduced interaction with human body and nearby electronic components, one of the current limitations of the prior-art is that generally the antenna system is customized for every particular wireless handheld device model. The mechanical architecture of each device model is different and the volume available for the antenna severely depends on the form factor of the wireless device model together with the arrangement of the multiple components embedded into the device (e.g., displays, keyboards, battery, connectors, cameras, flashes, speakers, chipsets, memory devices, etc.). As a result, the antenna within the device is mostly designed ad hoc for every model, resulting in a higher cost and a delayed time to market. In turn, as typically the design and integration of an antenna element for a radiating structure is customized for each wireless device, different form factors or platforms, or a different distribution of the functional blocks of the device will force to redesign the antenna element and its integration inside the device almost from scratch.

[0009] A radiating system for a wireless handheld or portable device typically includes a radiating structure comprising an antenna element which operates in combination with a ground plane layer providing a determined radio-frequency performance in one or more frequency regions of the electromagnetic spectrum. Typically, the antenna element has a dimension close to an integer multiple of a quarter of the wavelength at a frequency of operation of the radiating structure, so that the antenna element is at resonance or substantially close to resonance at the frequency of operation, and a radiation mode is excited on the antenna element.

[0010] Antenna elements operating in multiple frequency bands allocated at different regions of the electromagnetic spectrum usually present complex mechanical designs and considerable dimensions, mainly due to the fact that antenna performance is highly related to the electrical dimensions of the antenna element.

[0011] A further problem associated to the integration of the radiating structure, and in particular to the integration of the antenna element in a wireless device is that the volume dedicated for such integration has continuously shrunk with the appearance of new smaller and/or thinner form factors for wireless devices, and with the increasing convergence of different functionalities in a same wireless device. Therefore, from the conventional wisdom perspective, the trend in seeking for slimmer wireless device is incompatible with maximizing the performance of a traditional antenna device, which again, it is known to have a high correlation between antenna size (relative to the operating wavelengths) and performance.

[0012] Some techniques to miniaturize and/or optimize the multiband behavior of an antenna element have been described in the prior art. However the radiating structures described therein still rely on exciting a radiation mode on the antenna element for each one of the frequency bands of operation. This fact leads to complex mechanical designs and large antennas that usually are very sensitive to external effects (such as for instance the presence of plastic or dielectric covers that surround the wireless device), to components of the wireless device (such as for instance, but not limited to, a speaker, a microphone, a connector, a display, a shield can, a vibrating module, a battery, or an electronic module or subsystem) placed either in the vicinity of, or even underneath, the radiating element, and/or to the human loading. A multiband antenna system is sensitive to any of the above mentioned aspects because they may alter the electromagnetic coupling between the different geometrical portions of the radiating element, which usually translates into detuning effects, degradation of the radio-frequency performance of the antenna system and/or the radio-frequency performance of the wireless device, and/or greater interaction with the user (such as an increased level of SAR).

[0013] In this sense, a radiating system such as the one described in the appended claims not requiring a complex and/or large antenna formed by multiple arms, slots, apertures and/or openings and a complex mechanical design is preferable in order to minimize such undesired external effects and simplify the integration within the wireless device.

[0014] Some other attempts have focused on antenna elements not requiring a complex geometry while still providing some degree of miniaturization by using an antenna element that is not resonant in the one or more frequency ranges of operation of the wireless device.

[0015] For example, WO2007/128340 discloses a wireless portable device comprising a non-resonant antenna element for receiving broadcast signals (such as, for instance, DVB-H, DMB, T-DMB or FM). The wireless portable device further comprises a ground plane layer that is used in combination with said antenna element. Although the antenna element has a first resonant frequency above the frequency range of operation of the wireless device, the antenna element is still the main responsible for the radiation process and for the radio-frequency performance of the wireless device. This is clear from the fact that no radiation mode can be excited on the ground plane layer because the ground plane layer is electrically short at the frequencies of operation (i.e., its dimensions are much smaller than the wavelength). For this kind of non-resonant antenna elements, a matching circuitry is added for matching the antenna to a level of SWR in a limited frequency range, which in this particular case can be around SWR≤6. Such level of SWR together with the limited bandwidth results in antenna elements which are only acceptable for reception of electromagnetic wave signals but not desirable for transmission of electromagnetic wave signals. With such limitations, while the performance of the wireless portable device may be sufficient for reception of electromagnetic wave signals (such as those of a broadcast service), the antenna element could not provide an acceptable performance (for example, in terms of reflection coefficient or gain) for a communication service requiring also the transmission of electromagnetic wave signals.

[0016] Commonly-owned patent applications WO2008/119699 and US2010/0109955 describe a wireless handheld or portable device comprising a radiating system capable of operating in two frequency regions. The radiating system comprises an antenna element having a resonant frequency outside said two frequency regions, and a ground plane layer. In this wireless device, while the ground plane layer contributes to enhance the electromagnetic performance of the radiating system in the two frequency regions of operation, it is still necessary to excite a radiation mode on the antenna element. In fact, the radiating system relies on the relationship between a resonant frequency of the antenna element and a resonant frequency of the ground plane layer in order for the radiating system to operate properly in said two frequency regions. Nevertheless, the solution still relies on an antenna element whose size is related to a resonant frequency that is outside of the two frequency regions.

[0017] A different radiating system is disclosed in U.S. Pat. No. 6,674,411, in which a planar inverted-L antenna (i.e., a patch antenna) has a radiating element composed by a rectangular plate placed above and substantially parallel to a ground plane. The antenna is connected to a matching network that provides a match in one frequency band in a first frequency region, and in one frequency band in a second frequency region. Thus the antenna system is limited to single-band operation in both frequency regions. When operation in more bands is sought, the antenna system requires of a switched (active) matching network that provides non-simultaneous impedance matching in each frequency band. So in spite of having an antenna that occupies a large volume ($20\times10\times8mm^3$), not more than dual-band operation may be provided simultaneously.

[0018] For at least the above reasons, wireless device manufacturers regard the volume dedicated to the integration of the radiating structure, and in particular the antenna element, as being a toll to pay in order to provide wireless communication capabilities to the handheld or portable device.

[0019] In order to reduce as much as possible the volume occupied into the wireless handheld or portable device, recent trends in handset antenna design are oriented to maximize the contribution of the ground plane to the radiation process by using very small non-resonant elements. However, non-resonant elements usually are forced to include a complex radio-frequency system. Thus, the challenge of these techniques mainly relies on said complexity (combination of inductors, capacitors, and transmission lines), which is required to satisfy impedance bandwidth and efficiency specifications.

[0020] Commonly owned patent applications, WO2010/015365, and WO2010/015364 are intended for solving some of the aforementioned drawbacks. Namely, they describe a wireless handheld or portable device comprising a radiating system including a radiating structure and a radio-frequency system. The radiating structure is formed by a ground plane layer presenting suitable dimensions as for supporting at least one efficient radiation mode and at least one radiation booster capable of coupling electromagnetic energy to said ground plane layer. The radiation booster is not resonant in any of the frequency regions of operation and, consequently, a radio-frequency system is used to properly match the radiating structure to the desired frequency bands of operation.

[0021] More particularly, in WO2010/015364 each radiation booster is intended for providing operation in a particular frequency region. Thus, the radio-frequency system is designed in such a way that the first internal port associated to the first radiation booster is highly isolated from the second internal port associated to a second radiation booster. Said radio-frequency system usually comprises a matching network including resonators for each one of the frequency regions of operation and a set of filters for each one of the frequency regions of operation. Thus, said radio-frequency system requires multiple stages and the performance of the radiating systems in terms of efficiency may be affected by the additional losses of the components. As each radiation booster is generally intended for providing operation in a particular frequency region, the bandwidth capabilities may be limited for some applications requiring very wide bandwidth specially at the low frequency region, as for example for wireless devices operating at LTE700, GSM850 and GSM900.

[0022] Commonly owned patent applications WO2014/012796 and US2014/0015730 disclose a concentrated wireless device comprising a radiating system including a radiating structure and a radio-frequency system, such device operating two or more frequency regions of the electromagnetic spectrum. A feature of said radiating system is that the operation in at least two frequency regions is achieved by one radiation booster, or by at least two radiation boosters, or by at least one radiation booster and at least one antenna element, wherein the radio-frequency system modifies the impedance of the radiating structure, providing impedance matching to the radiating system in the at least two frequency regions of operation of the radiating system.

[0023] Commonly owned patent applications WO2014/012842 and US2014/0015728 disclose very compact, small size and light weight radiation boosters operating in single or in multiple frequency bands. Such radiation boosters are configured to be used in radiating systems that may be embedded into a wireless handheld device. Said patent applications further disclose radiation booster structures and their manufacturing methods that enable reducing the cost of both the booster and the entire wireless device embedding said booster inside the device.

[0024] Another technique, as disclosed in U.S. Patent 7,274,340, is based on the use of two coupling elements. Therein, quad-band operation (GSM 1800/1900 and GSM850/900 bands) is provided with two coupling elements: a low-band (LB) coupling element (for the GSM850/900 bands), and a high-band (HB) coupling element (for the GSM1800/1900 bands), where the impedance matching is provided through the addition of two matching circuits, one for the LB coupling element and another one for the HB coupling element. In spite of using non-resonant elements, the size of the element for the low band is significantly large, being 1/9.3 times the free-space wavelength of the lowest frequency for the low frequency band. Due to such size, the low band element would be a resonant element at the high band. Additionally, the operation of this solution is closely linked to the alignment of the maximum E-field intensity of the ground plane and the coupling element. The size of the low band element undesirably contributes to increase the printed circuit board (PCB) space required by the antenna module. Therein, the bandwidth at the low frequency region is 133MHz (from 821MHz to 954MHz) that is insufficient for some applications requiring very wide bandwidth, especially at the low frequency region, as for example for wireless devices operating at LTE700, GSM850 and GSM900.

[0025] Document US 2011/0117976 A1 discloses an antenna element and portable radio. Document US 2006/0214856 A1 discloses a broad band antenna. Document JP 2005175846 discloses an antenna apparatus and communication equipment equipped with it. Document US 2003/0063036 A1 discloses an antenna apparatus. Document WO 2012/017013 A1 discloses a wireless device capable of multiband MIMO operation.

[0026] Information about limitations of electrically small antennas is disclosed in L. J. Chu, "Physical Limitations of Omni-directional Antennas", Journal of Applied Physics, December 1948, vol. 19, pages 1163-1175, Harold A. Wheeler, "Fundamental Limitations of Small Antennas", Proceedings of the IRE, 1947, vol. 35, pages 1479-1484 and R. C. Hansen, "Fundamental Limitations in Antennas", Proceedings of the IEEE, 1981, vol. 69, pages 170-182.

[0027] Therefore, a wireless device not requiring an antenna element and including a slim radiating system would be advantageous to make simpler the integration of the slim radiating structure into the wireless electronic device minimizing the amount of the electronic device that is allocated towards the slim radiating system, and to provide a suitable radio-frequency performance to operate in a wide range of communication bands. The volume freed up by the absence of a large and complex antenna element would enable smaller and/or thinner devices, as slim electronic devices, or even to adopt radically new form factors which are not feasible today due to the presence of an antenna element featuring a considerable volume. Furthermore, by eliminating precisely the element that requires customization, a standard solution is sought which should only require minor adjustments to be implemented in different wireless electronic devices.

OBJECT AND SUMMARY OF THE INVENTION

[0028] The present invention is defined by the appended claim 1. Advantageous embodiments are the subject matter of the dependent claims.

[0029] The in the following described examples merely serve to illustrate certain technical aspects of the invention.

[0030] It is an object of the present invention to provide an electronic device (such as for instance but not limited to a mobile phone, a smartphone, a phablet, a PDA, an MP3 player, a headset, a USB dongle, a laptop computer, a tablet, a gaming device, a GPS system, a digital camera, a wearable device as a smart watch, a PCMCIA, Cardbus 32 card, a sensor, or generally a multifunction wireless device which combines the functionality of multiple devices) containing a slim radiating system that covers a wide range of radio-frequencies and handles multiple communication bands while exhibiting a suitable radio-frequency performance.

[0031] It is another object of the invention to provide a slim radiating system suitable for being included within electronic devices, and more preferably within slim electronic devices.

[0032] It is another object of the invention to provide a standard slim radiating system which only requires minor adjustments to be included within different electronic devices.

[0033] Another object of the invention refers to the location (on the device) of radiation boosters and, more particularly, booster bars for obtaining the most favorable frequency bandwidth values.

[0034] An electronic device according to an example may have a candy-bar shape, which means that its configuration is given by a single body. It may also have a two-body configuration such as a clamshell, flip-type, swivel-type or slider structure. In some other cases, the device may have a configuration comprising three or more bodies. It may further or additionally have a twist configuration in which a body portion (e.g. with a screen) can be twisted (i.e., rotated around two or more axes of rotation which are preferably not parallel). The electronic device may comprise a memory module, a processing circuitry module, a user interface module, a battery, and a wireless communication module.

[0035] The wireless communication module may include a slim radiating system, a radio-frequency transceiver circuit, a power amplifier circuit and a base-band module. The slim radiating system may be coupled to the power amplifier via a conductive path and to the radio transceiver circuit via a conductive path. The wireless communication module may include a multiplexing stage coupled to the slim radiating system via a conductive path.

[0036] A slim radiating system in accordance with an example may include a slim radiating structure, a radiofrequency system, at least one internal conductive path and at least one external conductive path. The slim radiating structure may include a ground element and at least one radiation booster, which in some examples may be a booster bar, separated from the ground element by a gap.

[0037] A slim radiating structure may comprise a ground element and one, two, three, four or even more radiation boosters. In some preferred examples, said radiation boosters may be booster bars featuring an elongated shape. In preferred examples, each booster bar or radiation booster is separated from the ground element by a gap.

[0038] An aspect of the present invention relates to the use of the ground element (or ground plane layer) of the slim radiating system as a main source of radiation.

[0039] A radiation booster includes a dielectric material and in some examples, a single standard layer of dielectric material spacing two or more conductive elements. A single standard layer of dielectric material refers to dielectric material with a standard thickness, which is available off-the-shelf. For example, 0.025" (0.635mm), 0.047" (1.2mm), 0.093" (2.36mm) or 0.125" (3.175mm) are common/standard thicknesses for dielectric materials which are available in the market. Examples of dielectric materials may include fiber-glass FR4, Cuclad, Alumina, Kapton, Ceramic and for instance commercial laminates and substrates from Rogers® Corporation (RO3000® and RO4000® laminates, Duroid substrates and alike) or other suitable non-conductive materials.

[0040] The radiation booster may be formed by printing or depositing conductive material in a first and a second surface of the dielectric material (e.g. top and bottom) and adding several vias to electrically connect the conductive material in the first surface with the conductive material in the second surface. The conductive material in the first and second surfaces may have a substantially polygonal shape. Some possible polygonal shapes are for instance, but not limited to, squares, rectangles, and trapezoids. When the conductive material in said first and second surfaces has an elongated shape, for instance a rectangular shape, the radiation booster takes the form of a booster bar; a booster bar may also include vias that electrically connect the conductive material in the first surface with the conductive material in the second surface.

[0041] The elongated shape of a booster bar is characterized by two slim form factors: a slim width factor and a slim height factor. The slim width factor is a ratio between a length of the booster bar and a width of the booster bar. The slim height factor is a ratio between the length of the booster bar and a height of the booster bar.

[0042] The slim width factor characterizes the ratio between the length and the width of the booster bar, whereas the slim height factor characterizes the ratio between the length and the height of the booster bar. In a preferred example, the value for the slim width factor and the slim height factor is greater than 2, for instance in one or more of those examples the value for the slim width factor is greater than 3, and preferably larger than 3.5, and the slim height factor is greater than 4. In another preferred example, the value for the slim width factor is greater than 6 and/or the slim height factor is greater than 6. In another preferred example, the value for the slim width factor is greater than 6 and/or the slim height factor is larger than 9. In some less preferred examples, the values for both the slim width factor and the slim height factor are between 1 and 2. The slim width factor and the slim height factor of a booster bar may take any of the values listed above yet being smaller than 25, and preferably smaller than 10.

[0043] A radiation booster may comprise one, two or more booster bars electrically connected, forming a booster element that fits in an imaginary sphere having a diameter smaller than 1/3 of a radiansphere corresponding to the lowest frequency of operation of the slim radiating system. Such a booster element may also be characterized by a slim width factor, a slim height factor, and a location factor. Any booster element may be limited by a slim width factor and a slim height factor, each of these factors being between 1 and 10, and preferably between 2 and 10.

[0044] An advantageous aspect of the invention refers to a booster bar built on a single standard layer of dielectric material that is manufactured at a competitive cost.

[0045] Another advantageous aspect of the invention refers to a booster bar having a slim width factor and/or slim height factor that enables the booster bar to occupy only a small portion within the electronic wireless device and making it suitable for its integration within slim electronic devices or flexible electronic devices.

[0046] Another advantageous aspect of the present invention refers to the location and slim form factors of a booster bar to guarantee the most advantageous frequency bandwidth for the available space.

[0047] A radiation booster, like for instance a booster bar, is separated from the ground plane layer by a gap. In the context of this document, the gap refers to a minimum distance between a point at an edge of the ground plane layer and a point at an edge of the bottom conductive surface of the radiation booster. The location of the radiation booster is characterized by a location factor that is a ratio between the width of the radiation booster and the gap. In a preferred example, the location factor is between 0.5 and 2. In another preferred example, the location factor is between 0.3 and 1.8.

[0048] Each radiation booster of the slim radiating system advantageously couples the electromagnetic energy from the radio-frequency system to the ground element in transmission, and from the ground element to the radio-frequency system in reception. The radiation boosters excite a radiation mode in the ground element enabling the radiation from the ground element.

[0049] The form factor of the radiation booster, together with its location in relation to the ground element, is configured to achieve a proper excitation of the radiation mode of the ground element. The location factor is selected to achieve the most favorable frequency bandwidth for a radiation booster with a certain form factor, particularly a booster bar.

[0050] Apart from the form factor of the radiation booster, the gap is also relevant for properly exciting a radiation mode in the ground plane layer and to achieve the most advantageous frequency bandwidth. The bandwidth of the slim radiating system may be degraded if the location factor is not properly selected.

[0051] The location factor and the slim form factors of a booster bar are selected to ensure the most favorable frequency bandwidth while minimizing/reducing the amount of space allocated towards the integration of the booster bar within the electronic device.

[0052] The slim radiating structure is mounted within the electronic device and is coupled to the radio-frequency system via a conductive path. The radiation booster is coupled to the ground element via a conductive path and is located at certain distance from the ground element. Said conductive path comprises a conductive element which may be linear or include a surface; the conductive element may comprise, for instance but not limited to, a metallic strip and/or a conductive trace.

[0053] In some examples, a slim radiating structure comprises one ground element or conductive material acting as a ground plane for the slim radiating structure. In some other examples, a slim radiating structure may comprise two, three or more ground elements or conductive materials acting as a ground plane for the radiating structure. In such examples, the plurality of ground elements may be electrically interconnected one to each other.

[0054] The at least one radiation booster for a slim radiating structure may have a maximum size at least smaller than 1/15 of the free-space wavelength corresponding to the lowest frequency of the first frequency region of operation. In some cases, said maximum size may be also smaller than 1/20, and/or 1/25, and/or 1/30, and/or 1/50, and/or 1/100 of the free-space wavelength corresponding to the lowest frequency of the first frequency region of operation. In some cases, the at least one radiation booster fits in an imaginary sphere having a diameter smaller than 1/3, or preferably smaller than 1/4, or preferably smaller than 1/6, or even more preferably smaller than 1/10 of a radiansphere at said free-space wavelength. The radiansphere is defined as an imaginary sphere having a radius equal to the operating wavelength divided by two times π (pi).

[0055] Furthermore, in some examples, the at least one radiation booster also has a maximum size smaller than 1/15, and/or 1/20, and/or 1/25, and/or 1/30, and/or 1/50 of the free-space wavelength corresponding to the lowest frequency of the second frequency region of operation. In some cases, the at least one radiation booster fits in an imaginary sphere having a diameter smaller than 1/3, or preferably smaller than 1/4, or preferably smaller than 1/6, or even more preferably smaller than 1/10 of a radiansphere at said free-space wavelength.

[0056] Additionally, in some of these examples the at least one radiation booster has a maximum size larger than 1/1400, 1/700, 1/350, 1/250, 1/180, 1/140, or 1/120 times the free-space wavelength corresponding to the lowest frequency of said first frequency region.

[0057] The maximum size of a radiation booster is preferably defined by the largest dimension of a booster box that completely encloses said radiation booster, and in which the radiation booster is inscribed. More specifically, a booster box for a radiation booster is defined as being the minimum-sized parallelepiped of square or rectangular faces that completely encloses the radiation booster and wherein each one of the faces of said minimum-sized parallelepiped is tangent to at least a point of said radiation booster. Moreover, each possible pair of faces of said minimum-size parallelepiped sharing an edge forms an inner angle of 90°. In those cases in which the radiating structure comprises more than one radiation booster, a different booster box is defined for each of them.

[0058] In some preferred examples, the area defined by the two largest dimensions of a booster box is advantageously small compared to the square of the wavelength corresponding to the lowest frequency of the first frequency region; in particular, a ratio between said area and the square of the wavelength corresponding to the lowest frequency of the first frequency region may be advantageously smaller than at least one of the following percentages: 0.15%, 0.12%, 0.10%, 0.08%, 0.06%, 0.04%, or even 0.02%. In some of these examples, a ratio between the area defined by the two largest dimensions of a booster box and the square of the wavelength corresponding to the lowest frequency of the second frequency region may also be advantageously smaller than at least one of the following percentages: 0.50%, 0.45%, 0.40%, 0.35%, 0.30%, 0.25%, 0.20%, 0.15%, 0.10%, or even 0.05%.

[0059] Moreover, in some examples, the at least one radiation booster will entirely fit inside a limiting volume equal or smaller than $L^3/25000$, and in some cases equal or smaller than $L^3/50000$, $L^3/100000$, $L^3/150000$, $L^3/200000$, $L^3/300000$, $L^3/400000$, or even smaller than $L^3/500000$, being L the wavelength corresponding to the lowest frequency of the first frequency region of operation.

[0060] A slim radiating system according to an example is configured to handle multiple communication bands, and to provide coverage and an acceptable level of reflection coefficient in a wide range of communication bands in one or more frequency regions of operation exhibiting a suitable radio-frequency performance. The slim radiating system is designed to transmit and receive radio-frequency signals in multiple communication bands of interest, including frequency bands that may be added, for instance, through the deployment of future cellular telephone bands and/or data service bands.

[0061] In the context of this document, a frequency band preferably refers to a range of frequencies used by a particular cellular communication standard, a wireless connectivity standard or a broadcast standard, while a frequency region preferably refers to a continuum of frequencies of the electromagnetic spectrum. For example, the GSM 1800 standard is allocated in a frequency band from 1710MHz to 1880MHz while the GSM 1900 standard is allocated in a frequency band from 1850MHz to 1990MHz. A device operating the GSM 1800 and the GSM1900 standards must have a radiating system capable of operating in a frequency region from 1710MHz to 1990MHz. As another example, a wireless device operating the GSM 850 standard (allocated in a frequency band from 824MHz to 894MHz) and the GSM 1800 standard must have a radiating system capable of operating in two separate frequency regions.

[0062] Some frequency bands that the slim radiating system may be configured to transmit and receive signals in are, for example, GSM 850 (824-894MHz), GSM 900 (880-960MHz), GSM 1800 (1710-1880MHz), GSM 1900 (1850-1990MHz), WCDMA 2100 (1920-2170MHz), CDMA 1700 (1710-2155MHz), LTE 700 (698-798MHz), LTE 800 (791-862MHz), LTE 2600 (2500-2690MHz), LTE 3500 (3.4-3.6GHz), LTE 3700 (3.6-3.8GHz), WiFi or WLAN (2.4-2.5GHz and/or 4.9-5.9GHz), etc. A wireless handheld or portable device according to an example may operate one, two, three, four or more cellular communication standards, wireless connectivity standards, and/or broadcasts standards, each standard being allocated in one, two or more frequency bands, and said frequency bands being contained within one, two or more frequency regions of the electromagnetic spectrum.

[0063] The slim radiating system is designed to provide an acceptable level of reflection coefficient in the frequency regions of operation. A slim radiating system according to an example is configured to operate in at least one frequency region. In some examples, the slim radiating system is configured to operate in a first frequency region comprising at least a first frequency band, and a second frequency region comprising at least a second frequency band. Such radiating system is configured to satisfy the radio-frequency bandwidths and frequency coverage goals. A slim radiating system according to an example may advantageously feature an impedance bandwidth in the first frequency region larger than 5%, 10%, 15%, or even larger than 20%. In addition, such radiating system may also feature an impedance bandwidth in the second frequency region larger than 5%, 10%, 15%, 20%, 25%, 30%, 35%, or even larger than 40%. The impedance bandwidth is defined as the difference between the highest and lowest frequencies of a frequency region, divided by the central frequency of the same frequency region.

[0064] Due to the small size of the radiation boosters, the radiation boosters and booster bars may be electrically short at some or all frequencies of operation. A slim radiating structure according to an example may feature a first resonant frequency, measured at an internal path, at a frequency higher (i.e. above) than the highest frequency of the first frequency region of operation when said radio-frequency system is disconnected. Moreover, when the radio-frequency system is disconnected, the input impedance of the slim radiating structure measured at the internal path may have an important reactance, in particular a capacitive reactance, within the frequencies of said first frequency region. In this case, a ratio between the first resonant frequency of the slim radiating structure and the highest frequency of the first frequency region is advantageously greater than 1.2. In some cases, said ratio may be even greater than one or more of the following values: 1.5, 1.8, 2.0, 2.2, 2.4, 2.6, 2.8, or 3.0. In some examples, a ratio between said first resonant frequency and the lowest frequency of the first frequency region of operation is advantageously greater than 1.3, or even greater than one or more of the following values: 1.4, 1.5, 1.8, 2.0, 2.2, 2.4, 2.6, 2.8, or 3.0.

[0065] In some examples, the first resonant frequency of the slim radiating structure, measured at an internal path when the radio-frequency system is disconnected, is above the highest frequency of the second frequency region, wherein a ratio between said first resonant frequency and said highest frequency of the second frequency region may be larger than one or more of the following values: 1.0, 1.1, 1.2, 1.4, 1.6, 1.8, or 2.0. In some other examples, said first resonant frequency is within the second frequency region. In some other examples, said first resonant frequency is above the highest frequency of the first frequency region and below the lowest frequency of the second frequency region.

[0066] In the context of this document, a resonant frequency associated to a radiation booster of the slim radiating structure preferably refers to a frequency at which the input impedance of the slim radiating structure, the impedance being measured at the internal path coupling the radiation booster to the radio-frequency system when the radio-frequency system is not connected, has an imaginary part equal or substantially equal to zero.

[0067] The radio-frequency system may comprise one or more matching circuits that modify the impedance of the slim radiating structure providing impedance matching to the slim radiating system, at an external path, in one or more frequency regions of operation of the slim radiating system.

[0068] A radio-frequency system according to an example may include at least one matching network with a plurality of stages, for instance, two, three, four, five, six or more stages. A stage comprises one or more circuit components (for example but not limited to, inductors, capacitors, resistors, jumpers, short-circuits, delay lines, or other reactive or resistive components). In some cases, a stage has a substantially inductive behavior in the frequency region or regions of operation of the slim radiating system, while another stage has a substantially capacitive behavior in said frequency region/s, and yet a third one may have a substantially resistive behavior in said frequency region/s. In an example, a stage may substantially behave as a resonant circuit (such as, for instance, a parallel LC resonant circuit or a series LC resonant circuit) in at least one frequency region of operation of the slim radiating system. The use of stages having a resonant circuit behavior allows one part of a given matching network be effectively connected to another part of said matching network for a given range of frequencies, or in a given frequency region, and be effectively disabled for another range of frequencies, or in another frequency region.

[0069] In some examples, the at least one matching network alternates stages connected in series (i.e. cascaded) with stages connected in parallel (i.e. shunted), forming a ladder structure. In some cases, a matching network comprising two stages forms an L-shaped structure (i.e. series-parallel or parallel-series). In some cases, a matching network comprising three stages forms either a pi-shaped structure (i.e. parallel-series-parallel) or a T-shaped structure (i.e. series-parallel-series).

[0070] In some examples, a radio-frequency system comprises a matching circuit in a ladder topology. Such matching circuit preferably comprises one reactive component per stage. In some other examples, a radio-frequency system comprises a matching circuit at least including a series LC resonant circuit and a parallel LC resonant circuit.

[0071] In a preferred example, an electronic device comprises a slim radiating system configured to transmit and receive electromagnetic wave signals in at least one frequency region of the electromagnetic spectrum, and comprising a slim radiating structure, a radio-frequency system, at least one internal conductive path and at least one external conductive path. The slim radiating structure comprises at least one ground element and at least one booster bar. The at least one internal conductive path comprises a conductive element that couples the at least one booster bar to the radio-frequency system. The radio-frequency system comprises at least one matching circuit modifying the impedance of the slim radiating structure providing impedance matching to the slim radiating system in the at least one frequency region at the at least one external conductive path. The at least one booster bar has an elongated shape, and is characterized by a slim width factor greater than 3 and a slim height factor greater than 3, is separated from the at least one ground element by a gap and is characterized by a location factor between 0.5 and 2.

[0072] Another preferred example relates to an electronic device including a slim radiating system that comprises a slim radiating structure, a radio-frequency system, an internal conductive path and at least one external conductive path; the slim radiating system is configured to transmit and receive electromagnetic wave signals in a first frequency region and a second frequency region. The slim radiating structure comprises at least one ground element, and one booster bar separated from the ground element by a gap and is characterized by a location factor between 0.3 and 1.8. The internal conductive path comprises a conductive element that couples the booster bar to the radio-frequency system. The radio-frequency system comprises a matching circuit that modifies the impedance of the slim radiating structure providing impedance matching to the slim radiating system in the first and second frequency regions at the at least one external conductive path. The first and second frequency regions are preferably separated so that the lowest frequency of the second frequency region is above the highest frequency of the first frequency region. Some preferred matching circuits for such preferred example are described in FIGs. 15A-15F.

[0073] Further, an advantageous aspect of the invention refers to a radio-frequency system comprising a matching circuit that provides impedance matching to the slim radiating system in first and second frequency regions preferably not requiring a filtering circuit or component that separates frequencies of the first frequency region from frequencies of the second frequency region (e.g. a diplexer, a bank of filters, etc.) for providing impedance matching in the first frequency region and second frequency region independently (i.e. in two separate branches or paths). Thus preferred matching circuits may provide impedance matching in said first and second frequency regions with one branch.

[0074] According to an example, some preferred matching circuits preferably comprise seven or less components, for instance: two, three, four, five, six or seven. Such matching circuits preferably do not comprise active circuits or components.

[0075] In some examples in which the slim radiating system is configured to transmit and receive signals in a first frequency region and a second frequency region, a ratio between the lowest frequency of the second frequency region and the lowest frequency of the first frequency region may be greater than 1.5. In some of these examples, said ratio may be also greater than 1.8, 2.0, 2.2, or 2.4. In addition, in some examples in which the slim radiating system is configured to operate signals from first and second frequency regions, a ratio between the lowest frequency of the second frequency and the highest frequency of the first frequency region may be greater than 1.2, 1.5, 1.8, 2.0, 2.2, or 2.4.

[0076] Accordingly, an advantageous aspect of such radio-frequency system is its efficiency in that impedance matching in the first and second frequency regions may be provided with one matching circuit using a reduced number of components, which consequently introduces lower losses in the radio-frequency system and makes it more robust against the tolerances of the components. Moreover, by not including filtering circuits such as diplexers, the radio-frequency system avoids the insertion losses characterizing such type of circuits and the necessity of having two separate matching circuits, which consequently makes the radio-frequency system have less components and the slim radiating system smaller in terms of area occupied in the device.

[0077] In a third preferred example, an electronic device includes a slim radiating system comprising a slim radiating structure, a radio-frequency system, first and second internal conductive paths and at least one external conductive path; the slim radiating system is configured to transmit and receive electromagnetic wave signals in a first frequency region and a second frequency region. The slim radiating structure comprises at least one ground plane layer, first and second radiation boosters, each of the first and second radiation boosters being separated from the ground plane layer by a gap. The first internal conductive path comprises a conductive element that couples the first radiation booster to the radio-frequency system, and the second internal conductive path comprises a conductive element that couples the second radiation booster to the radio-frequency system. The radio-frequency system comprises a matching circuit coupled to the first and second internal conductive paths and to the external conductive path, the matching circuit modifies the impedance of the slim radiating structure providing impedance matching to the slim radiating system in the first and second frequency regions.

[0078] In some cases, the slim radiating system may comprise a first external conductive path and a second external conductive path, and the radio-frequency system may include a diplexer circuitry that advantageously filters signals from first and second frequency regions, said signals being matched in impedance in the first and second frequency regions by the matching circuit within the radio-frequency system. A first port of the diplexer is connected to the matching circuit, and the two remaining ports of the diplexer are connected to the first and second external conductive paths. The first and second external paths comprise, respectively, signals for frequencies from the first frequency region, and signals for frequencies from the second frequency region.

[0079] A further technical aspect relates to a test platform for electromagnetically characterizing radiation boosters. Said platform comprises a substantially square conductive surface on top of which, and substantially close to the central point, the element to be characterized is mounted perpendicular to said surface in a monopole configuration, said conductive surface acting as the ground plane.

[0080] The substantially square conductive surface comprises sides with a dimension larger than a reference operating wavelength. In the context of the present example, said reference operating wavelength is the free-space wavelength equivalent to a frequency of 900MHz. A substantially square conductive surface according to the present example is made of copper with sides measuring 60 centimeters, and a thickness of 0.5 millimeters.

[0081] In the test configuration as set forth above, a booster bar according to the present example may be characterized by a ratio between the first resonance frequency and the reference frequency (900MHz) being larger than a minimum ratio of 3.0. In some cases, said ratio may be even larger than a minimum ratio such as: 3.4, 3.8, 4.0, 4.2, 4.4, 4.6, 4.8, 5.0, 5.2, 5.4, 5.6, 5.8, 6.0, 6.2, 6.6 or 7.0.

[0082] A booster bar according to the present example may also be characterized by a radiation efficiency measured in said platform, at a frequency equal to 900MHz, being less than 50%, preferably being less than 40%, 30%, 20%, or 10%, and in some cases being less than 7.5%, 5%, or 2.5%. All those are quite remarkably low efficiency values considering the additional 1:3 frequency mismatch and beyond obtained in some of the examples as described above. Such a frequency shift would introduce further mismatch losses that would result in an overall antenna efficiency below 5%, and quite typically below 2%, which would be ordinarily considered unacceptable for a mobile phone or wireless application. Still, quite surprisingly, when combining at least one booster bar with the radio-frequency system of a slim radiating system according to the present example, said slim radiating system recovers the efficiency required for the performance of a typical wireless device.

BRIEF DESCRIPTION OF THE DRAWINGS

[0083] Examples for illustrating certain technical aspects of the invention are shown in the enclosed figures.

FIGs. 1A-1B - Show examples of wireless handheld devices including slim radiating systems according to preferred examples.

FIGs. 2A-2D - Block diagram representations of five examples of slim radiating systems in according with some preferred examples.

FIG. 3 - Shows a perspective view of an example of a slim radiating structure including a booster bar.

FIGs. 4A-4B - Graphs showing bandwidth performances of several slim radiating systems as a function of the booster bar's width and gap dimensions.

FIG. 5 - Graph showing bandwidth performances of a slim radiating system as a function of the booster bar's width and gap dimensions for three different depth values.

FIG. 6 - Graph showing an example of an acceptable radio-electric frequency behavior for a slim radiating system.

FIG. 7 - Shows a perspective view of an example of slim radiating structure including four booster bars in accordance with a preferred example.

FIG. 8 - Plan view of an exemplary radio-frequency system coupled to a slim radiating structure.

FIG. 9 - Graph showing the radio-electric frequency behavior of a slim radiating system including the slim radiating structure of FIG. 7 and the radio-frequency system of FIG. 8.

FIG. 10 - Perspective view of an exemplary slim radiating structure including three booster bars in accordance with a preferred example.

FIG. 11 - Plan view of an example of a radio-frequency system coupled to a slim radiating structure.

FIG. 12 - Graph showing the radio-electric frequency behavior of a slim radiating system including the slim radiating structure of FIG. 10 and the radio-frequency system of FIG. 11.

FIG. 13 - Shows another exemplary slim radiating structure.

FIGs. 14A-14B - Show schematic representations of radio-frequency systems in accordance with a preferred example.

FIGs. 15A-15F - Show six preferred exemplary matching circuits.

FIGs. 16A-16F - Show the impedance transformation of an exemplary slim radiating system as the different stages of a matching circuit in the radio-frequency system are added.

FIG. 17 - Shows the reflection coefficient of exemplary slim radiating system of FIG. 16F.

FIG. 18A-18B - Show the impedance and the reflection coefficient of an exemplary slim radiating system comprising a radio-frequency system.

FIG. 19 - Shows an exemplary radiation booster.

FIG. 20 - Shows a slim radiating structure and an internal path in the form of a conductive trace in accordance with a preferred example.

FIG. 21A-21B - Show a test platform for the electromagnetic characterization of radiation boosters.

FIG. 22 - Shows the radiation efficiency and antenna efficiency of a radiation booster measured with the test platform depicted in FIGs. 21A and 21B.

DETAILED DESCRIPTION

[0084] Further exemplary technical aspects of the invention will become apparent in view of the detailed description of some preferred examples which follows. Said detailed description of some preferred examples is given for purposes of illustration only.

[0085] Illustrative wireless electronic devices including a slim radiating system are shown in FIGs. 1A and 1B. In the particular arrangement of FIG. 1A, the wireless electronic device 100 is a smartphone although it might represent other wireless electronic devices such as for instance a phablet or a tablet. The slim radiating system includes a first booster bar 101, a second booster bar 102, a booster element 110, and a ground element 105 (which may be included in a layer of a multilayer printed circuit board). The booster element 110 comprises two contiguous booster bars: the third booster bar 103 and the fourth booster bar 104. The first booster bar 101 is coupled to a radio-frequency system 109 via a conductive path 106, the second booster bar 102 is coupled to the radio-frequency system 109 via a conductive path 107, and the booster element 110 is coupled to the radio-frequency system 109 via a conductive path 108.

[0086] In FIG. 1B there is shown a wireless handheld device 150 in an exploded perspective view, the device comprises a slim radiating structure and a radio-frequency system 153. The slim radiating structure comprises a radiation booster 151 taking the form of a booster bar with an elongated shape, and a ground plane layer 152. The booster bar 151 is coupled to the radio-frequency system via the internal conductive path 154 which, in this particular example, may be a conductive trace.

[0087] In the examples of FIGs. 1A and 1B, the booster bars are arranged on a part of the device free of ground plane, so there is no ground plane in the orthogonal projection of the booster bars onto the plane comprising the ground plane layers 105 and 152, respectively. In other examples, the orthogonal projection of a booster bar or other radiation booster onto the plane comprising the ground plane layer may be overlapped partially or completely by the ground plane layer.

[0088] FIG. 2A shows a block diagram representation of a slim radiating system for an electronic device. The slim radiating system 201a comprises slim radiating structure 202a, radio-frequency system 203a, internal conductive path 204a, and external conductive path 205a. The slim radiating structure is coupled to the radio-frequency system via the internal path 204a, and to other RF circuitry for handling RF wave signals via the external path 205a. A slim radiating system in accordance with this block diagram is configured to operate in at least one frequency region, or in at least two frequency regions, or in at least three frequency regions.

[0089] FIG. 2B shows another block diagram of a slim radiating system for an electronic device. The slim radiating system 201b comprises slim radiating structure 202b, radio-frequency system 203b, two internal conductive paths 204b and 205b, and two external conductive paths 206b and 207b. The slim radiating structure is coupled to the radio-frequency system via the internal paths 204b and 205b, and to other RF circuitry for handling RF wave signals via the external paths 206b and 207b. A slim radiating system in accordance with this block diagram is configured to operate in at least two frequency regions, or in at least three frequency regions.

[0090] FIG. 2C shows another block diagram of a slim radiating system for an electronic device according to an example. The slim radiating system 201c comprises slim radiating structure 202c, radio-frequency system 203c, three internal conductive paths 204c, 205c and 206c, and three external conductive paths 207c, 208c, and 209c. The slim radiating structure is coupled to the radio-frequency system via the internal conductive paths 204c, 205c and 206c, and to other RF circuitry for handling RF wave signals via the external conductive paths 207c, 208c and 209c. A slim radiating system in accordance with this block diagram is configured to operate in at least three frequency regions.

[0091] FIG. 2D shows another block diagram of a slim radiating system for an electronic device according to an example. The slim radiating system 201d is similar to 201a from FIG. 2A. It comprises slim radiating structure 202a, radio-frequency system 203d, internal conductive path 204a, and two external conductive paths 205d and 206d. The slim radiating structure is coupled to the radio-frequency system via the internal paths 204a, and to other RF circuitry for handling RF wave signals via the external paths 205d and 206d. The radio-frequency system 203d may comprise a matching circuit configured to provide impedance matching in at least two frequency regions, and a diplexer may be connected to said matching circuit and coupled to the external paths. A slim radiating system in accordance with this block diagram is configured to operate in at least two frequency regions. The radio-frequency system 203d is convenient for the interconnection with an RF (radio-frequency) front-end module or RF circuitry that includes separate inputs for signals from the first frequency region and the second frequency region. If such RF front-end module (not illustrated) had one input/output for all the signals, the radio-frequency system 203a from FIG. 2A would be more suitable.

[0092] FIG. 3 illustrates a preferred example of a slim radiating structure 301 according to an example. The slim radiating structure comprises a booster bar 303 and a ground plane layer 302, the booster bar comprises a single standard layer of dielectric material 306 with a top 304 and a bottom 305 conductive surfaces. The booster bar has a length 310, a width 311 and a height 312. The length of the booster bar is taken along the dimension that is substantially parallel to the ground plane layer in the top or bottom conductive surface, the width is taken along the dimension that is substantially perpendicular to the ground plane layer in the top or bottom conductive surface, and the height is taken as the minimum distance between the top conductive surface and the bottom conductive surface. In some examples the booster bar comprises pads on a first and a second surface so that the mounting of the booster can be reversed and top and bottom sides can be interchanged.

[0093] The size and shape of the booster bar is characterized by a slim width factor and a slim height form factor. The slim width factor is a ratio between the length and the width of the booster bar, and the slim height factor is a ratio between the length and height of the booster bar, being the slim width factor and the slim height factor preferably larger than 3. In this example, where the booster is configured to operate in one or more frequency bands within the 600MHz-6GHz range (e.g. GSM 850 (824-894MHz), GSM 900 (880-960MHz), GSM 1800 (1710-1880MHz), GSM 1900 (1850-1990MHz), WCDMA 2100 (1920-2170MHz), CDMA 1700 (1710-2155MHz), LTE 700 (698-798MHz), LTE 800 (791-862MHz), LTE 2600 (2500-2690MHz), LTE 3500 (3.4-3.6GHz), LTE 3700 (3.6-3.8GHz), WiFi (2.4-2.5GHz and/or 4.9-5.9GHz)), the length is 10 millimeters, the width is 3.2 millimeters and the height is 3.2 millimeters, being the slim width factor 3.125 and the slim height factor 3.125, all those dimensions in these and other examples, within a typical tolerance of, for instance +/- 1%-3% and in some occasions up to a 10% variation. The booster bar is separated from the ground plane by a gap 313; the gap is taken as the minimum distance between the bottom conductive layer and the ground plane layer. The gap distance plus the booster bar's width 311 is characterized as the depth of the radiation booster. The location of the booster bar in relation to the ground plane layer is characterized by a location factor. The location factor is a ratio between the width of the booster bar and the gap, being the location factor preferably in the range of between 0.5 and 2. In this example, the width is 3.2mm and the gap is 3.3mm, being the location factor 0.96 and the depth 6.5mm, all those dimensions within a typical tolerance of, for instance +/- 10% variation.

[0094] FIG. 4A and FIG. 4B illustrate two examples of the relevance of the location and width of the booster bar in the radio-frequency performance of the slim radiating system; the radio-frequency performance of the slim radiating system is affected by the location of the booster bar with respect to the ground plane layer and the width of the booster bar. FIG. 4A and FIG. 4B plot the potential bandwidths achieved by six slim radiating systems as a function of the booster bar's width and gap dimensions. Curve 401 represents the potential bandwidth of a slim radiating system comprising a booster bar characterized by a height of 2.4mm and a length of 11.5mm. Curve 402 represents the potential bandwidth of a slim radiating system that includes a booster bar having a height of 3.2mm and a length of 9mm. Curve 403 represents the potential bandwidth of a slim radiating system comprising a booster bar characterized by a height of 2.4mm and a length of 10.5mm. Curve 404 represents the potential bandwidth of a slim radiating system comprising a booster bar characterized by a height of 3.2mm and a length of 7mm. Curve 405 represents the potential bandwidth of a slim radiating system comprising a booster bar characterized by a height of 2.4mm and a length of 9mm. Curve 406 represents the potential bandwidth of a slim radiating system comprising a booster bar characterized by a height of 2.4mm and a length of 7mm. As shown in FIG. 4A and FIG. 4B, the potential bandwidth of the slim radiating system depends on the width dimension of the booster bar and the location of the booster bar in relation to the ground plane layer; for each of the curves, there is a region where the most favorable bandwidth values are achieved. In this example, such region is referred as the effective bandwidth region which corresponds to a range of location factor values that provide the region of most advantageous bandwidth values for the slim radiating system. The preferred values for the location factor are in the range of between 0.5 and 2. Such result is against conventional wisdom as the wider the width of the antenna element, the greater the bandwidth as, for example, in a monopole antenna.

[0095] FIG. 5 illustrates another example of the effect of the booster bar's location and width on the radio-frequency performance of a slim radiating system; the radio-frequency performance of the slim radiating system is affected by the location of the booster bar with respect to the ground plane layer and the width of the booster bar. FIG. 5 plots the potential bandwidth achieved by the slim radiating system as a function of the booster bar's width and gap dimensions; the three curves 501, 502 and 503 represent the potential bandwidth of a slim radiating system comprising a booster bar having a height of 3.2mm and a length of 7mm. Curve 501 refers to the booster bar having a depth of 7.5mm, curve 502 corresponds to a depth of 7mm and curve 503 is for a depth of 6.5mm. As previously shown in FIGs. 4A and 4B, the potential bandwidth of the slim radiating system depends on the gap that separates the booster bar from the ground plane layer and the width of the booster bar; for each of the curves, there is an effective bandwidth region where the most advantageous bandwidth values are achieved.

[0096] One way to characterize the radio-frequency performance of the slim radiating system entails the use of a reflection coefficient plot; a reflection coefficient of less than -4.4 dB is generally acceptable. FIG. 6 illustrates an example of an acceptable radio-frequency performance for a slim radiating system according to an example. The slim radiating system comprises a booster bar which is characterized by a width form factor of 3.125, a height form factor of 3.125 and a location factor of 0.96. Curve 601 shows the reflection coefficient of the slim radiating system versus frequency, and line 602 shows an acceptable reference level for the reflection coefficient. In this example, the reflection coefficient is less than -4.4 dB for all the frequencies of the operating frequency region which covers a frequency range of about 824MHz to about 960MHz. Such frequency range enables the slim radiating system to be used to cover at least two communication frequency bands such as a band from 824MHz to 894MHz and a band from 880MHz to 960MHz. These two bands are examples of bands that can be covered by a slim radiating system; other bands may also be handled by the slim radiating system. In another example, a suitable radio-frequency performance for the slim radiating system corresponds to a reflection coefficient of -6 dB or less for all the frequencies of the operating frequency range.

[0097] FIG. 7 illustrates a preferred example of a slim radiating structure according to an example suitable for a slim radiating system configured to operate in three frequency regions. The slim radiating structure 701 comprises a first booster bar 702, a second booster bar 703, a booster element 704 comprising two adjacent booster bars 705 and 706, and a ground plane layer 707. As shown in FIG. 3, each booster bar comprises a single standard layer of dielectric material with top and bottom conductive surfaces; in this example the dielectric material has a height of 3.2mm. In this example, the first and second booster bars 702, 703 have a slim width factor of 3.125, a slim height factor of 3.125, and a location factor of 0.96; the booster element 704 has a slim width factor of 6.25, a slim height factor of 6.25 and a location factor of 0.96. In general, any suitable shape may be used for the ground plane layer. FIG. 7 illustrates an example of a slim radiating structure according to an example suitable for a slim radiating system configured to operate in three frequency regions. The ground plane layer 707 includes clearance regions that may be used to mount other components of the electronic wireless device, or to adjust the ground plane layer to the shape of the electronic wireless device housing or for SAR purposes. The ground plane rectangle 708 (represented with dashed lines for illustrative purposes only) is characterized as the minimum sized rectangle that encompasses the ground plane layer 707. That is, the ground plane rectangle is a rectangle whose sides are tangent to at least one point the ground plane layer. In accordance with an example, a first long side of the ground plane layer refers to a long side of the ground plane rectangle 709 or 710; a second long side of the ground plane layer refers to a second long side of the ground plane rectangle 710 or 709; a first short side of the ground plane layer refers to a first short side of the ground plane rectangle 711 or 712; and a second short side of the ground plane layer relates to a second short side of the ground plane rectangle 712 or 711.

[0098] FIG. 8 shows an example of a radio-frequency system 805 coupled to a slim radiating structure 801 via internal conductive paths 802, 803 and 804. An example of a suitable slim radiating structure 801 to be coupled to the radio-frequency system 805 is the slim radiating structure shown in FIG. 7. The radio-frequency system 805 comprises a first matching circuit 806, a second matching circuit 807, and a third matching circuit 808. The first matching circuit 806 is configured to ensure that the slim radiating system is impedance-matched at a first frequency region to other circuitry coupled via external conductive path 809. The second matching circuit 807 is configured to provide impedance matching at a second frequency region for other circuitry coupled to external conductive path 810. The third matching circuit 808 is configured to guarantee that the slim radiating system is matched in impedance at a third frequency region at the external conductive path 811. The first, second and third matching networks are therefore configured to ensure an acceptable reference level for the reflection coefficient over an entirety of the first, second and third operating frequency ranges. Each of the first, second and third matching circuits comprises a network of passive components such as inductors and capacitors, which are arranged with a suitable architecture like, for instance, an inductor plus an LC network. Other suitable matching circuits may be used to ensure that the slim radiating system is matched in impedance at the operating frequency ranges; other suitable matching circuits may comprise a network of passive and/or active components, which may be arranged with other suitable architectures.

[0099] FIG. 9 illustrates the radio-frequency performance of the slim radiating system resulting from the interconnection of the slim radiating structure 701 to the radio-frequency system 805. Curve 901 shows the reflection coefficient of the slim radiating system versus frequency at a terminal in the external path 809, curve 902 shows the reflection coefficient of the slim radiating system versus frequency at a terminal in the external path 810, curve 903 shows the reflection coefficient of the slim radiating system versus frequency at a terminal in the external path 811, and line 904 shows an acceptable reference level for the reflection coefficient. In this example, the reflection coefficient 901 is less than -4.4 dB for all the frequencies of a first operating frequency region 905, the reflection coefficient 902 is less than -4.4 dB for all the frequencies of a second operating frequency region 906, and the reflection coefficient 903 is less than -4.4 dB for all the frequencies of a third operating frequency region 907. The first operating frequency region 905 of the slim radiating system covers a first frequency range of about 698MHz to about 798MHz, the second operating frequency region 906 of the slim radiating system covers a frequency range of about 824MHz to about 960MHz, and the third operating frequency region 907 of the slim radiating system covers a third frequency range of about 1710MHz to about 2690MHz. The first frequency range enables the slim radiating system to be used to cover at least three communication bands such as a band from 699MHz to 746MHz, a band from 746MHz to 787MHz, and a band from 758MHz to 798MHz. The second frequency range enables the slim radiating system to cover at least two communication frequency bands such as a band from 824MHz to 894MHz and a band from 880MHz to 960MHz. The third frequency range enables the slim radiating system to cover at least five communication frequency bands such as a band from 1710MHz to 1880MHz, a band from 1850MHz to 1990MHz, a band from 1920MHz to 2170MHz, a band from 2300MHz to 2400MHz, and a band from 2496MHz to 2690MHz. Other desirable communication frequency bands may also be handled by the slim radiating system.

[0100] FIG. 10 illustrates another example of a slim radiating structure in accordance to an example; the slim radiating structure is suitable for a slim radiating system that is configured to operate in at least two frequency regions. The slim radiating structure 1001 comprises a first booster element 1002 including a first booster bar 1003 and a second booster bar 1004 adjacent to the first booster bar; the slim radiating structure 1001 further comprises a third booster bar 1005, and a ground plane layer 1006. As shown in FIG. 3, each booster bar may be formed by a single standard layer of dielectric material with top and bottom conductive surfaces. In this example, the dielectric material has a height of 2.4mm; the first booster element 1002 has a slim width factor of 8, a slim height factor of 10, and a location factor of 0.375; the third booster bar 1005 has a slim width factor of 4, a slim height factor of 5 and a location factor of 0.375.

[0101] FIG. 11 shows an example of a radio-frequency system 1101 coupled to a slim radiating structure 1102 via internal conductive paths 1103 and 1104. An example of a suitable slim radiating structure 1102 to be coupled to the radio-frequency system 1101 is illustrated in FIG. 10. The radio-frequency system 1101 comprises a matching circuit being configured to ensure that the slim radiating system is impedance-matched to other circuitry coupled via external conductive path 1105 at a first frequency region and a second frequency region. The matching network is therefore configured to ensure an acceptable reference level for the reflection coefficient over an entirety of the first and second operating frequency ranges. The matching circuit comprises a network of passive components such as inductors, capacitors and transmission lines, which are arranged with a suitable architecture as shown in FIG. 11. Other suitable matching circuits may be used to ensure that the slim radiating system is impedance matched at the operating frequency ranges; other suitable matching circuits may comprise a network of passive and/or active components, which may be arranged with other suitable architectures.

[0102] FIG. 12 illustrates the radio-frequency performance of the slim radiating system resulting from the interconnection of the slim radiating structure 1001 to the radio-frequency system 1101. Curve 1201 shows the reflection coefficient of the slim radiating system versus frequency at a terminal in the external path 1105, and line 1202 shows an acceptable reference level for the reflection coefficient. In this example, the reflection coefficient 1201 is less than -4.4 dB for all the frequencies of the first and second frequency regions. The first operating frequency region of the slim radiating system covers a first frequency range of about 698MHz to about 960MHz, and the second operating frequency region of the slim radiating system coves a frequency range of about 1710MHz to about 3800MHz. The first frequency range enables the slim radiating system to be used for covering at least five communication bands such as a band from 699MHz to 746MHz, a band from 746MHz to 787MHz, a band from 758MHz to 798MHz, a band from 824MHz to 894MHz, and a band from 880MHz to 960MHz. The second frequency range enables the slim radiating system to cover at least seven communication frequency bands such as a band from 1710MHz to 1880MHz, a band from 1850MHz to 1990MHz, a band from 1920MHz to 2170MHz, a band from 2300MHz to 2400MHz, a band from 2496MHz to 2690MHz, a band from 3400MHz to 3600MHz, and a band from 3600MHz to 3800MHz. Other desirable communication frequency bands may also be handled by the slim radiating system.

[0103] Another example of a slim radiating structure is shown in FIG. 13. The slim radiating structure 1300 comprises ground plane layer 1302 on a printed circuit board 1307, and radiation booster 1301 characterized by a slim width factor between 1 and 2, and a slim height factor between 1 and 2. The radiation booster 1301 is separated from the ground plane layer by a gap and is characterized by a location factor between 0.5 and 2, preferably between 0.5 and 1. The ground plane layer may be inscribed in ground plane rectangle 1306 (in dashed lines for illustrative purposes only), and the radiation booster may be inscribed in booster box 1305 (in dashed lines for illustrative purposes only).

[0104] A wireless electronic device comprising a slim radiating system that includes slim radiating structure 1300 may advantageously provide penta-band operation: two frequency bands in the first frequency region, like for example the frequency bands corresponding to the GSM 850 and GSM 900 cellular communication standards (i.e. the first frequency region comprising the 824MHz to 960MHz frequency range), and three frequency bands in the second frequency region, like for example the frequency bands corresponding to the GSM 1800, GSM 1900 and WCDMA 2100 cellular communication standards (i.e. the second frequency region comprising the 1710MHz to 2170MHz frequency range). In another example, a device according to an example could provide triple-band or quad-band operation with at least two frequency bands in the first frequency region, and at least another two frequency bands in the second frequency region, wherein first and second frequency regions do not overlap in frequency. Such device could operate, for instance but not limited to, the GSM 850 and GSM 900 cellular communication standards, and the GSM 1800 and GSM 1900 cellular communication standards.

[0105] FIG. 14A illustrates a radio-frequency system 1400 that comprises a first port 1401, a second port 1402, and a matching circuit 1403. Such radio-frequency system is particularly convenient to be used in the slim radiating system of FIG. 2A. Port 1401 may be connected to an internal conductive path (for instance 204a), and port 1402 may be connected to an external conductive path (for instance 205a). The matching circuit 1403 may be configured to provide impedance matching in at least one frequency region, or in at least two frequency regions, or in at least three frequency regions.

[0106] FIG. 14B illustrates another radio-frequency system 1410 comprising a first port 1411, a second port 1412, a third port 1413, a matching circuit 1414, a diplexer 1415, and a conductive path 1416 connecting the matching circuit to the diplexer. In reception, the diplexer 1415 is configured to split the signal from conductive path 1416 in a first signal extracted at port 1412, preferably comprising the frequencies corresponding to the first frequency region, and in a second signal extracted at port 1413, preferably comprising the frequencies corresponding to the second frequency region; in transmission, diplexer 1415 combines signals from ports 1412 and 1413 and are extracted in conductive path 1416. The matching circuit 1414 provides impedance matching to the slim radiating system in the first and second frequency regions. Ports 1412 and 1413 may be respectively connected to first and second external paths as shown in FIG. 2D.

[0107] FIGs. 15A to 15F show preferred matching circuits configured to provide impedance matching in at least two frequency regions.

[0108] FIG. 15A shows matching circuit 1500 comprising first and second ports 1501 and 1502, and a circuit including five stages forming a ladder topology (series-parallel-series-parallel-series). The first stage, which is connected to port 1501, is an inductor in series 1503, the second stage is a shunted inductor 1504, the third stage is a capacitor in series 1505, the fourth stage is an inductor in parallel 1506, and the fifth stage is a capacitor in series 1507, said fifth stage being connected to the second port 1502.

[0109] In FIG. 15B there is shown matching circuit 1510 comprising six stages that form an alternative ladder topology (series-parallel-series-parallel-series-parallel). The first stage (in series) is connected to the first port 1501 of the matching circuit, and the sixth stage comprising an inductor in parallel 1511 is connected to the second port 1502 of the matching circuit.

[0110] FIG. 15C depicts another preferred matching circuit 1520 comprising two stages: the first stage comprises a capacitor in parallel 1521, and the second stage comprises an inductor in series 1522. A preferred range of capacitor values for shunted capacitor 1521 of matching circuit 1520 is 0.01pF to 30pF.

[0111] FIG. 15D shows another preferred matching circuit 1530 comprising a series inductor 1531 connected to port 1501 and to a series LC resonator formed by inductive component 1532a and capacitive component 1532b. The LC resonator is connected to an LC resonator in parallel, comprising inductor 1533a and capacitor 1533b, and to a series capacitor 1534. The series capacitor is connected to second port 1502 of the matching circuit 1530. This matching circuit comprises a single branch formed by four stages (series-series-parallel-series).

[0112] FIG. 15E shows a fifth preferred matching circuit 1540 comprising: inductor 1541 in series connected to port 1501, inductor 1542 in parallel, capacitor 1543 in series, inductor 1544a and capacitor 1544b in parallel forming a parallel LC circuit, and capacitor 1545 in series connected to port 1502.

[0113] FIG. 15F illustrates another preferred matching circuit 1550 that is similar to matching circuit 1540 with the difference that capacitor 1545 is connected to inductor in series 1551 forming a series LC circuit, and said inductor being connected to port 1502 instead of capacitor 1545 as in FIG. 15E.

[0114] Inductors 1503, 1531 and 1541 corresponding to the first stage of matching circuits 1500, 1510, 1530, 1540 and 1550 may preferably have a value in the range of 0.1nH to 80nH.

[0115] Matching circuits 1500, 1510, 1520, 1530, 1540, and 1550 are suitable for being used as matching circuit 203a and 203d shown in FIGs. 2A and 2D.

[0116] FIG. 16A shows the impedance 1600 of a slim radiating system comprising a radiation booster, measured at its internal conductive path, when it is disconnected from a radio-frequency system. Points 1601 and 1602 from said impedance correspond to the lowest and highest frequencies of a first frequency region (in this example, said frequencies are 824MHz and 960MHz); and points 1603 and 1604 correspond to the lowest and highest frequencies of a second frequency region (for this particular example, said frequencies are 1710MHz and 2170MHz). The impedance 1600 has a substantially large negative reactance, namely the impedance in the first frequency region is capacitive, for the entire range of frequencies limited by points 1601 and 1602, and is also capacitive for the frequencies of the second frequency region. The first resonant frequency of said slim radiating structure is at a frequency above the highest frequency of the second frequency region (as indicated by point 1604).

[0117] FIGs. 16B to 16F show the evolution of the impedance of slim radiating system of FIG. 16A after the slim radiating system is connected to a radio-frequency system comprising a matching circuit like 1500 as the stages are added successively to the matching circuit. FIG. 16B shows the impedance 1610 when the matching circuit only comprises the first stage (an inductor in series). In FIG. 16C, the impedance 1620 of the slim radiating system is shown after adding the inductor in parallel (corresponding to the second stage) to the matching circuit. The impedance 1630 from FIG. 16D is obtained after the series capacitor from the third stage is added. The impedance 1640 from FIG. 16E is obtained after the shunted inductor from the fourth stage is added. And with the addition of the fifth stage corresponding to another capacitor in series, the impedance 1650 of the slim radiating system is obtained. In addition to the impedance 1650 as shown in FIG. 16F, the reflection coefficient 1700, when the slim radiating structure is connected to a radio-frequency system comprising the five-stage ladder matching network is also shown in FIG. 17. In this particular example, the operating frequency range for the radiating system covers a first frequency region at least comprising the range of frequencies delimited by points

1701 and 1702 (824MHz and 960MHz respectively), and a second frequency region at least comprising the range of frequencies delimited by points 1703 and 1704 (1710MHz and 2170MHz respectively), wherein said points establish a minimum level of reflection coefficient for a good radio-frequency performance for this particular example, although in other examples said minimum level could be, for example, -4.4dB.

[0118] A ratio between the lowest frequency of the second frequency region and the lowest frequency of the first frequency region is, for this particular case, greater than 1.5 and even greater than 2.0. In addition, a ratio between the first resonant frequency of the slim radiating structure measured at an internal path, when disconnected from the radio-frequency system, and the lowest frequency of the first frequency region is greater than 1.3, also greater than 2.0, and even greater than 2.4.

[0119] FIGs. 18A and 18B show the impedance and reflection coefficient of another exemplary example. Such example corresponds to a slim radiating system comprising a slim radiating structure featuring an impedance similar to that of FIG. 16A, and a radio-frequency system according to an example. The radio-frequency system comprises a six-stage matching circuit in a ladder topology, like for example matching circuit 1510 from FIG. 15B. The impedance 1800, when the slim radiating structure is connected to such radio-frequency system, is shown in FIG. 18A. In said figure, points 1801 and 1802 refer to the lower and higher frequencies of a first frequency region (824MHz and 960MHz respectively), and points 1803 and 1804 refer to the lower and higher frequencies of a second frequency region (1710MHz and 2170MHz respectively). The reflection coefficient 1810 of FIG. 18B corresponds to the slim radiating system of FIG. 18A. The operating frequency range for a slim radiating system according to this particular example at least covers a first frequency region including the first range delimited by points 1811 and 1812 (824MHz and 960MHz), and a second frequency region including the second range delimited by points 1813 and 1814 (1710MHz and 2170MHz).

[0120] FIG. 19 shows a radiation booster 1900 comprising conducting surfaces 1901 and 1902, a dielectric material 1904 (shown transparent for illustrative purposes only), and a plurality of vias 1903 electrically interconnecting the two conducting surfaces 1901 and 1902 (in other examples, said conducting surfaces may be interconnected by just one via). Said radiation booster is a booster bar featuring a slim width factor of 3.125, and a slim height factor of 3.125. The booster bar 1900 may be used, for example, in slim radiating structure 1300 instead of radiation booster 1301.

[0121] A booster bar such as 1900 is configured to be used in slim radiating systems. As such, a slim radiating system comprising a slim radiating structure, a radio-frequency system and at least one external conductive path, wherein the slim radiating structure comprises a radiation booster like, for example, 1900 and a ground plane layer, may be configured to transmit and receive electromagnetic wave signals in at least one frequency region, or in at least two frequency regions. The radio-frequency system comprises a matching circuit configured to provide impedance matching to the slim radiating system in said at least one or at least two frequency regions at the at least one external path.

[0122] FIG. 20 shows a slim radiating structure comprising a radiation booster (e.g. booster bar) 2001, a ground plane layer 2002. There is also shown a conductive element 2003 that may advantageously function as an internal conductive path. The conductive element 2003 is connected to radiation booster 2001, advantageously tuning the input impedance of the radiation booster prior its connection to a radio-frequency system (not shown). The conductive element may improve the efficiency of the slim radiating system comprising said slim radiating structure, or make the slim radiating system operable in more frequency bands in at least one frequency regions or in at least two frequency regions. In this example, the booster bar features a height of 2.4mm, a slim width factor of 4, a slim height factor of 5, and a location factor of 0.33. Although the conductive element 2003 is L-shaped, in other examples the conductive element may take other forms as well such as a straight I.

[0123] The electrical length of conductive element 2003 may be shorter than 10% of the free-space wavelength corresponding to the lowest frequency of the first frequency region, and preferably it may be shorter than 5% of said free-space wavelength.

[0124] FIG. 21A schematically shows, in a 3D perspective, a test platform for the characterization of radiation boosters. The platform comprises substantially square conductive surface 2101 and connector 2102 (for instance an SMA connector) electrically connected to the device or element 2100 to be characterized. The conductive surface 2101 has sides with a length larger than the reference operating wavelength corresponding to the reference frequency.

[0125] For instance, at 900MHz, said sides are at least 60 centimeters long. The conductive surface may be a sheet or plate made of copper, for example. The connector 2102 is placed substantially in the center of conductive surface 2101.

[0126] In FIG. 21B the same test platform of FIG. 21A is schematically represented in a 2D perspective wherein the conductive surface 2101 is partially drawn. In this example, the element that is to be characterized 2100 in FIG. 21A corresponds to booster bar 1900 from FIG. 19, which is arranged so that its largest dimension is perpendicular to conductive surface 2101, and one of the first or second conductive surfaces (1901 or 1902 of FIG. 19) is in direct electrical contact with connector 2102 (for clearer interpretation of the orientation of radiation booster 1900, via holes 1903 connecting the first and second conductive surfaces of the radiation booster are also drawn in FIG. 21B). The radiation booster 1900 lies on a dielectric material (not shown) attached to the conductive surface 2101 so as to minimize the distance between radiation booster 1900 and surface 2101. Said dielectric material may be a dielectric tape or coating, for example.

[0127] FIG. 22 shows a graph of the radiation efficiency and antenna efficiency measured in a test platform like the one shown in FIG. 21A and FIG. 21B, when the element 2100 to be characterized is radiation booster 1900. In this particular example, the radiation efficiency measured 2201 (represented with a solid line) at 900MHz is less than 5%, and the antenna efficiency measured 2202 (represented with a dashed line) at 900MHz is less than 1%.

[0128] This patent application is part of a project that has received funding from the European Union's Horizon 2020 Research and Innovation Programme under grant agreement No. 674491.

Claims

1. A wireless handheld or portable electronic device comprising:

a slim radiating system configured to transmit and receive electromagnetic wave signals in a first frequency region, the slim radiating system comprising a slim radiating structure, a radio-frequency system, a first internal conductive path and a first external conductive path;

the slim radiating structure comprises a first booster bar (702) and a ground plane layer (707);

the first booster bar (702) comprises a single standard layer of dielectric material including a top and a bottom conductive surface electrically connected, said conductive top and bottom surface being formed by conductive material printed or deposited in the top and bottom surface of the dielectric material and said conductive surfaces being electrically connected by at least one via, the first booster bar (702) being further **characterized by** a slim width factor greater than 3 and a slim height factor greater than 3, wherein the slim width factor characterizes the ratio between the length and the width of the booster bar, and the slim height factor characterizes the ratio between the length and the height of the booster bar, the first booster (702) bar being separated from the ground plane layer (707) by a gap and **characterized by** a location factor in a range of 0.3 to 1.8, wherein the location factor is a ratio between the width of the booster bar and the gap;

the first booster bar (702) fits in an imaginary sphere having a diameter smaller than 1/3 of a radiansphere having a radius equal to a free-space wavelength corresponding to a lowest frequency of the first frequency region, divided by two times π (pi);

the first internal conductive path couples the first booster bar (702) to the radio-frequency system; and the radio-frequency system comprises a first matching circuit configured to provide impedance matching within the first frequency region at the first external conductive path,

wherein the slim radiating system is configured to transmit and receive electromagnetic wave signals in a second frequency region, wherein a lowest frequency of the second frequency region is at a frequency higher than a highest frequency of the first frequency region; and

the first matching circuit is further configured to provide impedance matching within the second frequency region at the first external conductive path,

wherein the first frequency region comprises an 824-960MHz frequency range and the second frequency region comprises a 1710-2170MHz frequency range, and

wherein a maximum size of the first booster bar is smaller than 1/15 of the free-space wavelength corresponding to a lowest frequency of the first frequency region.

2. The wireless handheld or portable electronic device of claim 1, wherein:

the slim radiating system comprises a second internal conductive path and a second external conductive path;

the slim radiating structure comprises a second booster bar (703);

the second booster bar (703) comprises a single standard layer of dielectric material including a top and a bottom conductive surfaces electrically connected, is **characterized by** a slim width factor greater than 3 and a slim height factor greater than 3, the second booster bar (703) being separated from the ground plane layer by a gap and **characterized by** a location factor in a range of 0.3 to 1.8;

the second booster bar (703) fits in an imaginary sphere having a diameter smaller than 1/3 of a radiansphere having a radius equal to a free-space wavelength corresponding to a lowest frequency of the first frequency region, divided by two times π (pi);

the second internal conductive path couples the second booster bar (703) to the radio-frequency system; and

the radio-frequency system comprises a second matching circuit configured to provide impedance matching within the second frequency region at the second external conductive path.

3. The wireless handheld or portable electronic device of claim 2, wherein:

the slim radiating system is configured to transmit and receive electromagnetic wave signals in a third frequency region, wherein a highest frequency of the third frequency region is at a frequency lower than a lowest frequency of the first frequency region;
the slim radiating system comprises a third internal conductive path and a third external conductive path;
the slim radiating structure comprises a booster element (704) including third and fourth booster bars (705, 706), the third booster bar (705) being adjacent to the fourth booster bar (706), and wherein the third and fourth booster bars (705, 706) are electrically connected;
each of the third and fourth booster bars (705, 706) comprises a single standard layer of dielectric material including a top and a bottom conductive surfaces electrically connected;
the booster element (704) is **characterized by** a slim width factor greater than 6 and a slim height factor greater than 6, the booster element being separated from the ground plane layer by a gap and **characterized by** a location factor in a range of 0.3 to 1.8;
the booster element fits in an imaginary sphere having a diameter smaller than 1/3 of a radiansphere having a radius equal to a free-space wavelength corresponding to a lowest frequency of the first frequency region, divided by two times π (pi);
the third internal conductive path couples the booster element to the radio-frequency system; and
the radio-frequency system comprises a third matching circuit configured to provide impedance matching within the third frequency region at the third external conductive path.

4. The wireless handheld or portable electronic device of claim 1, wherein the first matching circuit comprises a single branch.

5. The wireless handheld or portable electronic device of claim 1, wherein the first matching circuit comprises no more than seven lumped components.

6. The wireless handheld or portable electronic device of claim 1, wherein:

the slim radiating system comprises a second external conductive path;
the radio-frequency system comprises a diplexer coupled to the first matching circuit, the first external conductive path and the second external conductive path; and
the first matching circuit is further configured to provide impedance matching within the second frequency region at the second external conductive path.

7. The wireless handheld or portable electronic device of claim 1, wherein an area defined by the two largest dimensions of a booster box completely enclosing the first booster bar divided by a square of the free-space wavelength corresponding to the lowest frequency of the first frequency region is less than 0.06%.

8. The wireless handheld or portable electronic device of claim 7, wherein the area defined by the two largest dimensions of the booster box completely enclosing the first booster bar divided by a square of the free-space wavelength corresponding to the lowest frequency of the second frequency region is less than 0.15%.

9. The wireless handheld or portable electronic device of claim 1, wherein the first internal conductive path comprises an L-shaped conductive trace.

Patentansprüche

1. Ein drahtloses handgehaltenes oder tragbares elektronisches Gerät, umfassend:

ein schlankes Strahlungssystem, das zum Senden und Empfangen von elektromagnetischen Wellensignalen in einem ersten Frequenzbereich konfiguriert ist, wobei das schlanke Strahlungssystem eine schlanke Strahlungsstruktur, ein Radiofrequenzsystem, einen ersten internen leitenden Pfad und einen ersten externen leitenden Pfad umfasst;
wobei die schlanke Strahlungsstruktur einen ersten Boosterbalken (702) und eine Masseebenenschicht (707) umfasst;
der erste Boosterbalken (702) eine einzelne Standardschicht aus dielektrischem Material umfasst, die eine obere und eine untere leitende Oberfläche aufweist, die elektrisch verbunden sind, wobei die leitende obere und untere Oberfläche durch leitendes Material gebildet werden, das in die obere und untere Oberfläche des dielektrischen Materials gedruckt oder aufgebracht ist, und die leitenden Oberflächen durch mindestens ein Durchgangsloch elektrisch verbunden sind, der erste Boosterbalken (702) ferner durch einen Schlankheits-Breiten-Faktor größer als 3 und einen Schlankheits-Höhen-Faktor größer als 3 gekennzeichnet ist, wobei der Schlankheits-Breiten-Faktor das Verhältnis zwischen der Länge und der Breite des Boos-

terbalkens charakterisiert und der Schlankheits-Höhen-Faktor das Verhältnis zwischen der Länge und der Höhe des Boosterbalkens charakterisiert, wobei der erste Boosterbalken (702) von der Masseebenenschicht (707) durch eine Lücke getrennt ist und durch einen Lagefaktor in einem Bereich von 0,3 bis 1,8 gekennzeichnet ist, wobei der Lagefaktor ein Verhältnis zwischen der Breite des Boosterbalkens und dem Spalt ist;
der erste Boosterbalken (702) in eine imaginäre Kugel passt mit einem Durchmesser, der kleiner ist als 1/3 einer Radiuskugel mit einem Radius, der gleich einer Freiraumwellenlänge ist, die einer niedrigsten Frequenz des ersten Frequenzbereichs entspricht, geteilt durch das Zweifache von π (pi);
der erste interne leitende Pfad den ersten Boosterbalken (702) mit dem Radiofrequenzsystem koppelt; und das Radiofrequenzsystem eine erste Anpassungsschaltung umfasst, die so konfiguriert ist, dass sie eine Impedanzanpassung innerhalb des ersten Frequenzbereichs an dem ersten externen leitenden Pfad bereitstellt, wobei das schlanke Strahlungssystem so konfiguriert ist, dass es elektromagnetische Wellensignale in einem zweiten Frequenzbereich sendet und empfängt, wobei eine niedrigste Frequenz des zweiten Frequenzbereichs bei einer höheren Frequenz als eine höchste Frequenz des ersten Frequenzbereichs liegt; und
die erste Anpassungsschaltung ferner so konfiguriert ist, dass sie eine Impedanzanpassung innerhalb des zweiten Frequenzbereichs an dem ersten externen leitenden Pfad bereitstellt, wobei der erste Frequenzbereich einen Frequenzbereich von 824-960 MHz und der zweite Frequenzbereich einen Frequenzbereich von 1710-2170 MHz umfasst, und
wobei eine maximale Größe des ersten Boosterbalkens kleiner ist als 1/15 der Freiraumwellenlänge, die einer niedrigsten Frequenz des ersten Frequenzbereichs entspricht.

2. Das drahtlose handgehaltene oder tragbare elektronische Gerät nach Anspruch 1, wobei:

das schlanke Strahlungssystem einen zweiten internen leitenden Pfad und einen zweiten externen leitenden Pfad umfasst;
die schlanke Strahlungsstruktur einen zweiten Boosterbalken (703) umfasst;
der zweite Boosterbalken (703) eine einzelne Standardschicht aus dielektrischem Material umfasst, die eine obere und eine untere leitende Oberfläche umfasst, die elektrisch verbunden sind, und durch einen Schlankheits-Breiten-Faktor größer als 3 und einen Schlankheits-Höhen-Faktor größer als 3 gekennzeichnet ist, wobei der zweite Boosterbalken (703) von der Masseebenenschicht durch eine Lücke getrennt ist und durch einen Lagefaktor in einem Bereich von 0,3 bis 1,8 gekennzeichnet ist;
und der zweite Boosterbalken (703) in eine imaginäre Kugel passt mit einem Durchmesser, der kleiner ist als 1/3 einer Radiuskugel mit einem Radius, der gleich einer Freiraumwellenlänge ist, die einer niedrigsten Frequenz des ersten Frequenzbereichs entspricht, geteilt durch das Zweifache von π (pi);
der zweite interne leitende Pfad den zweiten Boosterbalken (703) mit dem Radiofrequenzsystem koppelt; und
das Radiofrequenzsystem eine zweite Anpassungsschaltung umfasst, die so konfiguriert ist, dass sie eine Impedanzanpassung innerhalb des zweiten Frequenzbereichs an dem zweiten externen leitenden Pfad bereitstellt.

3. Das drahtlose handgehaltene oder tragbare elektronische Gerät nach Anspruch 2, wobei:

das schlanke Strahlungssystem so konfiguriert ist, dass es elektromagnetische Wellensignale in einem dritten Frequenzbereich sendet und empfängt, wobei eine höchste Frequenz des dritten Frequenzbereichs bei einer niedrigeren Frequenz als eine niedrigste Frequenz des ersten Frequenzbereichs liegt;
das schlanke Strahlungssystem einen dritten internen leitenden Pfad und einen dritten externen leitenden Pfad umfasst;
die schlanke Strahlungsstruktur ein Boosterelement (704) mit einem dritten und einem vierten Boosterbalken (705, 706) umfasst, wobei der dritte Boosterbalken (705) an den vierten Boosterbalken (706) angrenzt, und wobei der dritte und der vierte Boosterbalken (705, 706) elektrisch verbunden sind;
der dritte und der vierte Boosterbalken (705, 706) jeweils aus einer einzigen Standardschicht aus dielektrischem Material bestehen mit einer oberen und einer unteren leitenden Oberfläche, die elektrisch verbunden sind;
das Booster-Element (704) durch einen Schlankheits-Breiten-Faktor größer als 6 und einen Schlankheits-Höhen-Faktor größer als 6 gekennzeichnet ist, wobei das Booster-Element von der Masseebenenschicht durch einen Spalt getrennt ist und durch einen Lagefaktor in einem Bereich von 0,3 bis 1,8 gekennzeichnet ist;
das Booster-Element in eine imaginäre Kugel past mit einem Durchmesser, der kleiner ist als 1/3 einer Radiuskugel mit einem Radius, der gleich einer Freiraum-Wellenlänge ist, die einer niedrigsten Frequenz des ersten Frequenzbe-

reichs entspricht, geteilt durch das Zweifache von π (pi);
der dritte interne leitende Pfad das Booster-Element mit dem Radiofrequenzsystem koppelt; und
das Radiofrequenzsystem eine dritte Anpassungsschaltung umfasst, die so konfiguriert ist, dass sie eine Impedanzanpassung innerhalb des dritten Frequenzbereichs an dem dritten externen leitenden Pfad bereitstellt.

4. Das drahtlose handgehaltene oder tragbare elektronische Gerät nach Anspruch 1, wobei die erste Anpassungsschaltung einen einzigen Zweig umfasst.

5. Das drahtlose handgehaltene oder tragbare elektronische Gerät nach Anspruch 1, wobei die erste Anpassungsschaltung aus nicht mehr als sieben zusammengehörigen Komponenten besteht.

6. Das drahtlose handgehaltene oder tragbare elektronische Gerät nach Anspruch 1, wobei:

das schlanke Strahlungssystem einen zweiten externen leitenden Pfad umfasst;
das Radiofrequenzsystem einen Diplexer umfasst, der mit der ersten Anpassungsschaltung, dem ersten externen leitenden Pfad und dem zweiten externen leitenden Pfad verbunden ist; und
die erste Anpassungsschaltung ferner so konfiguriert ist, dass sie eine Impedanzanpassung innerhalb des zweiten Frequenzbereichs an dem zweiten externen leitenden Pfad bereitstellt.

7. Das drahtlose handgehaltene oder tragbare elektronische Gerät nach Anspruch 1, wobei eine Fläche, die durch die zwei größten Abmessungen einer Boosterbox, die den ersten Boosterbalken vollständig umschließt, geteilt durch ein Quadrat der Freiraumwellenlänge, die der niedrigsten Frequenz des ersten Frequenzbereichs entspricht, definiert ist, weniger als 0,06 % beträgt.

8. Das drahtlose handgehaltene oder tragbare elektronische Gerät nach Anspruch 7, wobei die Fläche, die durch die zwei größten Abmessungen der Booster-Box, die den ersten Boosterbalken vollständig umschließt, geteilt durch ein Quadrat der Freiraumwellenlänge, die der niedrigsten Frequenz des zweiten Frequenzbereichs entspricht, definiert ist, weniger als 0,15 % beträgt.

9. Das drahtlose handgehaltene oder tragbare elektronische Gerät nach Anspruch 1, wobei der erste interne leitende Pfad eine L-förmige leitende Bahn umfasst.

Revendications

1. Dispositif électronique portable ou sans fil comprenant :

un système de rayonnement mince configuré pour transmettre et recevoir des signaux d'ondes électromagnétiques dans une première zone de fréquence, le système de rayonnement mince comprenant une structure de rayonnement mince, un système de radiofréquence, une première chemin conducteur interne et un premier chemin conducteur externe ;
la structure de rayonnement mince comprend une première barre d'appoint (702) et une couche de plan de masse (707) ;
la première barre d'appoint (702) comprend une seule couche standard de matériau diélectrique comprenant une surface conductrice supérieure et une surface conductrice inférieure reliées électriquement, lesdites surfaces conductrices supérieure et inférieure étant formées par un matériau conducteur imprimé ou déposé dans la surface supérieure et inférieure du matériau diélectrique et lesdites surfaces conductrices étant reliées électriquement par au moins une connexion électrique, la première barre d'appoint (702) est en outre **caractérisée par** un facteur de largeur mince supérieur à 3 et un facteur de hauteur mince supérieur à 3, le facteur de largeur mince caractérisant le rapport entre la longueur et la largeur de la barre d'appoint, et le facteur de hauteur mince caractérisant le rapport entre la longueur et la hauteur de la barre d'appoint, la première barre d'appoint (702) étant séparée de la couche de plan de masse (707) par un espace et **caractérisée par** un facteur d'emplacement dans une plage allant de 0.3 à 1,8, le facteur de localisation correspondant à un rapport entre la largeur de la barre d'appoint et l'espace ;
la première barre d'appoint (702) s'inscrit dans une sphère imaginaire dont le diamètre est inférieur à 1/3 d'une radiansphère dont le rayon est égal à une longueur d'onde de l'espace libre correspondant à la fréquence la plus basse de la première zone de fréquence, divisée par deux fois π (pi) ;
le premier chemin conducteur interne relie la première barre d'appoint (702) au système de radiofréquence ; et le système de radiofréquence comprend un premier circuit d'adaptation configuré pour fournir une adaptation d'impédance dans la première zone de fréquence au niveau du premier chemin conducteur externe, le système de rayonnement mince étant configuré pour transmettre et recevoir des signaux d'ondes électromagnétiques dans une deuxiè-

me zone de fréquence, la fréquence la plus basse de la deuxième zone de fréquence étant supérieure à la fréquence la plus élevée de la première zone de fréquence ; et
le premier circuit d'adaptation étant en outre configuré pour fournir une adaptation d'impédance dans la deuxième zone de fréquence au niveau du premier chemin conducteur externe,
la première zone de fréquence comprenant une gamme de fréquences de 824-960 MHz et la deuxième zone de fréquence comprenant une gamme de fréquences de 1710-2170 MHz, et
la taille maximale de la première barre d'appoint étant inférieure à 1/15 de la longueur d'onde de l'espace libre correspondant à la fréquence la plus basse de la première zone de fréquence.

2. Dispositif électronique portable ou sans fil selon la revendication 1, dans lequel :

le système de rayonnement mince comprend une deuxième chemin conducteur interne et une deuxième chemin conducteur externe ;
la structure de rayonnement mince comprend une deuxième barre d'appoint (703) ;
la deuxième barre d'appoint (703) comprend une seule couche standard de matériau diélectrique comprenant une surface conductrice supérieure et une surface conductrice inférieure reliées électriquement, est **caractérisée par** un facteur de largeur mince supérieur à 3 et un facteur de hauteur mince supérieur à 3, la deuxième barre d'appoint (703) étant séparée de la couche du plan de masse par un espace et **caractérisée par** un facteur de localisation compris entre 0,3 et 1,8 ;
la deuxième barre d'appoint (703) s'inscrit dans une sphère imaginaire dont le diamètre est inférieur à 1/3 d'une radiansphère dont le rayon est égal à une longueur d'onde de l'espace libre correspondant à la fréquence la plus basse de la première zone de fréquence, divisée par deux fois π (pi) ;
le deuxième chemin conducteur interne relie la deuxième barre d'appoint (703) au système de radiofréquence ; et
le système radiofréquence comprend un deuxième circuit d'adaptation configuré pour assurer l'adaptation de l'impédance dans la deuxième zone de fréquence au niveau du deuxième chemin conducteur externe.

3. Dispositif électronique portable ou sans fil selon la revendication 2, dans lequel :

le système de rayonnement mince est configuré pour transmettre et recevoir des signaux d'ondes électromagnétiques dans une troisième zone de fréquence, dans laquelle la fréquence la plus élevée de la troisième zone de fréquence est inférieure à la fréquence la plus basse de la première zone de fréquence ;
le système de rayonnement mince comprend une troisième chemin conducteur interne et une troisième chemin conducteur externe ;
la structure de rayonnement mince comprend un élément d'appoint (704) contenant des troisième et quatrième barres d'appoint (705, 706), la troisième barre d'appoint (705) étant adjacente à la quatrième barre d'appoint (706), et dans laquelle les troisième et quatrième barres d'appoint (705, 706) sont connectées électriquement;
chacune des troisième et quatrième barres d'appoint (705, 706) comprend une seule couche standard de matériau diélectrique contenant une surface conductrice supérieure et une surface conductrice inférieure reliées électriquement ;
l'élément d'appoint (704) est **caractérisé par** un facteur de largeur mince supérieur à 6 et un facteur de hauteur mince supérieur à 6, l'élément d'appoint étant séparé de la couche de plan de masse par un espace et **caractérisé par** un facteur d'emplacement compris entre 0,3 et 1,8 ;
l'élément d'appoint s'inscrit dans une sphère imaginaire dont le diamètre est inférieur à 1/3 d'une radiansphère dont le rayon est égal à une longueur d'onde de l'espace libre correspondant à la fréquence la plus basse de la première zone de fréquence, divisée par deux fois π (pi) ;
le troisième chemin conducteur interne relie l'élément d'appoint au système de radiofréquence ; et
le système radiofréquence comprend un troisième circuit d'adaptation configuré pour fournir une adaptation d'impédance dans la troisième zone de fréquence au niveau du troisième chemin conducteur externe.

4. Dispositif électronique portable ou sans fil selon la revendication 1, dans lequel le premier circuit d'adaptation comprend une seule branche.

5. Dispositif électronique portable ou sans fil selon la revendication 1, dans lequel le premier circuit d'adaptation ne comprend pas plus de sept composants isolés.

6. Dispositif électronique portable ou sans fil selon la revendication 1, dans lequel :

le système de rayonnement mince comprend un deuxième chemin conducteur externe ;
le système radiofréquence comprend un diplexeur couplé au premier circuit d'adaptation,

au premier chemin conducteur externe et au second chemin conducteur externe ; et
le premier circuit d'adaptation est en outre configuré pour fournir une adaptation d'impédance dans la deuxième zone de fréquence au niveau du deuxième chemin conducteur externe.

7. Dispositif électronique portable ou sans fil selon la revendication 1, dans lequel une zone définie par les deux plus grandes dimensions d'une boîte d'appoint entourant complètement la première barre d'appoint divisée par le carré de la longueur d'onde de l'espace libre correspondant à la fréquence la plus basse de la première zone de fréquence est inférieure à 0,06 %.

8. Dispositif électronique portable ou sans fil selon la revendication 7, dans lequel la zone définie par les deux plus grandes dimensions de la boîte d'appoint entourant complètement la première barre d'appoint divisée par le carré de la longueur d'onde de l'espace libre correspondant à la fréquence la plus basse de la deuxième zone de fréquence est inférieure à 0,15 %.

9. Dispositif électronique portable ou sans fil selon la revendication 1, dans lequel le premier chemin conducteur interne comprend une trace conductrice en forme de L.

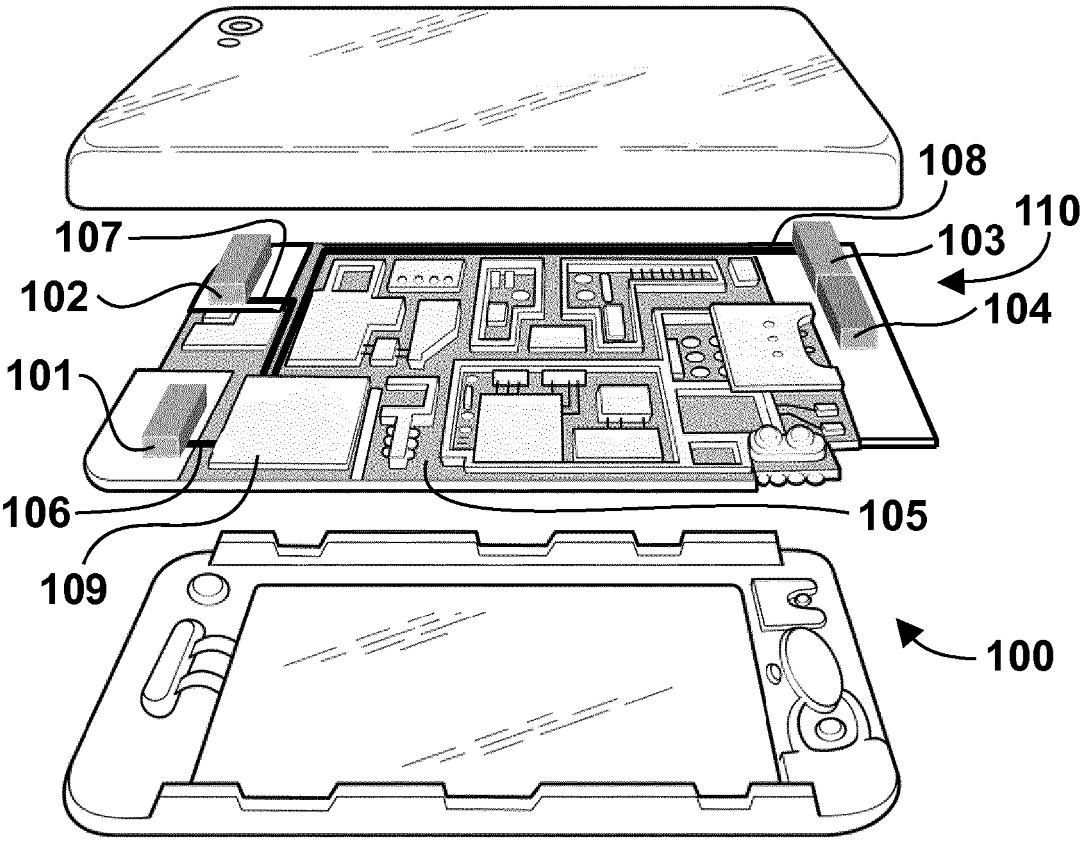

FIG. 1A

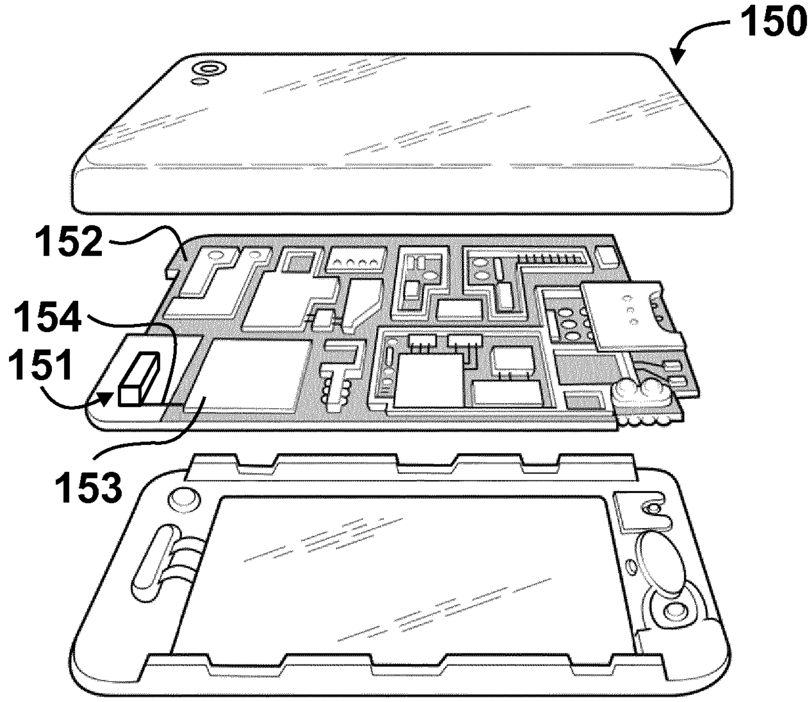

FIG. 1B

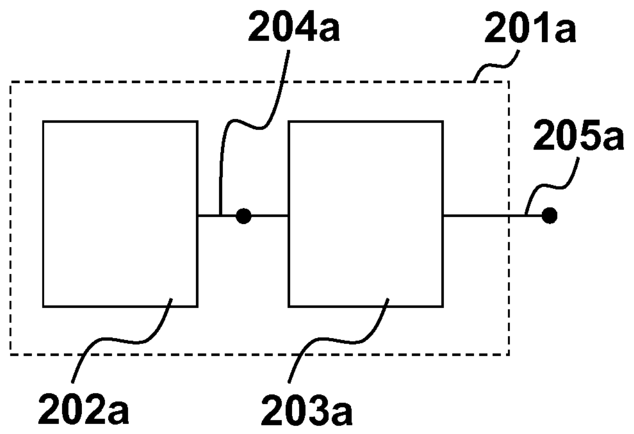

FIG. 2A

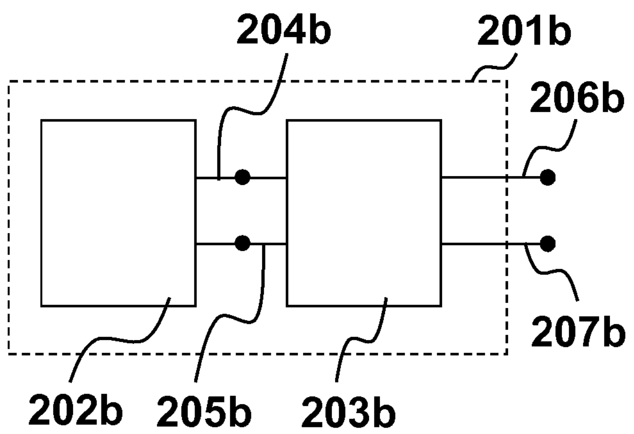

FIG. 2B

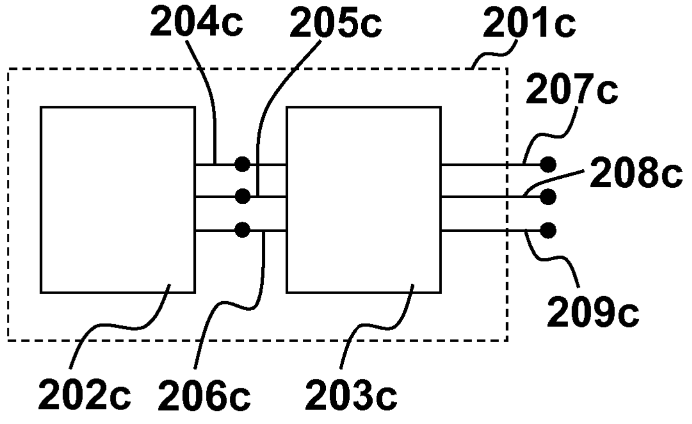

FIG. 2C

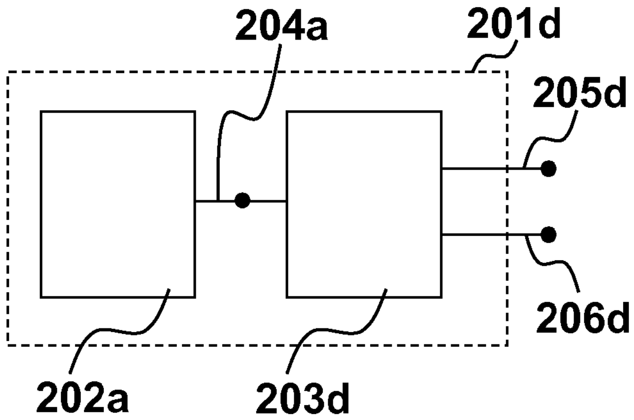
204a
201d
205d
206d
202a
203d

FIG. 2D

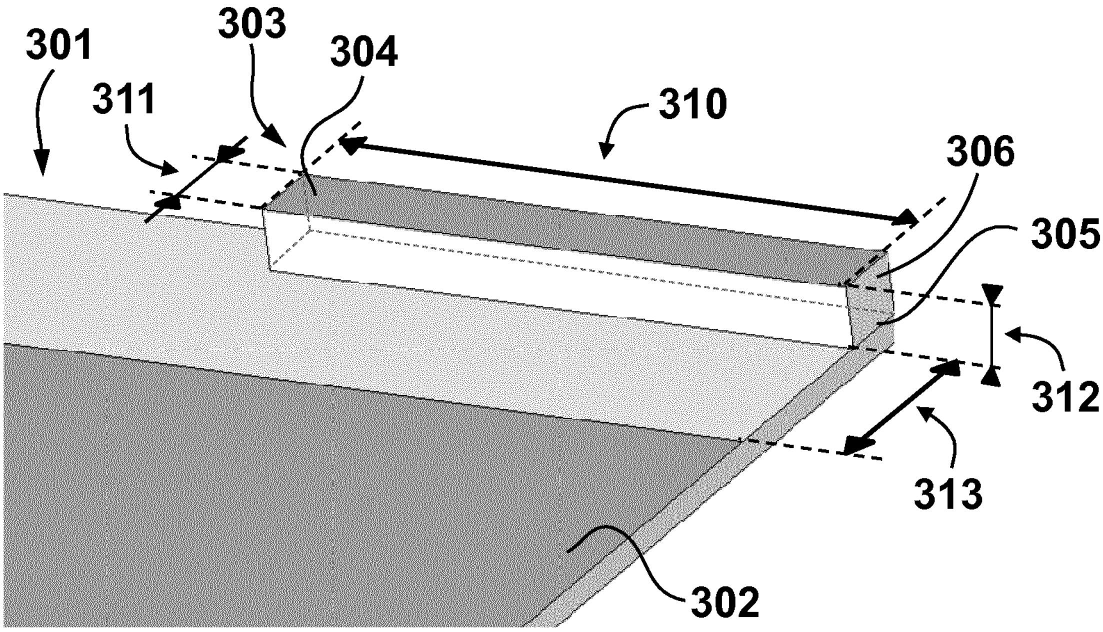
301
303
304
311
310
306
305
312
313
302

FIG. 3

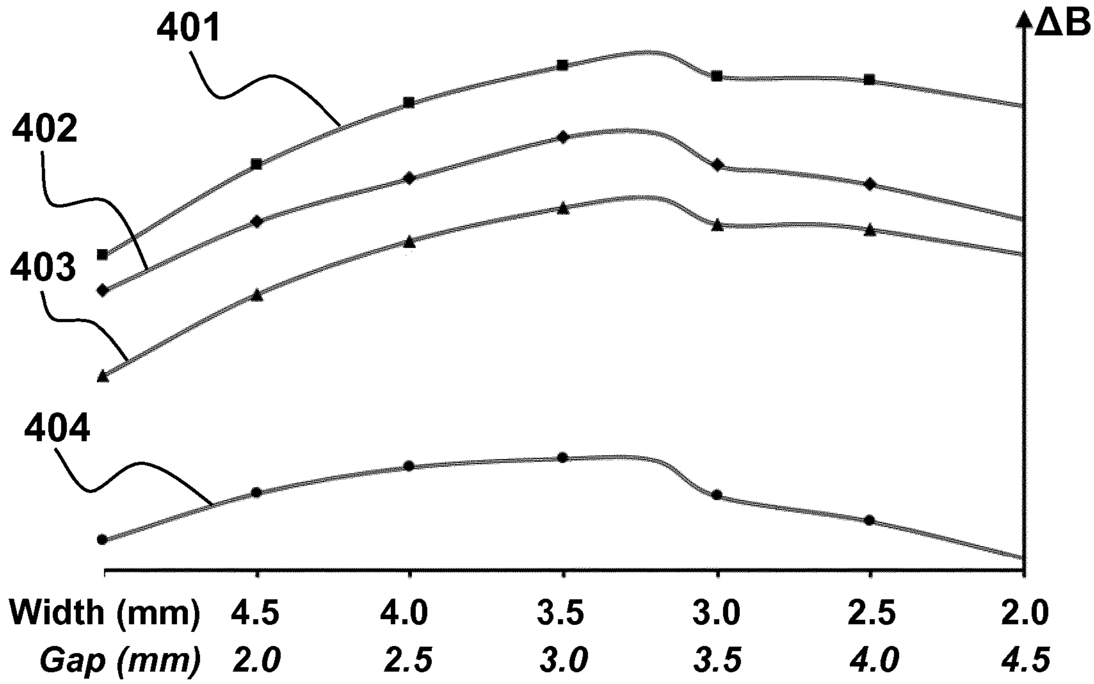
401
402
403
404
ΔB
Width (mm) 4.5 4.0 3.5 3.0 2.5 2.0
Gap (mm) 2.0 2.5 3.0 3.5 4.0 4.5

FIG. 4A

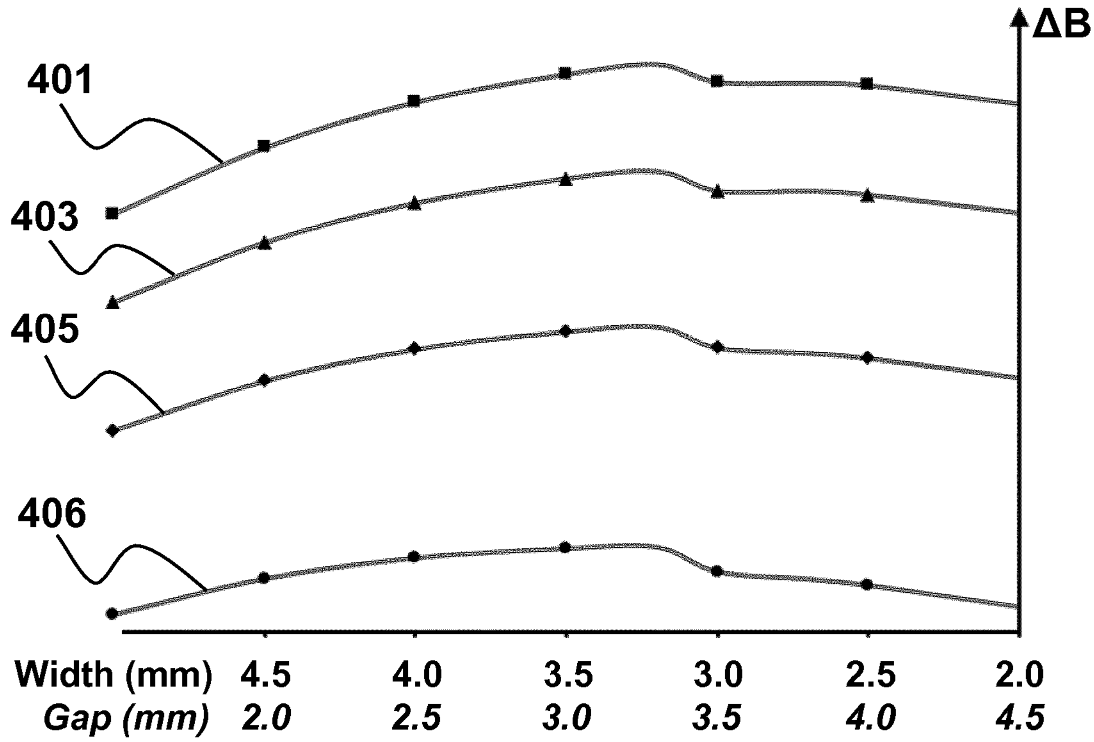
401
403
405
406
ΔB
Width (mm) 4.5 4.0 3.5 3.0 2.5 2.0
Gap (mm) 2.0 2.5 3.0 3.5 4.0 4.5

FIG. 4B

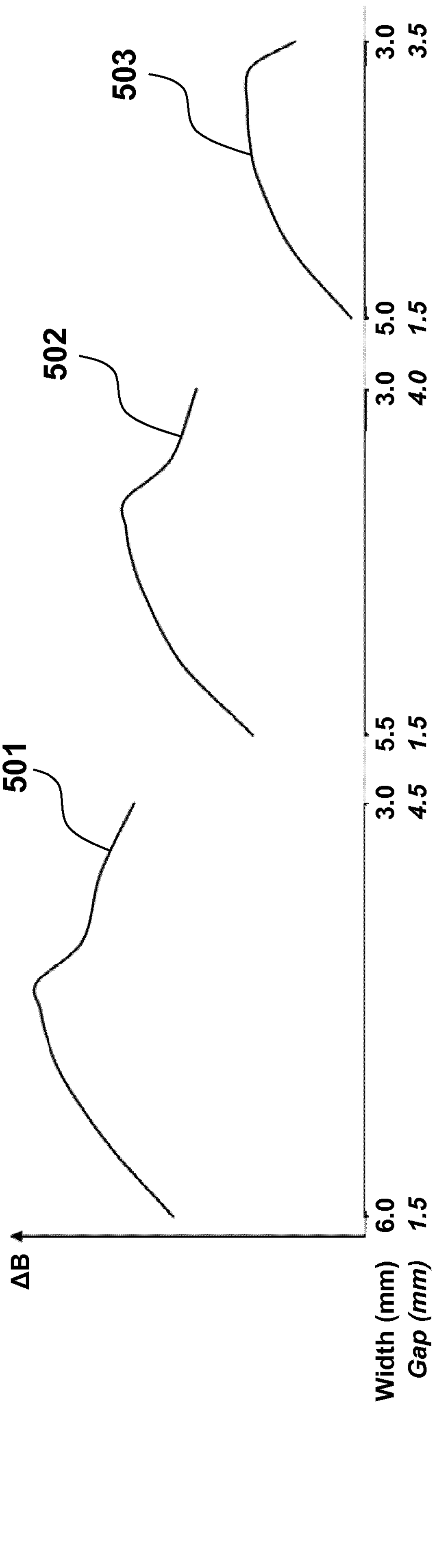

FIG. 5

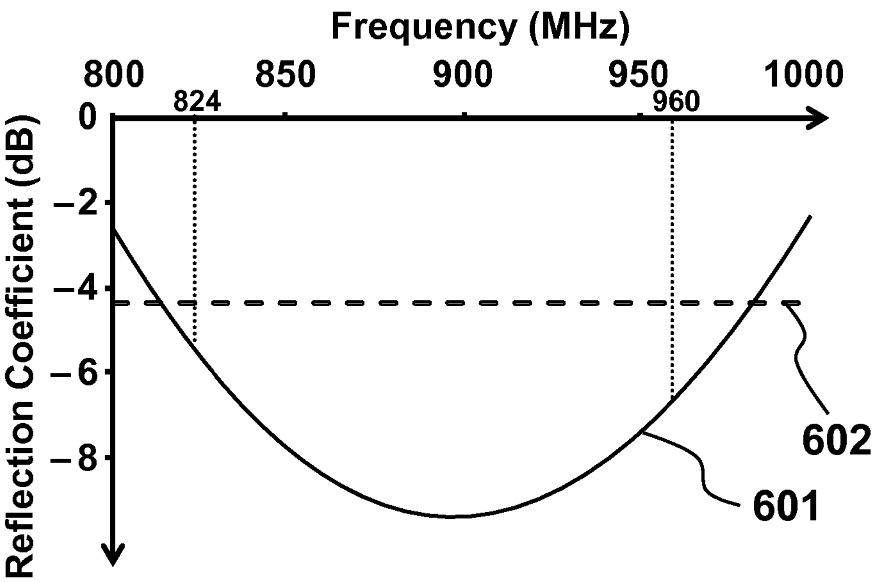
Frequency (MHz)
800
850
900
950
1000
824
960
0
−2
−4
−6
−8
Reflection Coefficient (dB)
602
601

FIG. 6

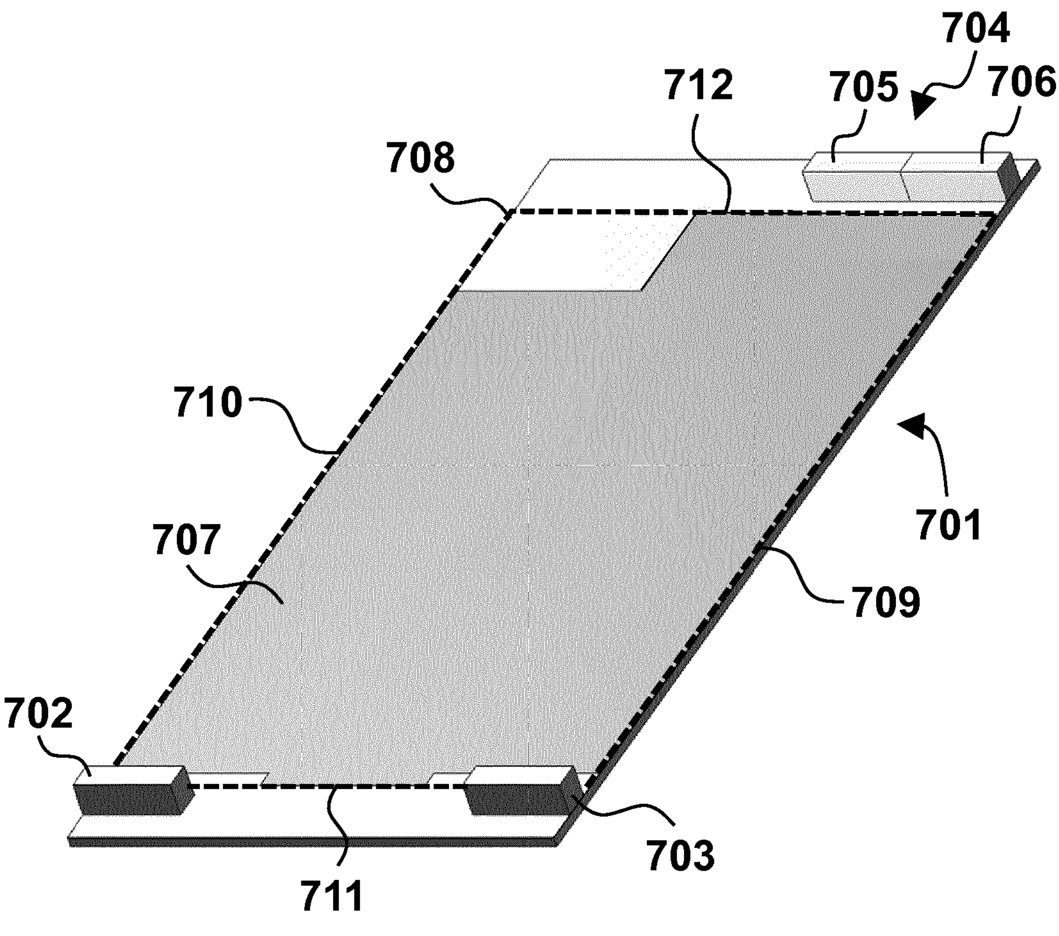
704
712
705
706
708
710
701
707
709
702
703
711

FIG. 7

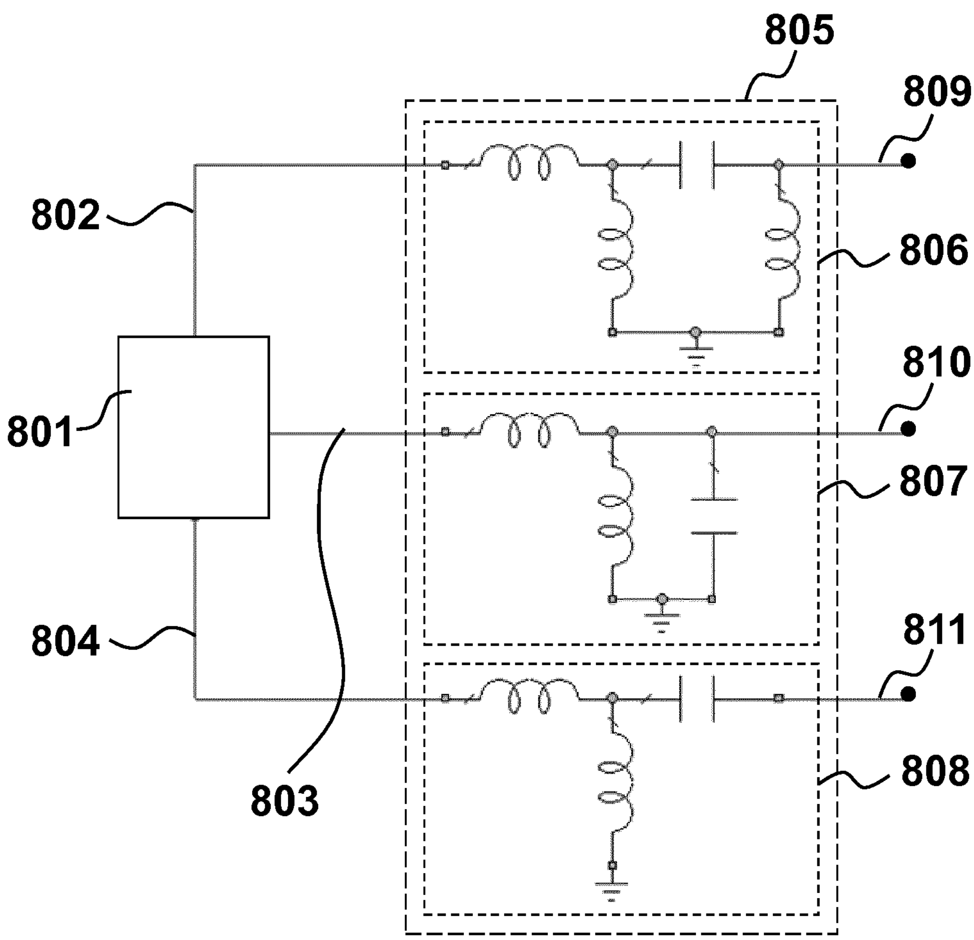
805
809
802
806
810
801
807
804
811
808
803

FIG. 8

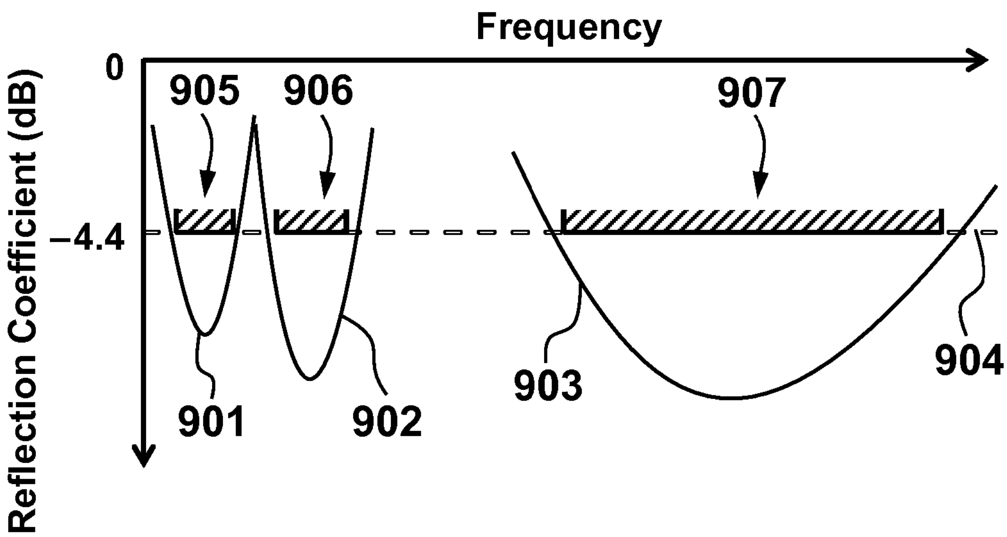
Frequency
0
905
906
907
Reflection Coefficient (dB)
−4.4
901
902
903
904

FIG. 9

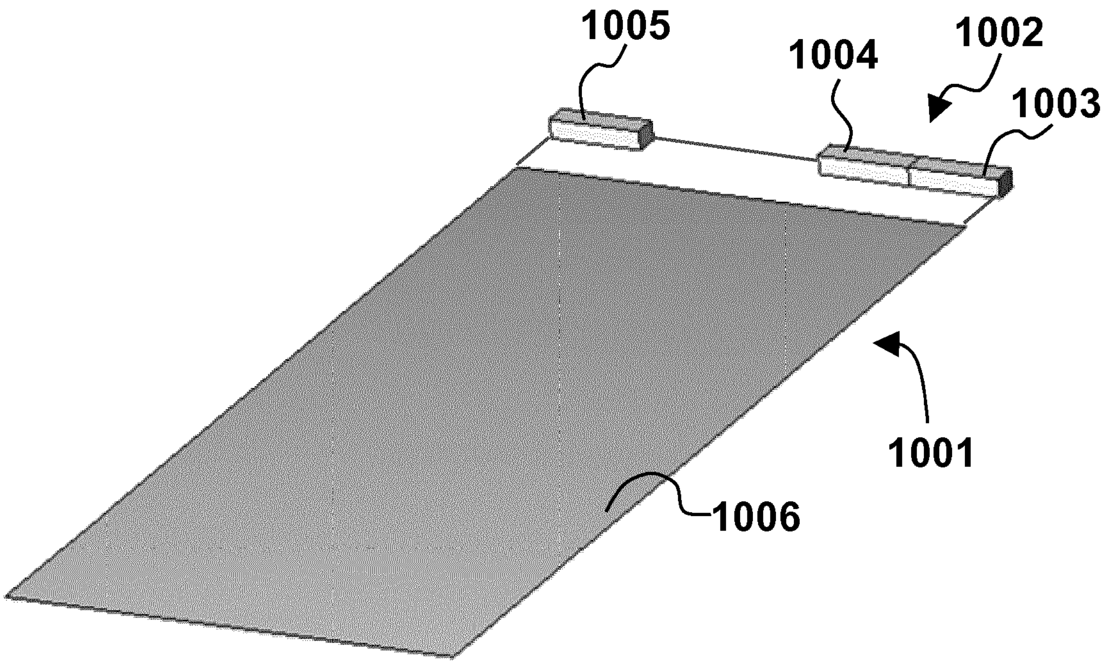

FIG. 10

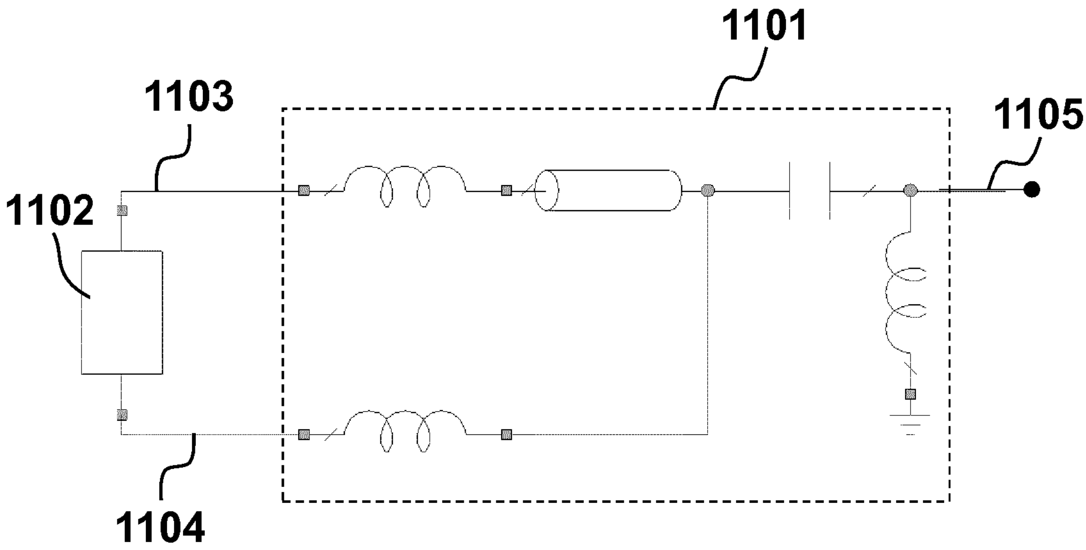

FIG. 11

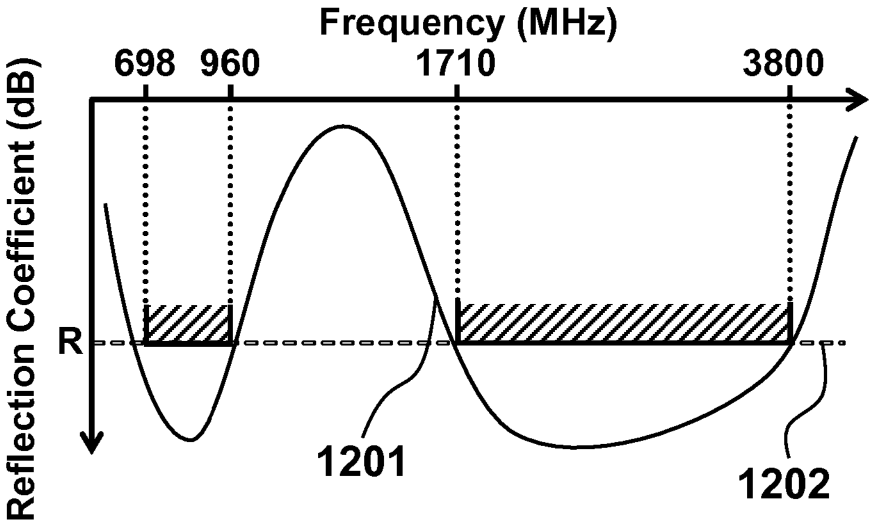
Frequency (MHz)
698
960
1710
3800
Reflection Coefficient (dB)
R
1201
1202

FIG. 12

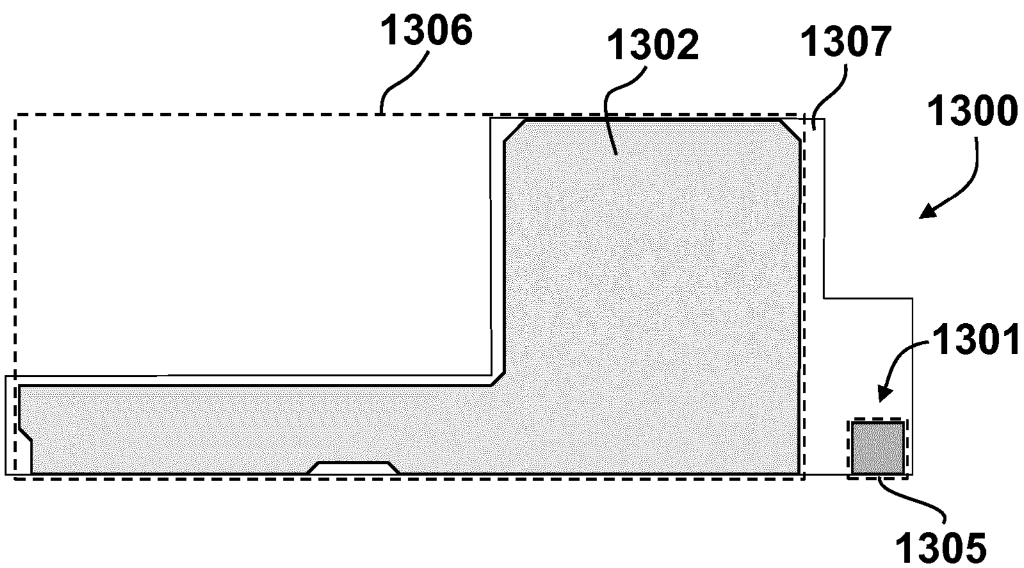
1306
1302
1307
1300
1301
1305

FIG. 13

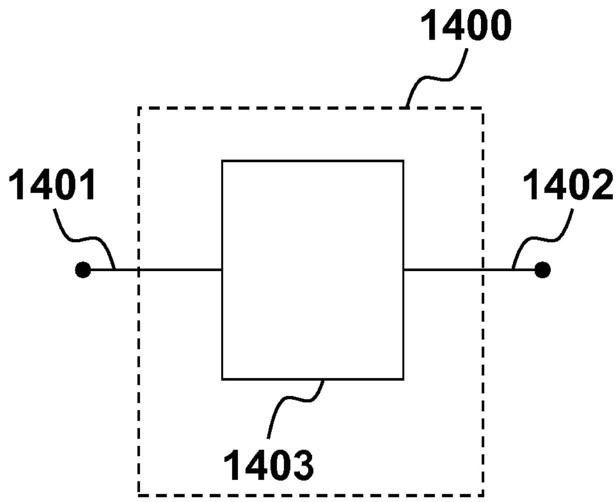

FIG. 14A

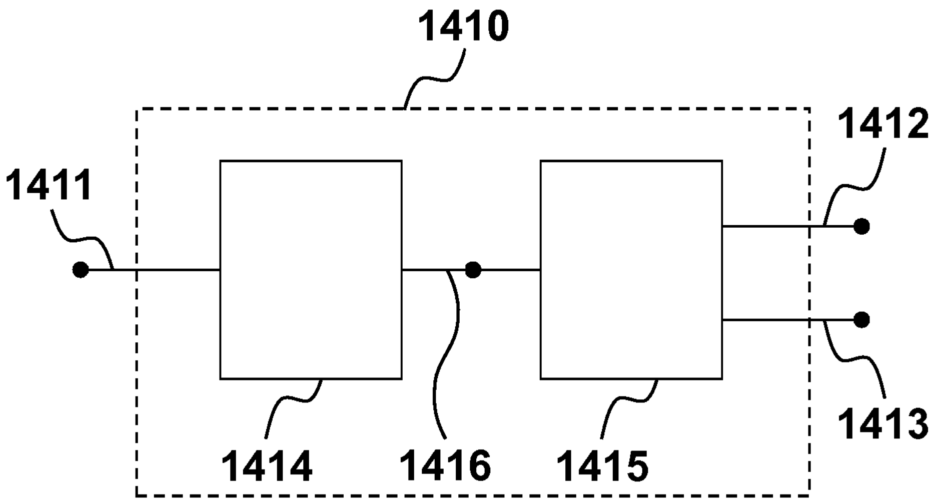

FIG. 14B

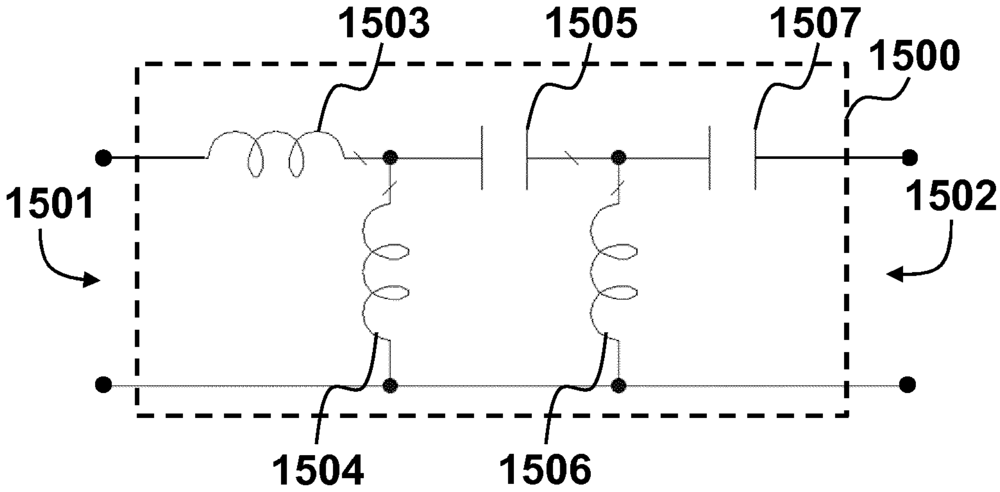

FIG. 15A

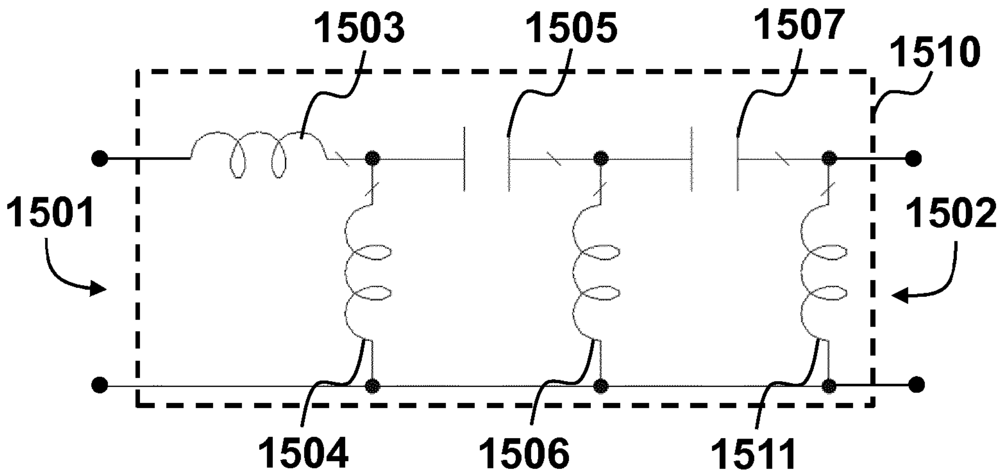

FIG. 15B

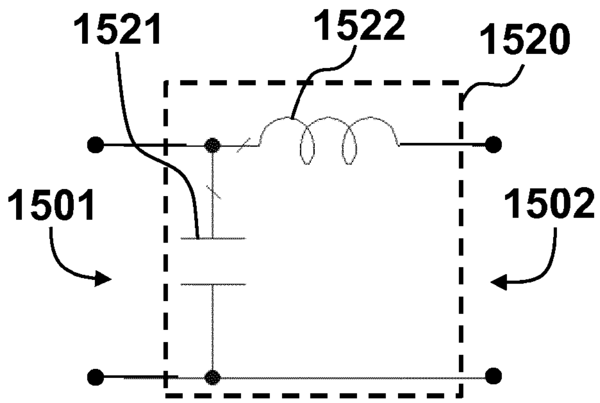

FIG. 15C

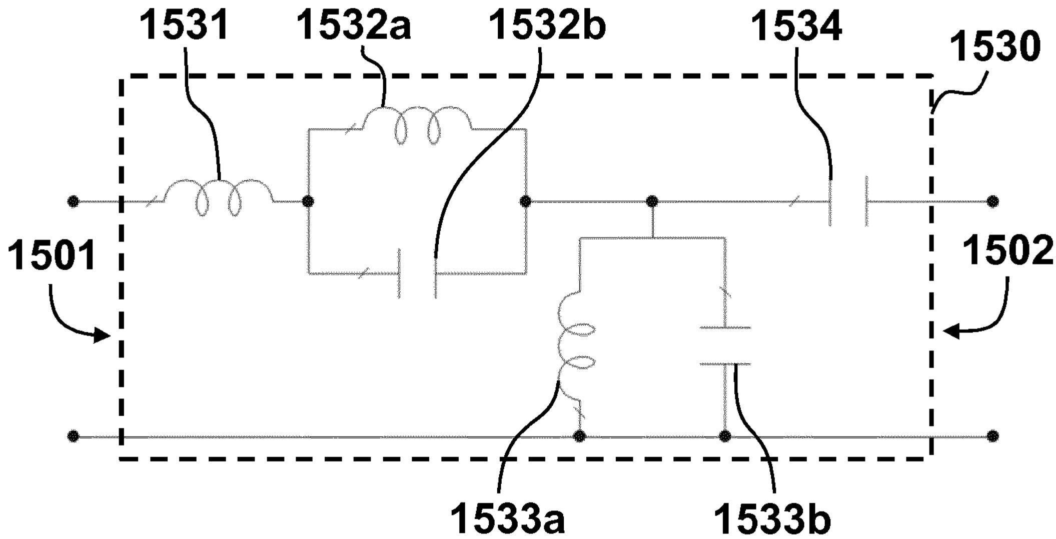

FIG. 15D

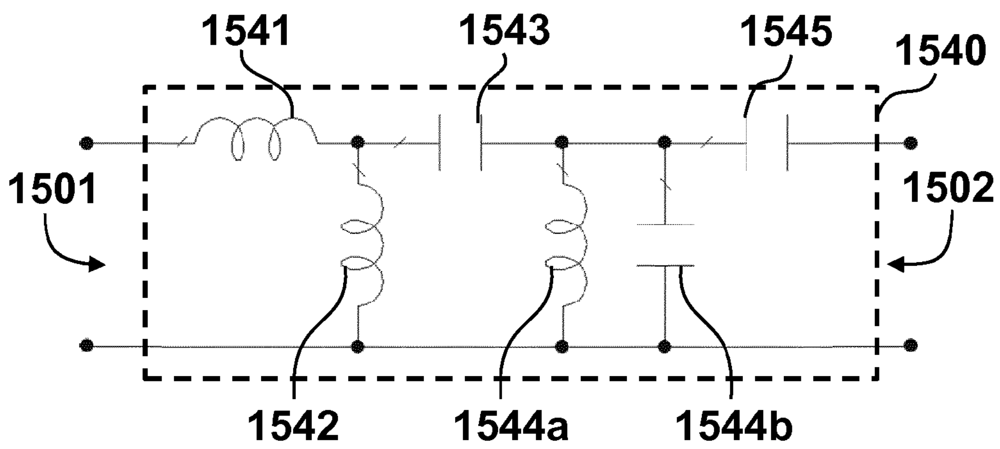

FIG. 15E

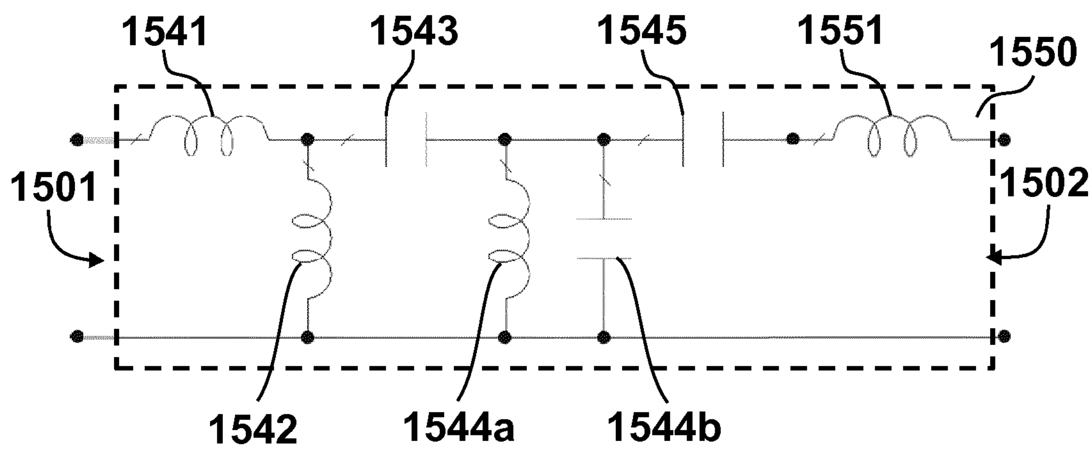

FIG. 15F

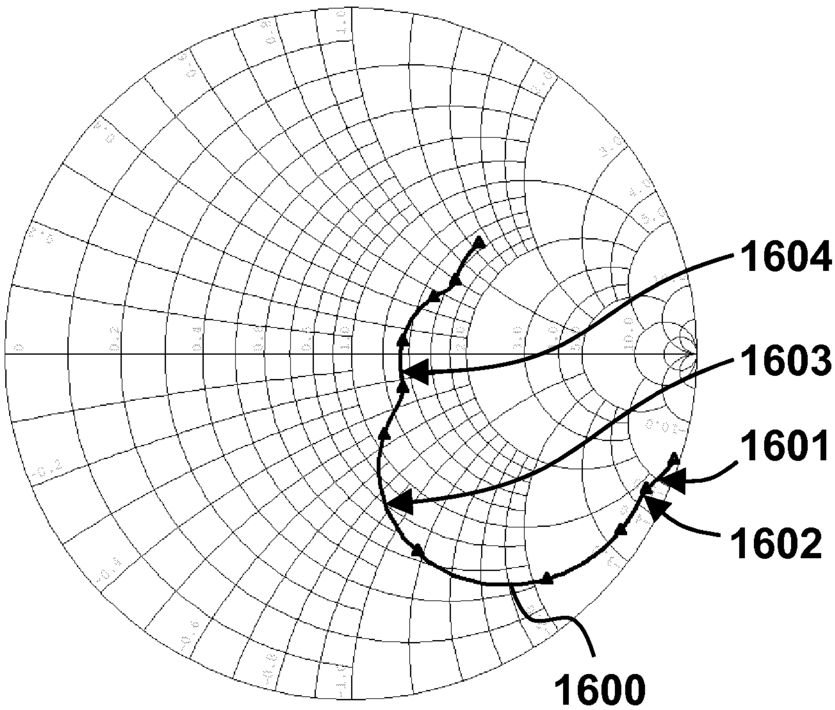

FIG. 16A

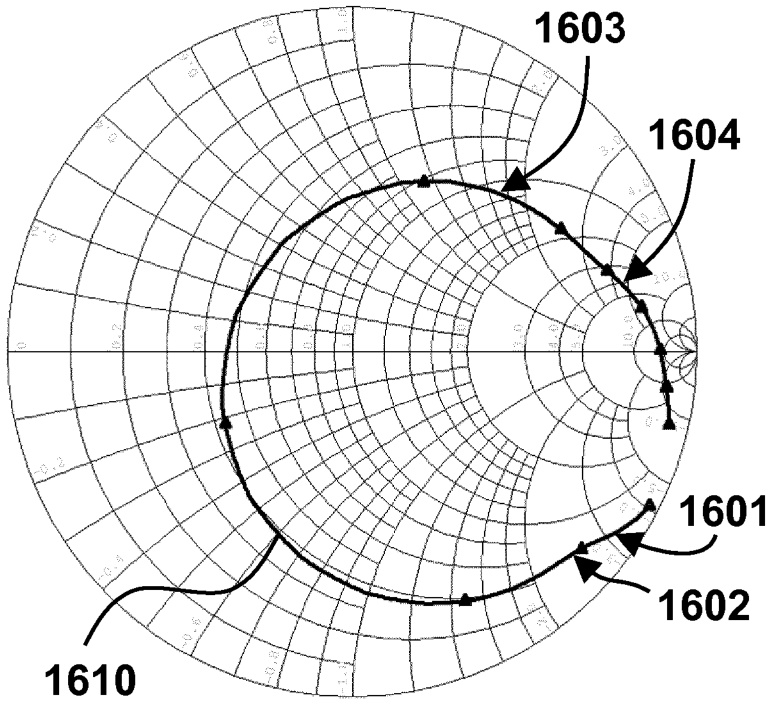

FIG. 16B

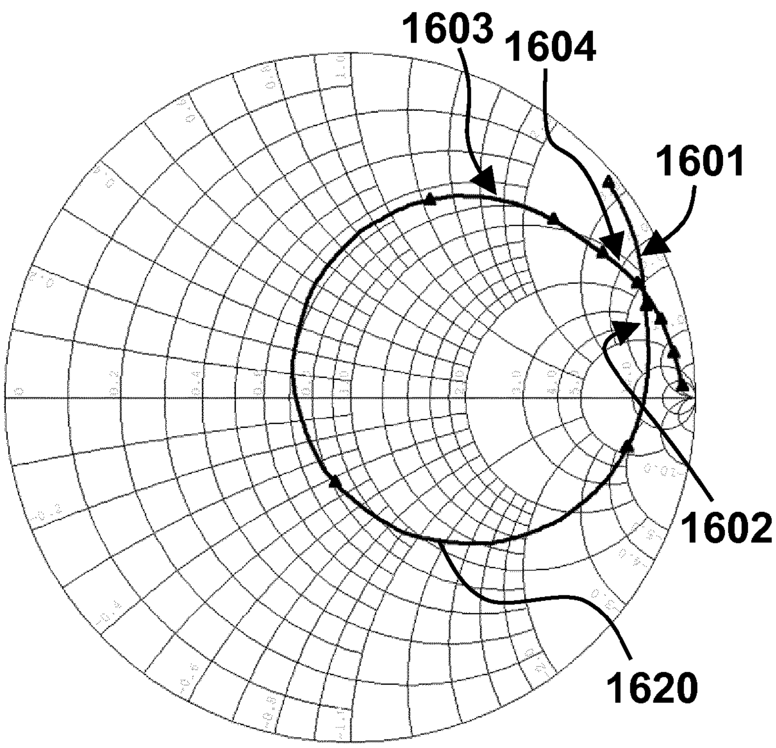

FIG. 16C

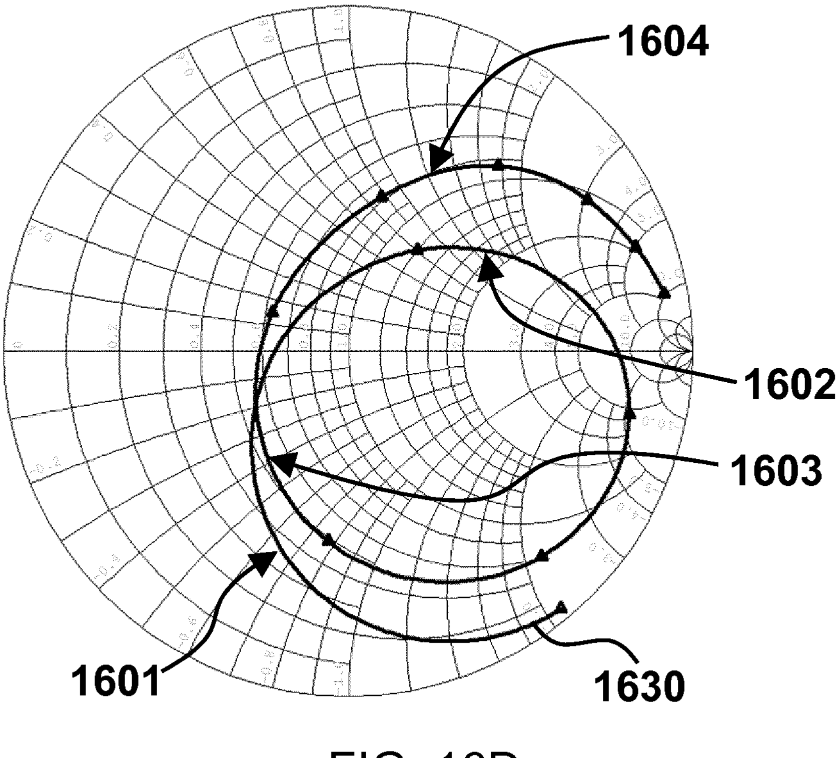

FIG. 16D

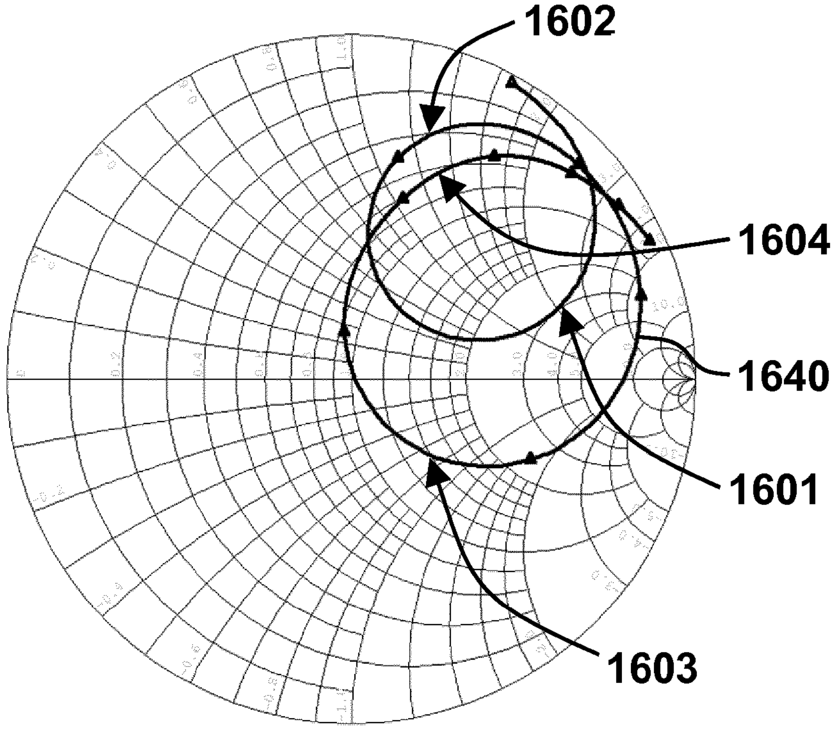

FIG. 16E

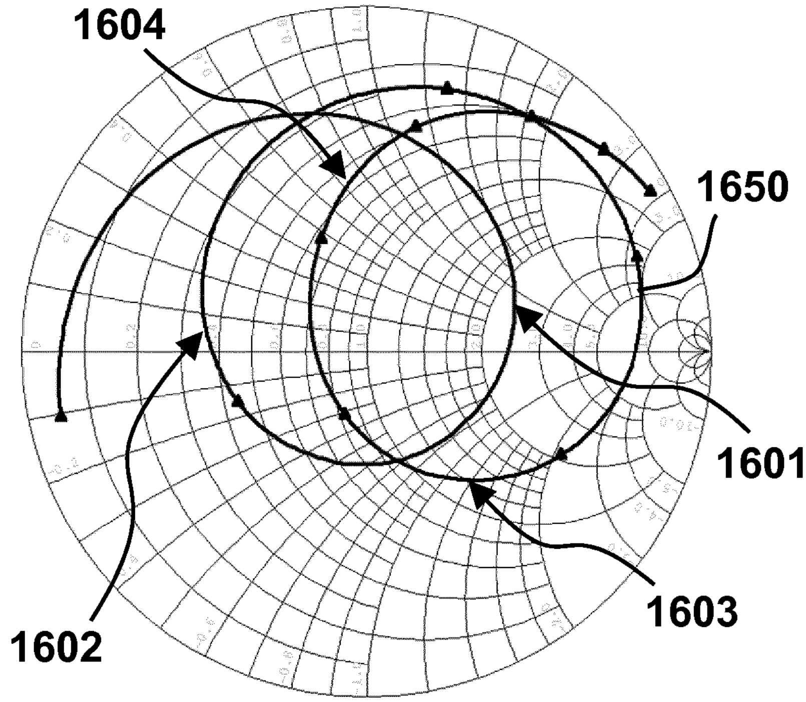

FIG. 16F

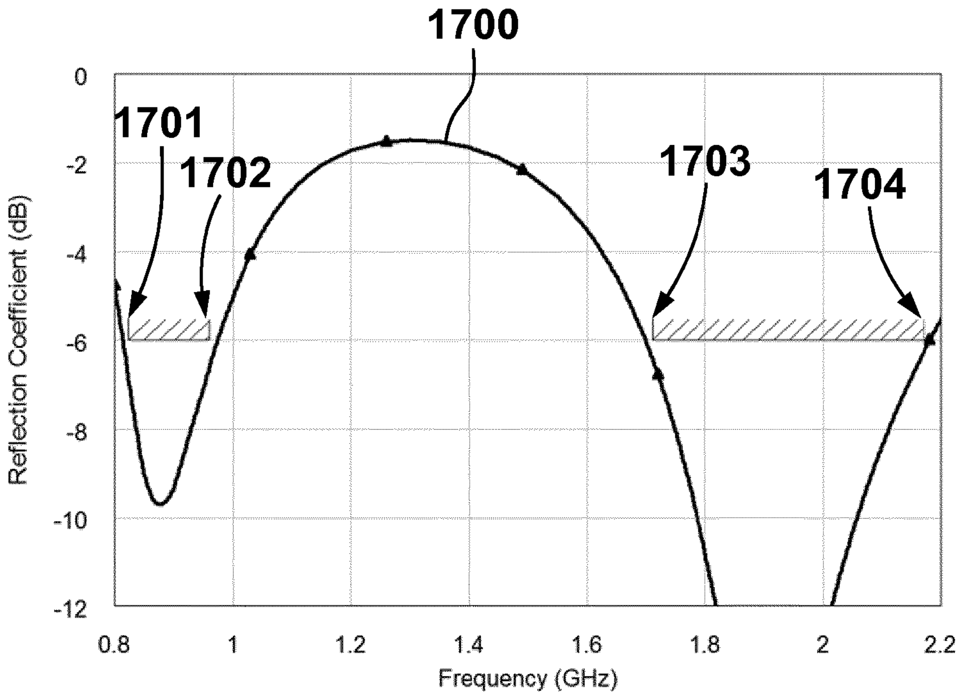

FIG. 17

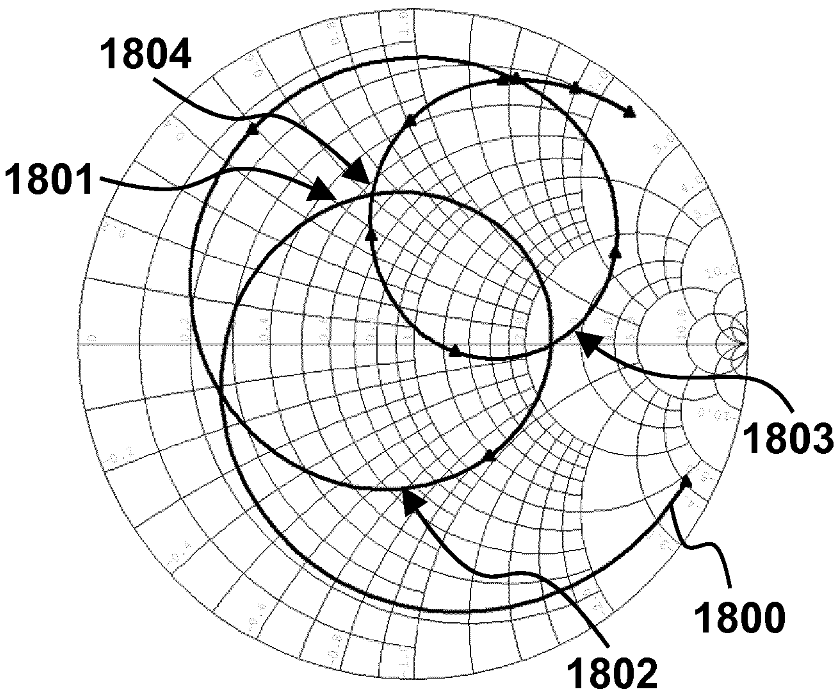

FIG. 18A

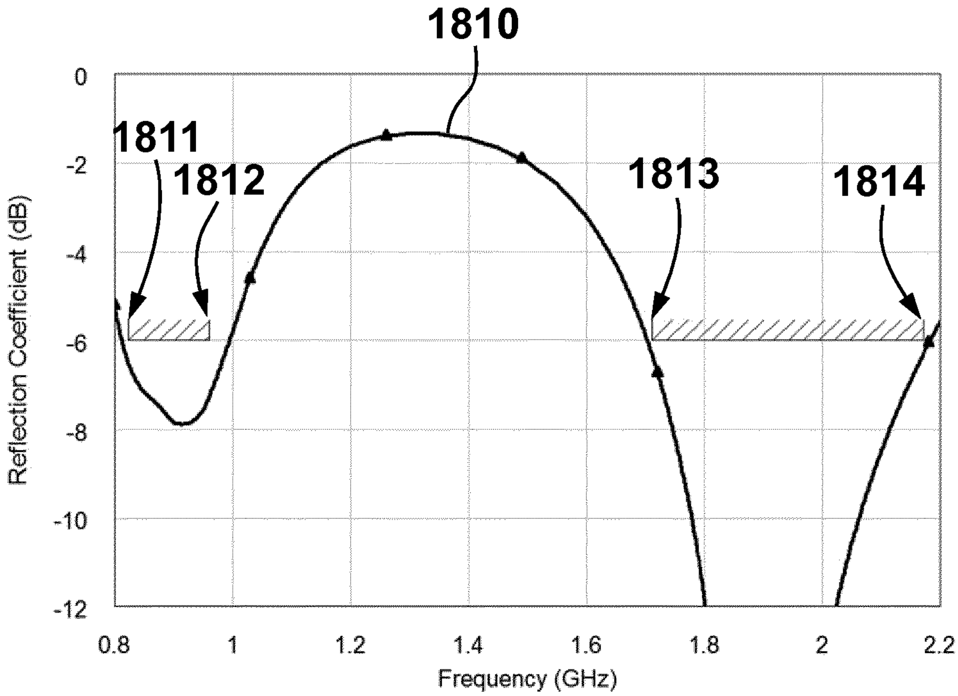

FIG. 18B

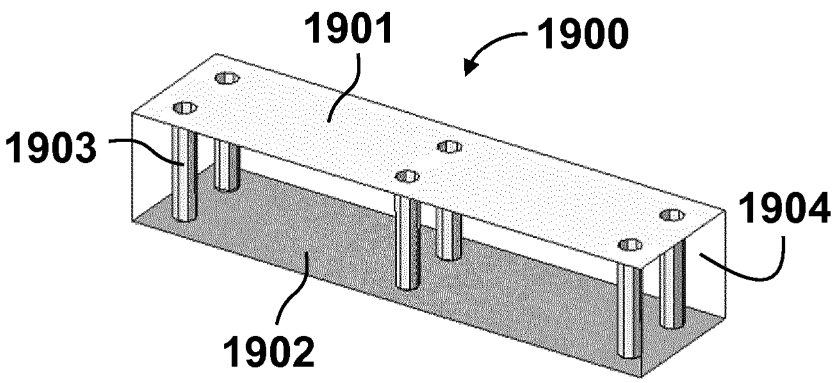

FIG. 19

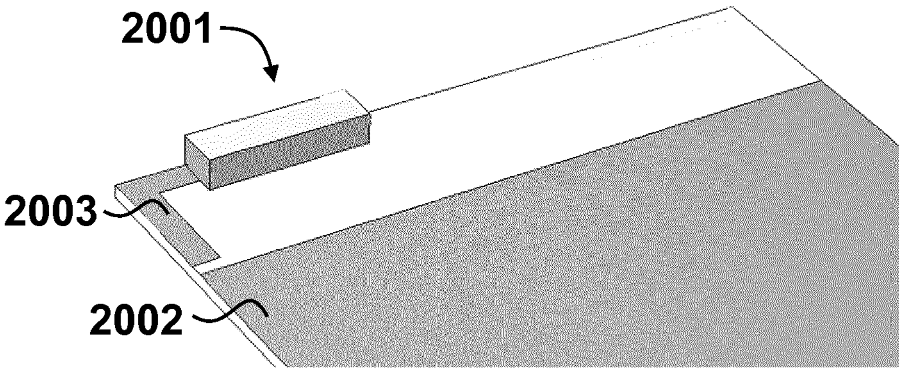

FIG. 20

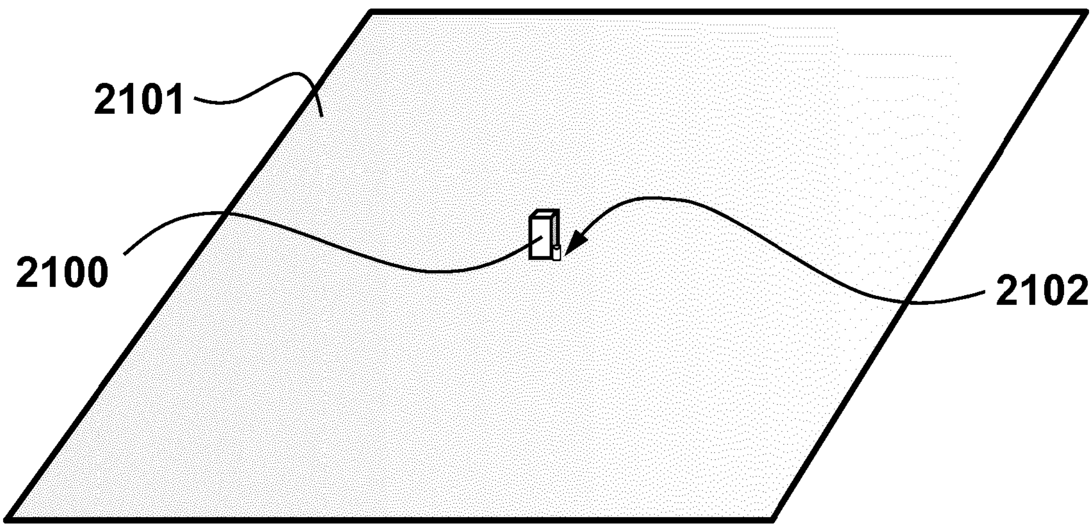

FIG. 21A

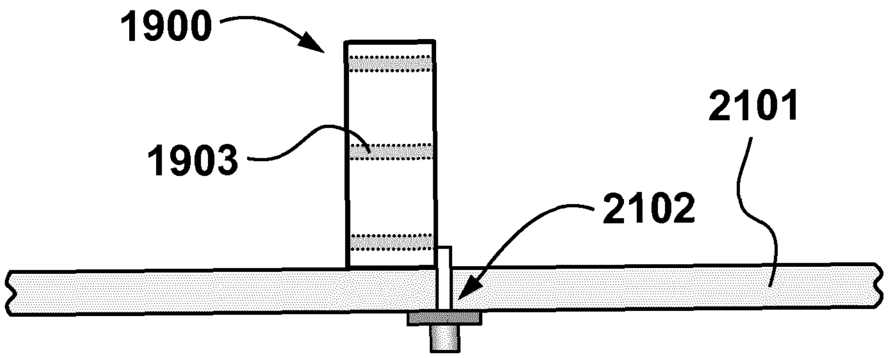

FIG. 21B

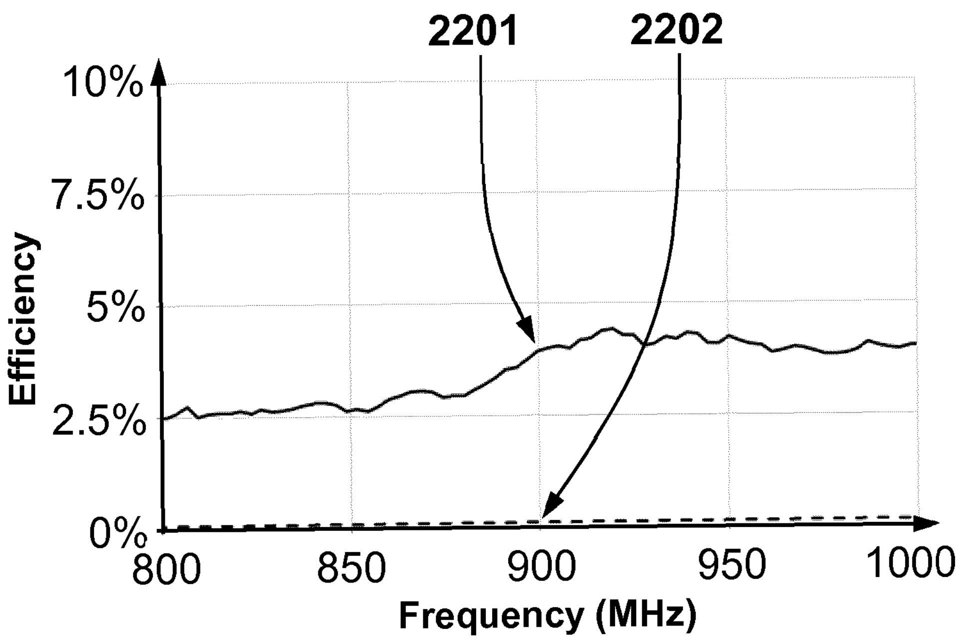

FIG. 22

REFERENCES CITED IN THE DESCRIPTION

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