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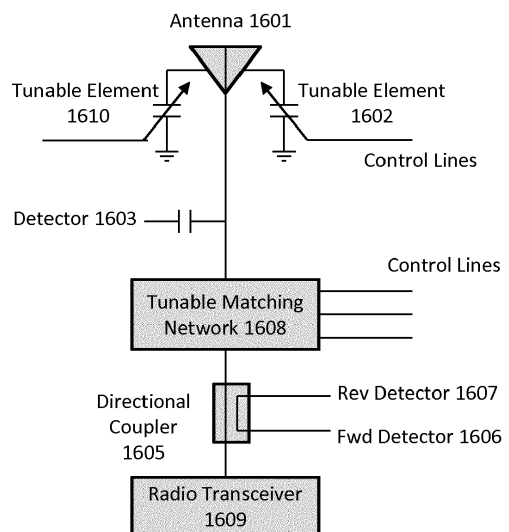
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(54) **METHOD AND APPARATUS FOR TUNING A COMMUNICATION DEVICE**

(57) A system that incorporates teachings of the present disclosure may include, for example, one or more matching network elements and a controller coupled with the one or more matching network elements. The controller can determine antenna efficiency information associated with one or more antennas of a group of antennas of a communication device. The controller can determine antenna isolation information associated with the one or more antennas. The controller can tune the one or more matching network elements for at least a portion of the group of antennas based on the antenna efficiency information and the antenna isolation information. Additional embodiments are disclosed.



1600

FIG. 16

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Description**CROSS-REFERENCE TO RELATED APPLICATIONS**

[0001] The present application is a PCT International Application claiming priority to U.S. Application Serial No. 13/108,463, filed May 16, 2011 and U.S. Application Serial No. 13/108,589, filed May 16, 2011, the disclosures of both of which are hereby incorporated by reference.

FIELD OF THE DISCLOSURE

[0002] The present disclosure relates generally to communication systems, and more specifically to a method and apparatus for tuning a communication device.

BACKGROUND

[0003] Existing multi-frequency wireless devices (e.g., radios) use an antenna structure that attempts to radiate at optimum efficiency over the entire frequency range of operation, but can really only do so over a subset of the frequencies. Due to size constraints, and aesthetic design reasons, the antenna designer is forced to compromise the performance in some of the frequency bands. An example of such a wireless device could be a mobile telephone that operates over a range of different frequencies, such as 800 MHz to 2200 MHz. The antenna will not radiate efficiently at all frequencies due to the nature of the design, and the power transfer between the antenna, the power amplifier, and the receiver in the radio will vary significantly.

[0004] Additionally, an antenna's performance is impacted by its operating environment. For example, multiple use cases exist for radio handsets, which include such conditions as the placement of the handset's antenna next to a user's head, or in the user's pocket or the covering of an antenna with a hand, can significantly impair wireless device efficiency. Further, many existing radios use a simple circuit composed of fixed value components that are aimed at improving the power transfer from power amplifier to antenna, or from the antenna to the receiver, but since the components used are fixed in value there is always a compromise when attempting to cover multiple frequency bands and multiple use cases.

[0005] Microwave devices for the propagation of electromagnetic waves can consist of tunable and non-tunable stages and components. The electrical path length of the tunable elements can be adjusted with a bias voltage. The stages and components can be realized with microstrip geometries, stripline geometries, coaxial geometries slotline or fineline geometries and co-planar waveguide geometries. The functions of the components could be phase shifting, delaying or filtering. A number of components may be collected together to form a multi-stage device. This collection can improve the bandwidth realized over a single stage microwave device. Stages may be put in series such as a tunable stage with a non-

tunable stage. Examples of tunable microwave devices with auto-adjusting matching circuits are described in U.S. Patent. No. 6,590,468 to duToit et al.

BRIEF DESCRIPTION OF THE DRAWINGS**[0006]**

FIG. 1 depicts an illustrative embodiment of a communication device;
 FIG. 2 depicts an illustrative embodiment of a portion of a transceiver of the communication device of FIG. 1;
 FIGs. 3-4 depict illustrative embodiments of a tunable matching network of the transceiver of FIG. 2;
 FIGs. 5-6 depict illustrative embodiments of a tunable reactive element of the tunable matching network;
 FIG. 7A depicts an illustrative embodiment of a portion of a communication device;
 FIG. 7B depicts an illustrative embodiment of another portion of a communication device;
 FIG. 8A depicts an illustrative embodiment of a portion of a multiple antenna communication device;
 FIGs. 8B-8F depict illustrative embodiments of components and configurations for use with the embodiment of FIG. 8A;
 FIGs. 9-16 depict illustrative embodiments of portions of communication devices;
 FIG. 17 depicts an exemplary method operating in portions of one or more of the devices of FIGS. 1-16;
 FIG. 18 depicts an illustrative embodiment of a look-up table utilized by one or more of the devices of FIGS. 1-16 and the method of FIG. 17; and
 FIG. 19 depicts an exemplary diagrammatic representation of a machine in the form of a computer system within which a set of instructions, when executed, may cause the machine to perform any one or more of the methodologies disclosed herein.

DETAILED DESCRIPTION

[0007] One or more of the exemplary embodiments described herein can have an antenna with a tunable element attached to the radiating elements of the antenna. The tunable element can be of various types, such as a Passive Tunable Integrated Circuit (PTIC) having one or more electrically tunable capacitors.

[0008] In one embodiment, the antenna can be directly tuned over frequency, moving the resonant frequency of the radiating element. By doing so, the magnitude of the VSWR that the antenna presents to the transceiver, can be adjusted, and can be kept within a range that is easier to match to the transceiver.

[0009] In another embodiment, on-antenna tuning can be combined with a tunable matching network such as positioned at a feed point of the antenna to achieve greater gains in total antenna efficiency as compared with uti-

lizing either of these tuning methods separately.

[0010] In one embodiment, the tunable element on the antenna can be tuned using an open loop methodology, such as tuning it strictly as a function of the band/frequency that the transceiver is operating in. In another embodiment, other criteria can also be used in combination with, or in place of, the band/frequency information, including mechanical configuration (slide up/down) or other use cases, and other inputs, such as proximity detector status and accelerometer position information. The use cases can vary and can include speaker phone operation, flip open and so forth.

[0011] In another embodiment, the tunable element on the antenna can be tuned to place the RF voltage present at a measuring component in proximity to the antenna, such as a detector, within a preset range. The range can be determined based on knowledge of the power being transmitted by the handset's transceiver, and can be used to establish the input impedance of the antenna within a range of Voltage Standing Wave Ratio (VSWR) that would allow a tunable matching network, such as coupled at a feed point of the antenna, to improve the impedance match between the antenna and the transceiver. This embodiment can incorporate two separate "loops" of a closed loop algorithm, allowing the tunable element of the antenna to be tuned in a closed loop algorithm utilizing feedback from a detector, and once that loop settled, then the tunable matching network can be tuned using information from a directional coupler and the detector.

[0012] Another embodiment can utilize information from a detector and a directional coupler in a combined closed loop algorithm. The algorithm can simultaneously adjust the tunable element(s) on the antenna and the tunable matching network while also increasing the RF voltage detected at the detector subject to the constraints on return loss and other figure of merit parameters determined by the directional coupler inputs. One or more of such algorithms are described in U.S. Patent No. 7,991,363 to Greene. By way of example, these algorithms can include applying, during a transmitter time slot, a continual tuning basis to move operation of a transmitter towards a target and when the receive time slot is activated adjusting to match for the receiver frequency. The adjustment to the receiver mode of operation may initially involve determining the current operating conditions and applying a translation for tuning of the various circuits. Another algorithm can utilize values for the tuned components set based on operational conditions and using a look-up table, such as initially setting tuning values by using a look-up table and then heuristically fine tuning, or heuristically determining on the fly during operation. For example, translations applied during the receiver operation can be determined empirically based on a design of the circuitry and/or testing and measurements of the operation of the circuit. Another technique is to apply an algorithm that operates to attain a target that is based on one or more transmitter related metrics (such as return

loss) and the values of the adjustable components to continuously attempt to maintain a compromised state of operation that keeps the operation of the transmitter and the receiver at a particular target FOM that represents a compromise performance metric level.

[0013] Another embodiment can utilize information obtained from a detector and/or a directional coupler using one or more of the methodologies described in U.S. Application Serial No. 13/005,122 to Greene. The methodologies can include using the derivatives or slopes of the RF voltages at the detectors responsive to changes in the control signals to the tunable elements. By way of example, the methodologies can include detecting first parameters associated with transmitting of a communication device, such as using a directional coupler connected between a front end module and a matching network of a transmit/receive antenna. Based on these first parameters or an analysis thereof, a range of impedances for an acceptable level of performance of the communication device can be established and a second set of parameters that can be utilized for tuning. For instance, a detector positioned at the input of the transmit/receive antenna can detect the second parameters, such as changes or increases in transmitted RF power. A target impedance within the range of impedances can be determined using the second parameters and the matching network for the transmit/receive antenna can be tuned based on the target impedance. For example, the methodology can continue to modify the matching network of the transmit/receive antenna to increase the detected RF voltage while constraining the return loss within a desired range. An offset can be applied for tuning of the antennas in the receive mode where the offset is based on the techniques described above, such as based on a translation where the frequency offset is known for the receive mode.

[0014] In yet another embodiment, detuning of a first antenna among a plurality of antennas can be performed in order to reduce coupling of the first antenna with one or more other antennas. The detuning of the first antenna can improve the performance of the one or more other antennas.

[0015] One embodiment of the present disclosure entails a tuning system for a communication device having an antenna, the tuning system includes at least one first tunable element connected with at least one radiating element of the antenna for tuning the antenna where the adjusting of the at least one first tunable element is based on at least one of a use case associated with the communication device and location information associated with the communication device, and a matching network having at least one second tunable element coupled at a feed point of the antenna, wherein the matching network receives control signals for adjusting the at least one second tunable element to tune the matching network.

[0016] One embodiment of the present disclosure entails a method including tuning an antenna of a commu-

nication device by adjusting at least one first tunable element of the communication device that is connected with at least one radiating element of the antenna where the adjusting of the at least one first tunable element is based on a use case associated with the communication device, and tuning a matching network of the communication device by adjusting at least one second tunable element of the matching network that is coupled between the antenna and a transceiver of the communication device, wherein the adjusting of the second tunable element is a closed loop process based on an operational parameter of the communication device.

[0017] One embodiment of the present disclosure entails a tuning system that includes a memory and a controller. The controller is programmed to receive antenna efficiency information associated with one or more antennas of a group of antennas of a communication device, receive antenna isolation information associated with one or more antennas of the group of antennas, and tune at least a portion of the group of antennas based on the antenna efficiency information and the antenna isolation information.

[0018] One embodiment of the present disclosure entails a tuning system for a communication device having an antenna. The tuning system includes at least one first tunable element connected with at least one radiating element of the antenna for tuning the antenna where the adjusting of the at least one first tunable element is based on a closed loop process, and a matching network having at least one second tunable element coupled at a feed point of the antenna for tuning the matching network based on an operational parameter of the communication device.

[0019] One embodiment of the present disclosure entails a method including tuning an antenna of a communication device utilizing a closed loop process by adjusting at least one first tunable element of the communication device that is connected with at least one radiating element of the antenna and tuning a matching network of the communication device by adjusting at least one second tunable element of the matching network that is coupled to a feed point of the antenna.

[0020] One embodiment of the present disclosure entails a tuning system for a communication device having an antenna with a Low Band (LB) radiating element and a High Band (HB) radiating element. The tuning system includes a plurality of first tunable elements, wherein at least one of the plurality of first tunable elements that is associated with the LB radiating element is tuned based on a desired Voltage Standing Wave Ratio (VSWR) associated with the antenna, and wherein at least another of the plurality of first tunable elements that is associated with the HB radiating element is tuned based on increasing attenuation of an undesired frequency. The tuning system also includes a matching network having at least one second tunable element coupled at a feed point of the antenna that is adjusted for tuning the matching network.

[0021] One embodiment of the present disclosure entails a method of tuning including determining, by a system having a processor, antenna efficiency information associated with one or more antennas of a group of antennas of a communication device that includes the system. The method can include determining, by the system, antenna isolation information associated with the one or more antennas of the group of antennas; and tuning, by the system, one or more matching network elements of the communication device based on the antenna efficiency information and the antenna isolation information.

[0022] One embodiment of the present disclosure entails a mobile communication device including a plurality of antennas; a matching network element; a transceiver; and a processor coupled with the plurality of antennas, the matching network element and the transceiver. The processor can determine antenna efficiency information associated with one or more antennas of the plurality of antennas. The processor can determine antenna isolation information associated with the one or more antennas of the plurality of antennas. The processor can tune the matching network element based on the antenna efficiency information and the antenna isolation information.

[0023] The exemplary embodiments can employ open loop tuning processes, such as at the on-antenna tunable element and/or at the matching network. The use cases can include a number of different states associated with the communication device, such as flip-open, flip-closed, slider-in, slider-out (e.g., Qwerty or numeric Keypad), speaker-phone on, speaker-phone off, hands-free operation, antenna up, antenna down, other communication modes on or off (e.g., Bluetooth/WiFi/GPS), particular frequency band, and/or transmit or receive mode. The use case can be based on object or surface proximity detection (e.g., a user's hand or a table). Other environmental effects can be included in the open loop process, such as temperature, pressure, velocity and/or altitude effects. The open loop process can take into account other information, such as associated with a particular location (e.g., in a building or in a city surrounded by buildings), as well as an indication of being out of range.

[0024] The exemplary embodiments can utilize combinations of open loop and closed loop processes, such as tuning a tunable element based on both a use case and a measured operating parameter (e.g., measured by a detector in proximity to the antenna and/or measured by a directional coupler between the matching network and the transceiver). In other examples, the tuning can utilize one process and then switch to another process, such as using closed loop tuning and then switching to open loop tuning based on particular factors associated with the communication device.

[0025] FIG. 1 depicts an exemplary embodiment of a communication device 100. The communication device 100 can comprise a wireless transceiver 102 (herein having independent transmit and receive sections and having one or more antennas 145 (two of which are shown

in this example)), a user interface (UI) 104, a power supply 114, and a controller 106 for managing operations thereof. The wireless transceiver 102 can utilize short-range or long-range wireless access technologies such as Bluetooth, WiFi, Digital Enhanced Cordless Telecommunications (DECT), or cellular communication technologies, just to mention a few. Cellular technologies can include, for example, CDMA-1X, WCDMA, UMTS/HSD-PA, GSM/GPRS, TDMA/EDGE, EV/DO, WiMAX, and next generation cellular wireless communication technologies as they arise.

[0026] The UI 104 can include a depressible or touch-sensitive keypad 108 with a navigation mechanism such as a roller ball, joystick, mouse, or navigation disk for manipulating operations of the communication device 100. The keypad 108 can be an integral part of a housing assembly of the communication device 100 or an independent device operably coupled thereto by a tethered wireline interface (such as a flex cable) or a wireless interface supporting for example Bluetooth. The keypad 108 can represent a numeric dialing keypad commonly used by phones, and/or a Qwerty keypad with alphanumeric keys. The UI 104 can further include a display 110 such as monochrome or color LCD (Liquid Crystal Display), OLED (Organic Light Emitting Diode) or other suitable display technology for conveying images to an end user of the communication device 100. In an embodiment where the display 110 is a touch-sensitive display, a portion or all of the keypad 108 can be presented by way of the display.

[0027] The power supply 114 can utilize common power management technologies (such as replaceable batteries, supply regulation technologies, and charging system technologies) for supplying energy to the components of the communication device 100 to facilitate portable applications. The controller 106 can utilize computing technologies such as a microprocessor and/or digital signal processor (DSP) with associated storage memory such as Flash, ROM, RAM, SRAM, DRAM or other like technologies.

[0028] The communication device 100 can utilize an on-antenna tuning element 150, which can be directly connected with the radiating element(s), including high band (HB) and low band (LB) radiating elements and/or a portion of the radiating elements. Tuning elements can be a number of components in a number of different configurations, including variable capacitors such as electrically tunable capacitors, although other tunable elements are also contemplated by the present disclosure including a semiconductor varactor, a micro-electro-mechanical systems (MEMS) varactor, a MEMS switched reactive element, a piezoelectric component or a semiconductor switched reactive element.

[0029] FIG. 2 depicts an illustrative embodiment of a portion of the wireless transceiver 102 of the communication device 100 of FIG. 1. In GSM applications, the transmit and receive portions of the transceiver 102 can include common amplifiers 201, 203 coupled to a tunable

matching network 202 and an impedance load 206 by way of a switch 204. The load 206 in the present illustration can be an antenna as shown in FIG. 1 (herein antenna 206). A transmit signal in the form of a radio frequency (RF) signal (TX) can be directed to the amplifier 201 which amplifies the signal and directs the amplified signal to the antenna 206 by way of the tunable matching network 202 when switch 204 is enabled for a transmission session. The receive portion of the transceiver 102 can utilize a pre-amplifier 203 which amplifies signals received from the antenna 206 by way of the tunable matching network 202 when switch 204 is enabled for a receive session. Other configurations of FIG. 2 are possible for other types of cellular access technologies such as CDMA. These undisclosed configurations are contemplated by the present disclosure.

[0030] FIGs. 3-4 depict illustrative embodiments of the tunable matching network 202 of the transceiver 102 of FIG. 2. In one embodiment, the tunable matching network 202 can comprise a control circuit 302 and a tunable reactive element 310. The control circuit 302 can comprise a DC-to-DC converter 304, one or more digital to analog converters (DACs) 306 and one or more corresponding buffers 308 to amplify the voltage generated by each DAC. The amplified signal can be fed to one or more tunable reactive components 504, 506 and 508 such as shown in FIG. 5, which depicts a possible circuit configuration for the tunable reactive element 310. In this illustration, the tunable reactive element 310 includes three tunable capacitors 504-508 and an inductor 502 with a fixed inductance. Other circuit configurations are possible, and thereby contemplated by the present disclosure.

[0031] The tunable capacitors 504-508 can each utilize technology that enables tunability of the capacitance of said component. One embodiment of the tunable capacitors 504-508 can utilize voltage or current tunable dielectric materials such as a composition of barium strontium titanate (BST). An illustration of a BST composition is the Parascan® Tunable Capacitor. In another embodiment, the tunable reactive element 310 can utilize semiconductor varactors. Other present or next generation methods or material compositions that can support a means for a voltage or current tunable reactive element are contemplated by the present disclosure.

[0032] The DC-to-DC converter 304 can receive a power signal such as 3 Volts from the power supply 114 of the communication device 100 in FIG. 1. The DC-to-DC converter 304 can use common technology to amplify this power signal to a higher range (e.g., 30 Volts) such as shown. The controller 106 can supply digital signals to each of the DACs 306 by way of a control bus of "n" or more wires to individually control the capacitance of tunable capacitors 504-508, thereby varying the collective reactance of the tunable matching network 202. The control bus can be implemented with a two-wire common serial communications technology such as a Serial Peripheral Interface (SPI) bus. With an SPI bus, the controller 106 can submit serialized digital signals to config-

ure each DAC in FIG. 3 or the switches of the tunable reactive element 404 of FIG. 4. The control circuit 302 of FIG. 3 can utilize common digital logic to implement the SPI bus and to direct digital signals supplied by the controller 106 to the DACs.

[0033] In another embodiment, the tunable matching network 202 can comprise a control circuit 402 in the form of a decoder and a tunable reactive element 404 comprising switchable reactive elements such as shown in FIG. 6. In this embodiment, the controller 106 can supply the control circuit 402 signals via the SPI bus which can be decoded with common Boolean or state machine logic to individually enable or disable the switching elements 602. The switching elements 602 can be implemented with semiconductor switches or micro-machined switches, such as utilized in micro-electromechanical systems (MEMS). By independently enabling and disabling the reactive elements (capacitor or inductor) of FIG. 6 with the switching elements 602, the collective reactance of the tunable reactive element 404 can be varied.

[0034] The tunability of the tunable matching networks 202, 204 provides the controller 106 a means to optimize performance parameters of the transceiver 102 such as, for example, but not limited to, transmitter power, transmitter efficiency, receiver sensitivity, power consumption of the communication device, a specific absorption rate (SAR) of energy by a human body, frequency band performance parameters, and so on.

[0035] FIG. 7A depicts an exemplary embodiment of a portion of a communication device 700 (such as device 100 in FIG. 1) having a tunable matching network which can include, or otherwise be coupled with, a number of components such as a directional coupler, RF detectors, control circuitry and/or a tuner. The tunable matching network can include various other components in addition to, or in place of, the components shown, including components described above with respect to FIGs. 1-6. In addition to the detector 701 coupled to the directional coupler 725, there is shown a detector 702 coupled to the RF line feeding the antenna 750. A tunable matching network 775 can be coupled to the antenna 750 and a transceiver 779 (or transmitter and/or receiver) for facilitating communication of signals between the communication device 700 and another device or system. In this exemplary embodiment, the tunable match can be adjusted using all or a portion of the detectors for feedback to the tuning algorithm.

[0036] Various algorithms can be utilized for adjusting the matching network 750, including utilizing Figures of Merit, which in this exemplary embodiment can be determined in whole or in part from measurements of the forward and reverse signals present at detector 701. This exemplary embodiment can also utilize detector 702 to further improve the ability of the tuning system to enable improved performance of the communication device. One embodiment of the algorithm can utilize the inputs from detector 701 to establish a maximum return loss or VSWR for the matching network. This method can es-

5 establish a range of impedances around the targeted impedance. This range of impedances may establish an acceptable level of performance. Input from detector 702 can then be utilized to allow the algorithm to find an improved or best impedance within that acceptable range. For instance, the algorithm could continue to modify the matching network 775 in order to increase the RF voltage detected at the antenna feed, while constraining the return loss (measured by detector 701) to stay within the target return loss. In this embodiment, communication device 700 can allow tuning for source impedances that are not 50 ohms. Additionally detector 702 allows the algorithm to minimize the insertion loss of the tunable match 775.

10 **[0037]** In another embodiment, the tuning algorithm can maintain the return loss while minimizing the current drain to determine desired tuning values. The tuning algorithm can utilize various parameters for tuning the device, including output power of the transmitter, return loss, received power, current drain and/or transmitter linearity.

15 **[0038]** Communication device 700 can include one or more radiating elements 755 of the antenna 750. One or more tunable elements 780 can be connected directly with one or more of the radiating elements 755 to allow for tuning of the antenna 750 in conjunction with tuning of the matching network 775. The tunable elements 780 can be of various types as described herein, including electrically tunable capacitors. The number and configuration of the tunable elements 780 can be varied based on a number of factors, including whether the tuning is an open loop or a closed loop process. In one embodiment, all of the radiating elements 755 have at least one tunable element 780 connected thereto to allow for tuning of the radiating element. In another embodiment, only a portion of the radiating elements 755 have a tunable element 780 connected thereto.

20 **[0039]** In one or more embodiments, an initial matching network stage input can be connected to a transmission line from the active-element portion of the radio where the output is the antenna feed point.

25 **[0040]** In one or more embodiments, the on-antenna tuning element can consist of a tunable reactive element such as a tunable capacitor (PTIC). The radiating element can consist of a segment of electrical conductor that is fed by the radio circuitry, and acts to create RF fields induced by the currents and voltage in the radiating element as well as the currents in the surrounding conductors near and within the same physical housing as the radiating element. In one or more embodiments, physically, the on-antenna element can either be placed in direct contact and on the same carrier substrate as the radiating element, or it could be connected to the radiating element by way of connector means being in close proximity (and electrically short) to the radiating element.

30 **[0041]** In one or more embodiments, the initial matching network stage can be placed proximally to the feed point or point where the RF circuitry (radio) is connected

to the radiating element, and can be electrically connected between the radio and the radiating element. Its purpose can be to match the impedance of the radiating element to that of the radio such that sufficient power is delivered to and from the radio from and to the base stations of the network the radio is communicating with, although the present disclosure contemplates the matching network being adjusted for other purposes as well.

[0042] Referring to FIG. 7B, in an exemplary embodiment that can be used with the device of FIG. 7A, the antenna 750 and/or the radiating element(s) 755 can be positioned on a carrier (e.g., a plastic carrier or substrate) that is coupled with, or otherwise connected to, a Printed Circuit Board (PCB) 740. The tunable element or device 780 (which in this example is a tunable capacitor) can be connected between a feed 741 and the antenna 750. The feed 741 can be coupled with an inductor 742 having a ground 743. In one embodiment, the inductor 742 can be one of a printed inductive trace or a chip inductor. In one embodiment, the antenna 750 can be coupled with the tunable element 780 of the PCB 740 via a spring contact 743.

[0043] The example PCB 740 can be utilized with multiple tunable devices at different points on the antenna(s). In this example, the tunable element 780 is not exposed to the user so as to reduce the risk of damage. The example of FIG. 7C can be used with various types of antennas and/or with various types of tunable elements. In this example, by placing the tunable element 780 and the inductor 742 on the PCB 740, the number of spring contacts can be reduced as compared to a system in which the tunable element and the inductor are separately positioned from the PCB. This example also facilitates and simplifies the manufacturing of the tunable element assembly. The PCB 740 provides for a more robust assembly, particularly with respect to dropping of a mobile communication device that utilizes the PCB 740.

[0044] In another exemplary embodiment, FIG. 8A depicts a portion of a communication device 800 (such as device 100 in FIG. 1) having tunable matching networks for use with a multiple antenna system. In this exemplary embodiment, there are two antennas, which are a transmit/receive antenna 805 and a diversity reception antenna 820. However, it should be understood that other numbers, types and/or configurations of antennas can be utilized with device 800. For instance, the antennas can be spatially diverse, pattern diverse, polarization diverse and/or adaptive array antennas. Tunable elements 880 can be connected with radiating elements or a portion thereof of the antenna 805. In another embodiment, tunable elements 880 can be connected with multiple antennas (not shown). Tunable elements 880 allow for tuning and/or detuning of one or more of the antennas, including in combination with the tuning of the matching networks 810 and/or 825.

[0045] In one or more embodiments, the antennas can be a group of antennas that are placed in a fashion to adequately isolate the antennas from each other in order

to allow them to deliver somewhat independent and uncorrelated signals to the radio. Their placement is determined by how they behave electrically (RF) in relation to each other. The particular number of antennas can vary.

[0046] In one embodiment, the antennas of communication device 800 can be part of a MIMO (multiple-input and multiple output) system. The multiple antennas can be utilized for improving communications, such as through switching or selecting techniques, including analyzing noise in the multiple signals and selecting the most appropriate signal. The multiple antennas can also be used with combining techniques where the signals can be added together, such as equal gain combining or maximal-ratio combining. Other techniques for utilizing multiple signals from multiple antennas are also contemplated by the exemplary embodiments, including dynamic systems that can adjust the particular techniques being utilized, such as selectively applying a switching technique and a combination technique. The particular position(s) of the antenna(s) can vary and can be selected based on a number of factors, including being in close enough proximity to couple RF energy with each other.

[0047] Communication device 800 can include a number of other components such as tunable matching networks which can include or otherwise be coupled with a number of components such as directional couplers, sensor ICs, bias control and other control ICs and tunable matching networks. The tunable matching networks can include various other components in addition to, or in place of the components shown, including components described above with respect to FIGs. 1-7. This example also includes a transceiver 850 of the communication device 800 that includes multiple receivers and/or transmitters for the multiple antennas 805 and 820 to serve the purpose of diversity reception.

[0048] In one embodiment, a first tunable matching network 810 can be coupled at the input to the transmit/receive antenna 805 and a second tunable matching network 825 can be coupled to the input to the diversity reception antenna 820. Both of these matching networks 810 and 825 can be adjusted (e.g., tuned) to improve performance of the communication device 800 in response to changes in bands, frequencies of operation, physical use cases and/or proximity of the antennas 805 and 820 to the user or other objects which can affect the impedances presented by the antennas to the Front End Module (FEM) 860 and transceiver 850. In one embodiment, the feedback line could be removed, such as by using the FEM to route these signals appropriately to perform these measurements (e.g., avoiding filtering out the signals).

[0049] Tunable matching network 810 can be adjusted using different methods and/or components. In one embodiment, a detector 830 can be coupled to the device 800 so as to detect RF voltage present at the connection to the diversity reception antenna 820. Received power levels at this point may be below -50 dBm. Some detectors, such as a diode detector or a logarithmic amplifier,

may not typically be adequate to detect such levels. However, since in this exemplary embodiment, the two antennas 805 and 820 are in the same device 800 and in proximity to each other, they can inherently couple RF energy from one antenna to the other. While the communication device 800 does not require this coupling, its presence can be utilized by the exemplary embodiments for the purposes of tuning the antenna matching networks. In one example, after establishing the tuning state for the diversity match at the transmit frequency, a predetermined relationship or offset can be applied to the matching network 825 in order to adjust the match to the receiver operating frequency.

[0050] Communication device 800 can include other components and configurations for determining, or otherwise measuring, parameters to obtain the desired tuning. Various configurations are illustrated in FIGS. 8B-8F. FIG. 8B illustrates a capacitive coupling configuration between the tunable matching network and the FEM. FIG. 8C illustrates a resistive coupling between the tunable matching network and the FEM for obtaining the desired parameters. The FEM 860 in the diversity path of the communication device 800 may be highly reflective at the transmission frequency. This can create a standing wave and the detector may be at a voltage minimum causing detection to be made more difficult for the capacitive and resistive couplings shown in FIGS. 8A and 8B. In FIG. 8D, a directional coupler can be utilized to sample only the forward power, which allows for obtaining the desired parameters despite the existence of any standing wave in the diversity path. FIGS. 8E and 8F utilize detectors, but sample multiple points along the path to avoid sampling at a voltage minimum.

[0051] In one embodiment, the tunable match on the transmit/receive antenna 805 can be tuned similar to the technique described above with respect to FIG. 7A but instead of using detector 815, detector 830 can be used to measure increases in transmitted RF power coupled to the diversity reception antenna 820. As such, detector 815 (shown in broken lines in FIG. 8A) can be removed from the device 800, thereby reducing the cost and complexity. Thus, this example would tune both antennas utilizing only one detector (e.g., detector 830) coupled with one of the antennas (e.g., the diversity reception antenna 820) and without another detector coupled to the other antenna. This example relies upon a fairly constant coupling coefficient between the two antennas at any particular band, frequency and use case, and for any operation of the algorithm these may all be considered constant.

[0052] In another embodiment, after tunable matching network 810 is adjusted by the algorithm, tunable matching network 825 can also be adjusted. By measuring the coupled transmitted power present at detector 830, the tunable matching network 825 can be adjusted to increase coupled transmitter power seen at detector 830. In one example, after establishing the tuning state for the diversity match at the transmit frequency, a predeter-

mined relationship or offset can be applied to the matching network 825 in order to adjust the match to the receiver operating frequency. For instance, the tuning circuits can be adjusted initially based on transmitter oriented metrics and then a predetermined relationship or offset can be applied to attain a desired tuning state for both transmitter and receiver operation. In another embodiment, the operational metric can be one or more of transmitter reflection loss, output power of the transmitter, current drain and/or transmitter linearity.

[0053] For example, in a time division multiplexed (TDM) system in which the transmitter and the receiver operate at different frequencies but only operate in their respective time slots (i.e., transmit time slot and receive time slot), this can be accomplished by identifying an optimal tuning for the transmitter and then adding an empirically derived adjustment to the tuning circuits in receive mode. As another example, in a frequency division multiplexed (FDM) system in which the transmitter and receiver operate simultaneously and at different frequencies, this can be accomplished by identifying a target operation for the transmitter, and then adjusting the tuning circuits first to the target value for the transmitter and then adjusting the values to approach a compromised value proximate to an equal or desired target value for the receiver. In one embodiment, a predetermined relationship, (e.g., an offset, scaling factor, translation or other change or modification) can be applied to the adjustments of the variable components when switching from the transmit mode to the receive mode. This translation can be a function of the values obtained while adjusting during the transmit time slot. The translation can then be removed upon return to the transmitter mode and the adjustment process is resumed. In one embodiment, because any frequency offset between the transmit signal and the receive signal is known, an adjustment or modification of the setting of the matching network in the form of a translation or some other function can be applied to the matching network during the receive time slot. In another embodiment, the adjustment can be performed in multiple steps if the transmission and reception frequencies are far apart.

[0054] In another embodiment, a Figure of Merit can be utilized that not only incorporates the transmit metrics, but also incorporates an element to attain a compromise between optimal transmitter and optimal receiver operation. This can be accomplished by identifying a target operation goal, such as a desired transmitter and receiver reflection loss and then identifying an operational setting that is a close compromise between the two. This embodiment thus can incorporate not only transmitter metrics but also tuning circuit settings or preferences into the algorithm. The tuning preferences can be empirically identified to ensure the desired operation.

[0055] In one embodiment where the communication device 800 employs antenna diversity for receive operation but does not employ antenna diversity for transmit operation, antenna 820 would be receive only. The trans-

ceiver can transmit on antenna 805 and can receive on both antennas 805 and 820. For adaptive closed loop tuning of the tunable matching network 825 on the diversity antenna, the communication device 800 can obtain a metric indicating the performance of the tunable matching circuit at the receive frequency. The metric can be used to tune the match to adjust the performance at the receive frequency. This can be done by measuring the level of the received signal using the receiver in the transceiver IC. This measurement is known as RSSI, received signal strength indicator. An RSSI measurement can be very noisy and unstable due to highly variable impairments in the propagation channel, such as fading. These variations can be filtered using averaging. However, the amount of averaging necessary could make such a measurement prohibitively slow and not suitable as feedback for closed loop antenna tuning.

[0056] In this embodiment, the transmit signal is moderately coupled to the tunable match in the diversity path because the main antenna and the diversity antenna are located on the same communications device. The main antenna and the diversity antenna may only have 20dB isolation in many cases. The transmit signal present at tunable match 825 may be a much stronger and more stable signal than the receive signal present at tunable matching network 825. The transmit signal can be used to make reliable measurements that can be used for closed loop tuning.

[0057] The transmit signal can be measured using detector 830. The detector can be placed between the tunable match and the transceiver. This is effectively the output of the tunable match. A directional coupler is not necessary for this measurement in this embodiment, and capacitive or resistive coupling may be used, as long as the detector has sufficient dynamic range. Other components and configurations of the components can also be utilized for the parameter detection, such as shown in U.S. Patent Publication No. 20090039976 by McKinzie, including the use of a multi-port RF matching network with a diplexer for signal routing among ports, a voltage divider with a diode detector, a resistive voltage divider using a multi-pole RF switch, a shunt RF branch having a series string of capacitors that enables tapping into various nodes along the string, a bias driving circuit for providing a bias signal to a reactive element, and so forth.

[0058] In this embodiment, maximizing the output voltage of a tunable match can be the equivalent to minimizing insertion loss, and for a lossless network it can be equivalent to minimizing mismatch loss. An alternative to using detector 830 is to use the receiver itself (tuned to the transmit frequency) to measure the transmit signal. These are a few viable methods for measuring the transmit signal through the diversity tunable match. Other forms of signal detection are contemplated by the present disclosure.

[0059] A complication with using the transmit signal for tuning can be that it is at a different frequency than the receive signal and the objective of the tunable match in

the diversity path is to adjust performance at the receive frequency. In one exemplary method, the tunable matching circuit is adjusted for reception performance based on transmission measurements. In this exemplary method, a tunable match can be optimized at the transmit frequency using measurements on the transmit signal and then the matching circuit can be adjusted using a predetermined relationship between the transmit settings and the receive settings to provide the desired performance at the receive frequency.

[0060] In one embodiment that utilizes a tunable matching network which contains two tunable capacitors, one set of tuning values, designated (C1TX, C2TX), can be applied only during the measurement of the transmit signal. The other set of tuning values, designated (C1RX, C2RX), can be applied in between the transmit slots, or just during the receive time slots allowing for alternate tuning during a slot which may be used to monitor other base stations or other networks. This embodiment describes two tunable capacitors, but this exemplary embodiment can apply to various numbers and types of tunable elements. In this embodiment, the Rx tuning values are a function of the Tx tuning values. As the Tx values adaptively change throughout the iterative algorithm, the Rx values will also change, tracking the Tx values with a predetermined relationship. If the figure of merit is set to maximize V_{out} , the Tx solution can converge at (C1TXopt, C2TXopt), and can be appropriately adjusted using the predetermined relationship to (C1RXopt, C2RXopt) to achieve the desired RX performance.

[0061] Each time the tunable match is set to (C1TX, C2TX) in order to perform a Tx measurement, the performance at the Rx frequency may be degraded during the time that (C1TX, C2TX) is applied. It is desirable in this embodiment to perform the measurement as quickly as possible to minimize the Rx degradation caused by Tx tuning during the measurement. In one embodiment, the Tx values can be applied for less than one percent of the time while still achieving adequate convergence time.

[0062] In one embodiment, the relationship between the TX and RX tuning solutions can be dependent upon the bands of operation, and in the case where the receiver is tuned to monitor signals in an alternate band, then an alternate tuning solution (C1RX2, C2RX2) can be applied during that measurement.

[0063] Another exemplary method for controlling the tuning can be employed, which does not require setting the tunable capacitors to values optimized for transmission while performing the Tx measurement. The objective is to operate the tuning matching network at settings that optimize Rx performance. These settings are at capacitance values that are a specific amount away from the Tx optimum in a specific direction. An algorithm can be utilized that will find this location in the capacitance plane without first needing to find the Tx optimum. The Tx level can change based on a number of circumstances, such as from power control commands in the transceiver or

from variations in supply voltage, temperature, component tolerances, and so forth. In this embodiment, since only measurement of the output RF voltage of the tuner is being performed, a determination may not be made as to whether the algorithm is at the Tx optimum or a specific amount away from the Tx optimum because the Tx level is changing. This may prevent the use of an algorithm that simply targets a specific Tx signal level.

[0064] A metric that can be useful in determining where the tuning matching network is operating relative to the Tx optimum is to utilize the slope, or derivative of the Tx level with respect to the value or setting of the tunable capacitors (or other types of tunable elements). If the RF voltage (V_{out}) present at the output of the tunable match at the TX frequency is determined, such as through use of a log detector, then the first derivatives are $dV_{out}/dC1$ and $dV_{out}/dC2$. These derivatives can be calculated using the finite difference of two sequential measurements. These slopes will be a function of the tunable capacitors. These slopes will not be a function of the absolute power level of the Tx signal since a log detector is being utilized. If a log detector or its equivalent is not utilized, the logarithm of the Tx voltage can be calculated prior to calculating the slope. By defining a Figure of Merit that includes $dV_{out}/dC1$ and $dV_{out}/dC2$, the algorithm can converge to a solution that is a specific amount away from the Tx optimum in a specific direction, in this case near the Rx optimum. In this embodiment, a log detector is a device having a logarithmic response.

[0065] In some cases, specifying the slopes alone will not result in a unique solution (i.e., there may be multiple solutions). The algorithm can resolve this situation by adding a PTC preference to the Figure of Merit. A tunable match may have many solutions that meet a Tx RL goal and a PTC preference can be included in the Figure of Merit to identify a solution that not only meets the Tx RL goal but also meets an Rx performance goal. Similarly, a tunable match may have many solutions that meet a slope criteria and a PTC preference can be included in the Figure of Merit to identify a solution that not only meets the slope criteria but also meets an Rx performance goal.

[0066] In cases where using dV_{out} alone results in multiple solutions, it is also possible to use the second derivative to resolve these cases. For example, second derivatives ($d^2V_{out}/dC2dC1$) can be utilized, which is $dV_{out}/dC2$ differentiated with respect to $C1$. Specifying $dV_{out}/dC2$ and $d^2V_{out}/dC2dC1$ can identify the correct or desired Rx solution from the multiple solutions. This exemplary method can include determining derivative information (e.g., one or more of a first derivative, and/or a second derivative, and/or etc.) associated with the RF voltage based on derivatives of the RF voltage and the variable capacitance values, and tuning the tunable matching network using the derivative information.

[0067] Another exemplary embodiment can use detector 830 of the communication device 800 in the diversity path as feedback to adjust tunable matching network 810 on the main antenna 805. The tunable matching network

810 coupled with the main antenna has both transmit and receive signals, and can be optimized for Tx performance, Rx performance, and Duplex performance. For the Tx solution, V_{out} can be maximized. For the Rx solution and the Duplex solution, dV_{out} can be included in the Figure of Merit. A PTC preference may be required to identify the optimal Rx solution but is not required to identify the optimal duplex solution. , return loss, received power, current drain or transmitter linearity

[0068] In one or more exemplary embodiments, the Figure of Merit may be constructed such that when it equals a certain value, or is minimized or maximized, the desired tuner settings are achieved. The Figure of Merit may be used with a number of different optimization algorithms. For example, a more exhaustive approach may be used that evaluates the Figure of Merit at every combination of capacitor values. Other suitable algorithms can also be utilized, including a simplex algorithm, a binary search algorithm, and/or a gradient algorithm.

[0069] In another embodiment, communication device 800 can tune antennas 805 and 820 without using detectors 815 and 830. The tunable matching network 810 can be adjusted using several different methods. After the tunable matching network 810 is adjusted, the tunable matching network 825 can be adjusted. By monitoring the detector 801 coupled to the directional coupler 875, the diversity match tuning state can be determined which adjusts the tunable matching network 825 to the transmit frequency. If significant coupling between the two antennas 805 and 820 is assumed, and by monitoring the return loss of the transmit/receive match while adjusting the diversity reception antenna 820 match during transmitting, the diversity match tuning state can be determined which tunes the diversity reception antenna 820 to the transmit frequency. This tuning state can minimize the return loss at the transmit frequency as measured at the directional coupler 875. After finding this tuning state the tunable matching network 825 can then be adjusted (e.g., offset) appropriately for the receive frequency.

[0070] In another embodiment depicted in FIG. 9, communication device 900 includes tunable element 902 for tuning antenna 901. The tuning can be in an open-loop manner, such as based on frequency and/or use case. Tunable element 902 can be adjusted such that the antenna VSWR is in a range that can be reasonably matched by tunable matching network 908.

[0071] Tunable element 902 can be adjusted in an open-loop manner to maximize rejection or attenuation at an unwanted frequency while maintaining the VSWR at the fundamental frequency in the range that can be reasonably matched by the tunable matching network 908. The unwanted frequency may be a harmonic or an interferer. Matching network 908 can be tuned in a closed-loop manner, such as based on operational parameter(s) collected from detector 903 and/or directional coupler 905 having forward and reverse detectors 906, 907 positioned between the matching network 908 and the transceiver 909.

[0072] In another embodiment depicted in FIG. 10, communication device 1000 includes tunable element 1002 for tuning antenna 1001 in an open-loop manner based on frequency and/or use case. Tunable element 1002 can be tuned such that the antenna VSWR is in the range that can be reasonably matched by tunable matching network 1008, and the on-antenna tuning can maximize rejection or attenuation at an unwanted frequency while maintaining a VSWR at the fundamental frequency in the range that can be reasonably matched by tunable matching network 1008. The tunable matching network can be tuned based on metrics gathered from detector 1003 without utilizing measurements from any measuring device in between the matching network and the transceiver 1009.

[0073] In another embodiment depicted in FIG. 11, communication device 1100 includes tunable element 1102 for tuning antenna 1101 in a closed loop manner while also tuning the matching network 1108 in a closed-loop manner. A directional coupler 1105 having forward and reverse detectors 1106, 1107 can be connected between the matching network 1108 and a transceiver 1109 for obtaining operational parameter(s) for performing the closed loop tuning of element(s) 1102 and matching network 1108. Tuning can be performed in this embodiment without obtaining measurements from a measuring component in proximity to the antenna.

[0074] In another embodiment depicted in FIG. 12, communication device 1200 includes tunable element 1202 for tuning antenna 1201 in a closed loop manner based on maintaining the RF voltage present at detector 1203 in a preset range relative to the transmit power. This can establish an antenna impedance that is in the range that can be reasonably matched by tunable matching network 1208. Matching network 1208 can be tuned in a closed loop manner based on operational parameter(s) obtained using directional coupler 1205 having forward and reverse detectors 1206, 1207 coupled with the device 1200 between the matching network and the transceiver 1209.

[0075] In another embodiment depicted in FIG. 13, communication device 1300 includes tunable element 1302 for tuning antenna 1301 in a closed loop manner based on the RF voltage obtained at detector 1303, such as maintaining the RF voltage in a preset range relative to the transmit power. Matching network 1308 can be tuned in a closed loop manner based on operational parameter(s) obtained using detector 1303 without obtaining measurements from any measuring components coupled between the matching network 1308 and the transceiver 1309.

[0076] In another embodiment depicted in FIG. 14, communication device 1400 includes tunable element 1402 for tuning antenna 1401 in a closed loop manner by placing the antenna VSWR detected using directional coupler 1410 with forward and reverse detectors 1411, 1412 in a preset range. This will establish an antenna VSWR that is in the range which can then be reasonably

matched by tunable matching network 1408. Within the acceptable range of the antenna VSWR, the solution can be biased using a tuning preference for on-antenna element 1402 to achieve a second criteria. Matching for the element 1402 can be performed at the Rx frequency and/or based on achieving linearity. The matching network 1408 can be tuned in a closed loop manner based on operational parameter(s) obtained from the directional coupler 1405 having forward and reverse detectors 1406, 1407 positioned between the matching network and the transceiver 1409.

[0077] In another embodiment depicted in FIG. 15, communication device 1500 includes tunable element 1502 for tuning antenna 1501 in a closed loop manner by placing the antenna VSWR detected using directional coupler 1510 with forward and reverse detectors 1511, 1512 in a preset range. This will establish an antenna VSWR that is in the range which can then be reasonably matched by tunable matching network 1508. Within the acceptable range of the antenna VSWR, the solution can be biased using a tuning preference for on-antenna tunable element 1502 to achieve a second criteria. Matching for the element 1502 can be performed at the Rx frequency and/or based on achieving linearity. The matching network 1508 can be tuned in a closed loop manner based on operational parameter(s) obtained from the detector 1503 coupled in proximity to the antenna 1501 without obtaining measurements from any measuring component positioned between the matching network and the transceiver 1509.

[0078] In another embodiment depicted in FIG. 16, communication device 1600 includes an antenna 1601 that includes two radiating elements which cover different frequency ranges, tunable element 1602 and tunable element 1610 for tuning antenna 1601. Tunable element 1602 can primarily affect a first frequency range or band and tunable element 1610 can primarily affect the second frequency range or band of the antenna 1601. Tunable element 1602 can be adjusted in an open-loop manner based on frequency and/or use case. Tunable element 1602 can be adjusted such that the antenna VSWR as determined or otherwise estimated from metrics of the detector 1603 and with knowledge of the transmitter output power is in a range that can be reasonably matched by tunable matching network 1608. Tunable element 1610 can be adjusted in an open-loop manner to maximize rejection or attenuation at an unwanted frequency while maintaining a VSWR at the fundamental frequency in the range that can be reasonably matched by tunable matching network 1608. The unwanted frequency may be a harmonic, such as in the High Band, while the fundamental (TX & RX) frequencies can be in the Low Band. Matching network 1608 can be tuned in a closed loop manner utilizing operational parameter(s) obtained from the directional coupler 1605 having forward and reverse detectors 1606, 1607 coupled between the matching network and the transceiver 1609.

[0079] Another embodiment provides for tuning one or

more of the antennas of a communication device. In a multiple antenna system, simply maximizing the over the air efficiency of all the antennas may not accomplish the best overall performance of the communication system. The isolation or de-correlation between antennas in a small handset can also be a key parameter in defining the overall performance in certain instances. A control method that considers the efficiency of both antennas and the isolation between them can be advantageous. For example, in an antenna diversity system, the antennas can be tuned so as to reduce coupling between the antennas without degrading the efficiency of either antenna, or to degrade efficiency minimally such that overall system performance is enhanced. Thus, even for closely spaced antennas in a handheld mobile application, the coupling may be reduced or otherwise kept to a minimum in spite of antenna proximity. Other parameters other than antenna cross-coupling may also be optimized to improve overall performance of the system, such as in a MIMO system where there can be simultaneously multiple output antennas and multiple input antennas.

[0080] FIG. 17 depicts an exemplary method 1700 operating in portions of one or more of the devices of FIGS. 1-16. Method 1700 can be utilized with communication devices of various configurations, including multiple antenna devices. Method 1700 can begin with step 1702 by detecting one or more parameters of the communication device, such as parameters associated with transmitting that are obtained through use of measuring components including a detector and/or a directional coupler. The number and positioning of the measuring components can vary and can be in proximity to the antenna and/or between a matching network and a transceiver.

[0081] In step 1704, it can be determined whether there are multiple on-antenna tuning elements. If there are more than one such tuning elements then in step 1706 tuning elements associated with a radiating element(s) can be tuned based on a desired VSWR at a frequency of operation. In step 1708, tuning elements associated with another radiating element(s) can be tuned based on a different factor, such as a rejection or attenuation of an unwanted frequency. If on the other hand, there is only one on-antenna tuning element and/or the tuning elements are only connected with one of the radiating elements of the antenna then method 1700 can proceed to step 1710 where the on-antenna tuning element(s) is tuned using an open loop and/or closed loop process. The open loop process can utilize various factors to determine tuning, including use case, operating frequency, proximity information accelerometer/position information, and so forth. The closed loop process can utilize various factors to determine tuning, including RF voltage, return loss, received power, current drain and/or transmitter linearity

[0082] In step 1712, tuning can be performed utilizing the matching network. The tuning of the matching network can be an open loop and/or closed loop process, including using one or more of the factors described

above with respect to the open and closed loop processes that can tune the on-antenna tuning elements. The timing of the tuning utilizing the matching network can vary, including being performed simultaneously with tuning of the on-antenna tuning elements, after tuning of the on-antenna tuning elements and/or before tuning of the on-antenna tuning elements. Method 1700 can be an iterative process that tunes the on-antenna tuning elements and/or the matching network.

[0083] In one embodiment, the tuning of the matching network(s) can be performed in combination with look-up tables such as shown in FIG. 18. For instance, one or more desirable performance characteristics of a communication device 100 can be defined in the form of Figures of Merits (FOMs), the communication device can be adapted to find a range of tuning states that achieve the desired FOMs by sweeping a mathematical model in fine increments to find global optimal performance with respect to the desired FOMs. In one embodiment, look-up table 1800 can be indexed (e.g., by the controller 106 of the communication device 100 of FIG. 1) during operation according to band and/or use case.

[0084] From the foregoing descriptions, it would be evident to an artisan with ordinary skill in the art that the aforementioned embodiments can be modified, reduced, or enhanced without departing from the scope and spirit of the claims described below. For example, detector 830 may include a directional coupler for the diversity antenna to compensate for out-of-band impedance of the Rx filter that may create a very high standing wave on the feed line and put voltage nulls at unpredictable places on the line (including at the base of the antenna).

[0085] In another embodiment, combinations of open and closed loop processes can be utilized for tuning of one or more of the tunable elements of the antenna and/or the matching network. For instance, a tunable element of the antenna can be tuned in part with a closed loop process based on an operational parameter of the communication system and in part with an open loop process based on a use case and/or location information of the communication device. In another embodiment, the use of closed loop and open loop processes can be alternated or otherwise arranged in being applied to a particular tunable element, such as initially applying an open loop process but then later applying a closed loop process, including switching from an open loop to a closed loop process based on operational parameters of the communication device. In another embodiment, the matching network can be tuned in whole or in part using an open loop process, such as based on a use case provided in a look-up table and/or based on location information associated with the communication device.

[0086] The exemplary embodiments can employ open loop tuning processes, such as at the on-antenna tunable element and/or at the matching network. The use cases can include a number of different states or status associated with the communication device, such as flip-open, flip-closed, slider-in, slider-out (e.g., Qwerty or numeric

Keypad), speaker-phone on, speaker-phone off, hands-free operation, antenna up, antenna down, other communication modes on or off (e.g., Bluetooth/WiFi/GPS), particular frequency band, and/or transmit or receive mode. The use case can be based on object or surface proximity detection (e.g., a user's hand or a table). Other environmental effects can be included in the open loop process, such as temperature, pressure, velocity and/or altitude effects. The open loop process can take into account other information, such as associated with a particular location (e.g., in a building or in a city surrounded by buildings), as well as an indication of being out of range. The exemplary embodiments can utilize combinations of open loop and closed loop processes, such as tuning a tunable element based on both a use case and a measured operating parameter (e.g., measured by a detector in proximity to the antenna and/or measured by a directional coupler between the matching network and the transceiver). In other examples, the tuning can utilize one process and then switch to another process, such as using closed loop tuning and then switching to open loop tuning based on particular factors associated with the communication device. The use case can be based on the knowledge of transmitter power level setting and receiver received signal strength, current drain, accelerometer direction/orientation, and any other information that is available within the device (e.g., a handset, tablet, or other wireless communication device) indicative of operating modes or use case.

[0087] In one embodiment, Low Band (LB) radiating element(s) and High Band (HB) radiating element(s) can be utilized with the antenna, where at least one tunable element is associated with the LB radiating element is tuned based on a desired Voltage Standing Wave Ratio (VSWR) associated with the antenna, and wherein at least another tunable elements that is associated with the HB radiating element is tuned based on a different performance metric. The different performance metric can be based on attenuation of an undesired frequency. As an example, the undesired frequency can be a harmonic frequency or can be associated with an interferer.

[0088] Methodologies and/or components that are described herein with respect to tuning of one tunable element can also be utilized with respect to tuning of other tunable elements. For example, derivative information utilized for tuning the matching network can be used for tuning of on-antenna tunable elements.

[0089] Other suitable modifications can be applied to the present disclosure. Accordingly, the reader is directed to the claims for a fuller understanding of the breadth and scope of the present disclosure.

[0090] FIG. 19 depicts an exemplary diagrammatic representation of a machine in the form of a computer system 1900 within which a set of instructions, when executed, may cause the machine to perform any one or more of the methodologies discussed above. In some embodiments, the machine operates as a standalone device. In some embodiments, the machine may be con-

nected (e.g., using a network) to other machines. In a networked deployment, the machine may operate in the capacity of a server or a client user machine in server-client user network environment, or as a peer machine in a peer-to-peer (or distributed) network environment.

[0091] The machine may comprise a server computer, a client user computer, a personal computer (PC), a tablet PC, a laptop computer, a desktop computer, a control system, a network router, switch or bridge, or any machine capable of executing a set of instructions (sequential or otherwise) that specify actions to be taken by that machine. It will be understood that a device of the present disclosure includes broadly any electronic device that provides voice, video or data communication. Further, while a single machine is illustrated, the term "machine" shall also be taken to include any collection of machines that individually or jointly execute a set (or multiple sets) of instructions to perform any one or more of the methodologies discussed herein.

[0092] The computer system 1900 may include a processor 1902 (e.g., a central processing unit (CPU), a graphics processing unit (GPU, or both), a main memory 1904 and a static memory 1906, which communicate with each other via a bus 1908. The computer system 1900 may further include a video display unit 1910 (e.g., a liquid crystal display (LCD), a flat panel, a solid state display, or a cathode ray tube (CRT)). The computer system 1900 may include an input device 1912 (e.g., a keyboard), a cursor control device 1914 (e.g., a mouse), a disk drive unit 1916, a signal generation device 1918 (e.g., a speaker or remote control) and a network interface device 1920.

[0093] The disk drive unit 1916 may include a machine-readable medium 1922 on which is stored one or more sets of instructions (e.g., software 1924) embodying any one or more of the methodologies or functions described herein, including those methods illustrated above. The instructions 1924 may also reside, completely or at least partially, within the main memory 1904, the static memory 1906, and/or within the processor 1902 during execution thereof by the computer system 1900. The main memory 1904 and the processor 1902 also may constitute machine-readable media.

[0094] Dedicated hardware implementations including, but not limited to, application specific integrated circuits, programmable logic arrays and other hardware devices can likewise be constructed to implement the methods described herein. Applications that may include the apparatus and systems of various embodiments broadly include a variety of electronic and computer systems. Some embodiments implement functions in two or more specific interconnected hardware modules or devices with related control and data signals communicated between and through the modules, or as portions of an application-specific integrated circuit. Thus, the example system is applicable to software, firmware, and hardware implementations.

[0095] In accordance with various embodiments of the present disclosure, the methods described herein are in-

tended for operation as software programs running on a computer processor. Furthermore, software implementations can include, but not limited to, distributed processing or component/object distributed processing, parallel processing, or virtual machine processing can also be constructed to implement the methods described herein.

[0096] The present disclosure contemplates a machine readable medium containing instructions 1924, or that which receives and executes instructions 1924 from a propagated signal so that a device connected to a network environment 1926 can send or receive voice, video or data, and to communicate over the network 1926 using the instructions 1924. The instructions 1924 may further be transmitted or received over a network 1926 via the network interface device 1920.

[0097] While the machine-readable medium 1922 is shown in an example embodiment to be a single medium, the term "machine-readable medium" should be taken to include a single medium or multiple media (e.g., a centralized or distributed database, and/or associated caches and servers) that store the one or more sets of instructions. The term "machine-readable medium" shall also be taken to include any medium that is capable of storing, encoding or carrying a set of instructions for execution by the machine and that cause the machine to perform any one or more of the methodologies of the present disclosure.

[0098] The term "machine-readable medium" shall accordingly be taken to include, but not be limited to: solid-state memories such as a memory card or other package that houses one or more read-only (non-volatile) memories, random access memories, or other re-writable (volatile) memories; magneto-optical or optical medium such as a disk or tape; and/or a digital file attachment to e-mail or other self-contained information archive or set of archives is considered a distribution medium equivalent to a tangible storage medium. Accordingly, the disclosure is considered to include any one or more of a machine-readable medium or a distribution medium, as listed herein and including art-recognized equivalents and successor media, in which the software implementations herein are stored.

[0099] Although the present specification describes components and functions implemented in the embodiments with reference to particular standards and protocols, the disclosure is not limited to such standards and protocols. Each of the standards for Internet and other packet switched network transmission (e.g., TCP/IP, UDP/IP, HTML, HTTP) represent examples of the state of the art. Such standards are periodically superseded by faster or more efficient equivalents having essentially the same functions. Accordingly, replacement standards and protocols having the same functions are considered equivalents.

[0100] The illustrations of embodiments described herein are intended to provide a general understanding of the structure of various embodiments, and they are not intended to serve as a complete description of all the

elements and features of apparatus and systems that might make use of the structures described herein. Many other embodiments will be apparent to those of skill in the art upon reviewing the above description. Other embodiments may be utilized and derived therefrom, such that structural and logical substitutions and changes may be made without departing from the scope of this disclosure. Figures are also merely representational and may not be drawn to scale. Certain proportions thereof may be exaggerated, while others may be minimized. Accordingly, the specification and drawings are to be regarded in an illustrative rather than a restrictive sense.

[0101] Such embodiments of the inventive subject matter may be referred to herein, individually and/or collectively, by the term "invention" merely for convenience and without intending to voluntarily limit the scope of this application to any single invention or inventive concept if more than one is in fact disclosed. Thus, although specific embodiments have been illustrated and described herein, it should be appreciated that any arrangement calculated to achieve the same purpose may be substituted for the specific embodiments shown. This disclosure is intended to cover any and all adaptations or variations of various embodiments. Combinations of the above embodiments, and other embodiments not specifically described herein, will be apparent to those of skill in the art upon reviewing the above description.

[0102] The present disclosure further includes the following aspects:

1. A method of tuning, comprising: determining, by a system having a processor, antenna efficiency information associated with one or more antennas of a group of antennas of a communication device that includes the system; determining, by the system, antenna isolation information associated with the one or more antennas of the group of antennas; and tuning, by the system, one or more matching network elements of the communication device based on the antenna efficiency information and the antenna isolation information.
2. The method of aspect 1, wherein the one or more matching network elements may be directly connected with at least one radiating element of at least a portion of the group of antennas.
3. The method of aspect 1, wherein the communication device may comprise a multiple-input and multiple-output (MIMO) system, and wherein the group of antennas may be utilized by the MIMO system for providing communication services.
4. The method of aspect 1, wherein the tuning of the one or more matching network elements may include tuning based on a use case associated with the communication device.
5. The method of aspect 4, wherein tuning parameters for the use case may be obtained from a look-up table stored in a memory of the communication device.

6. The method of aspect 4, wherein the use case may comprise at least one of an earpiece speaker status, a speakerphone status, a headset status, or a slider status.

7. The method of aspect 4, wherein the use case may comprise position information obtained from at least one of an accelerometer or a proximity detector of the communication device.

8. The method of aspect 1, wherein the one or more matching network elements may be coupled to a feed point of the group of antennas.

9. The method of aspect 1, wherein the tuning of the one or more matching network elements may be based on an operational parameter for the communication device.

10. The method of aspect 9, wherein the operational parameter may be obtained using a directional coupler and may be obtained during transmission by a transceiver of the communication device.

11. The method of aspect 1, wherein the tuning of the one or more matching network elements may comprise a closed loop process, wherein the one or more matching network elements may be directly connected with a Low Band (LB) radiating element and a High Band (HB) radiating element of at least a portion of the group of antennas, wherein at least one of the one or more matching network elements that may be associated with the LB radiating element may be tuned based on a desired Voltage Standing Wave Ratio (VSWR), and wherein at least another of the one or more matching network elements that may be associated with the HB radiating element may be tuned based on a different performance metric.

12. The method of aspect 11, wherein the different performance metric may be based on attenuation of an undesired frequency, and wherein the undesired frequency may be associated with one of a harmonic frequency or an interferer.

13. The method of aspect 1, wherein the tuning of the one or more matching network elements may be based on derivative information associated with a detected RF voltage of the communication device.

14. A mobile communication device, comprising: a plurality of antennas; a matching network element; a transceiver; and a processor coupled with the plurality of antennas, the matching network element and the transceiver, wherein the processor determines antenna efficiency information associated with one or more antennas of the plurality of antennas, wherein the processor determines antenna isolation information associated with the one or more antennas of the plurality of antennas, and wherein the processor tunes the matching network element based on the antenna efficiency information and the antenna isolation information.

15. The mobile communication device of aspect 14, wherein the communication device may comprise a

multiple-input and multiple-output (MIMO) system, and wherein the group of antennas may be utilized by the MIMO system for providing communication services.

16. The mobile communication device of aspect 14, wherein the matching network element may be directly connected with at least one radiating element of at least a portion of the plurality of antennas.

17. The mobile communication device of aspect 14, wherein the matching network element may be coupled to a feed point of the antenna.

18. The mobile communication device of aspect 14, wherein the matching network element may be a plurality of matching network elements that may include first and second matching network elements, wherein the first matching network element may be directly connected with at least one radiating element of at least a portion of the plurality of antennas, and wherein the second matching network element may be coupled to a feed point of the plurality of antennas.

19. A tuning system comprising: one or more matching network elements; and a controller coupled with the one or more matching network elements, wherein the controller determines antenna efficiency information associated with one or more antennas of a group of antennas of a communication device, wherein the controller determines antenna isolation information associated with the one or more antennas, and wherein the controller tunes the one or more matching network elements for at least a portion of the group of antennas based on the antenna efficiency information and the antenna isolation information.

20. The tuning system of aspect 19, wherein the one or more matching network elements may be directly connected with at least one radiating element of the at least a portion of the group of antennas being tuned.

21. The tuning system of aspect 19, wherein the communication device may comprise a multiple-input and multiple-output (MIMO) system, and wherein the group of antennas may be utilized by the MIMO system for providing communication services.

22. The tuning system of aspect 19, wherein the controller detunes a first antenna among the group of antennas thereby reducing coupling of the first antenna with one or more other antennas of the group of antennas.

[0103] The Abstract is provided with the understanding that it will not be used to interpret or limit the scope or meaning of the claims. In addition, in the foregoing Detailed Description, it can be seen that various features are grouped together in a single embodiment for the purpose of streamlining the disclosure. This method of disclosure is not to be interpreted as reflecting an intention that the claimed embodiments require more features than are expressly recited in each claim. Rather, as the following claims reflect, inventive subject matter lies in less

than all features of a single disclosed embodiment. Thus the following claims are hereby incorporated into the Detailed Description, with each claim standing on its own as a separately claimed subject matter.

Claims

1. A communication device (1600) comprising:

an antenna (1601) with a first radiating element covering a first frequency range and a second radiating element covering a second frequency range different from the first frequency range, a tunable matching network (1608) connected to the antenna (1601),
 a first tunable element (1602) for tuning the antenna (1601) connected with the first radiating element, wherein the communication device (1600) is configured to tune the first tunable element (1602) based on a desired Voltage Standing Wave Ratio VSWR,
 a second tunable element (1610) for tuning the antenna (1601) connected with the second radiating element, wherein the communication device (1600) is configured to tune the second tunable element (1610) based on an attenuation of an undesired frequency.

2. The communication device (1600) of claim 1, wherein the undesired frequency is at least one of a harmonic frequency and a frequency associated with an interferer.

3. The communication device (1600) of any one of the preceding claims, wherein the communication device (1600) is configured to tune the tunable matching network (1608) in a closed loop manner utilizing an operational parameter obtained from a directional coupler (1605) coupled between the tunable matching network (1608) and a transceiver (1609), wherein the directional coupler has a forward detector (1606) and a reverse detector (1607).

4. The communication device (1600) of any one of the preceding claims, wherein the communication device (1600) is configured to tune the first tunable element (1602) based on the desired VSWR such that a transmitter output power is in a range that can be matched by the tunable matching network (1608).

5. The communication device (1600) of any one of the preceding claims, wherein the communication device (1600) is configured to tune the second tunable element (1610) based on the attenuation of the undesired frequency in an open-loop manner to maximize attenuation at the unwanted frequency while maintaining the VSWR at a fundamental frequency

in a range that can be matched by tunable matching network (1608).

6. The communication device (1600) of any one of the preceding claims, wherein the desired VSWR is estimated from metrics of a detector (1603) and with knowledge of the transmitter output power.

7. The communication device (1600) of any one of the preceding claims, wherein the communication device (1600) is configured to tune the first tunable element (1602) in an open-loop manner based on a use case, wherein the use case comprises position information obtained from at least one of an accelerometer or a proximity detector of the communication device (1600).

8. A method of tuning, comprising:

providing an antenna (1601) with a first radiating element covering a first frequency range and a second radiating element covering a second frequency range different from the first frequency range,
 connecting a tunable matching network (1608) to the antenna (1601),
 connecting a first tunable element (1602) for tuning the antenna (1601) with the first radiating element,
 tuning the first tunable element (1602) based on a desired Voltage Standing Wave Ratio VSWR,
 connecting a second tunable element (1610) for tuning the antenna (1601) with the second radiating element, and
 tuning the second tunable element (1610) based on an attenuation of an undesired frequency.

9. The method of claim 8, wherein the undesired frequency is at least one of a harmonic frequency and a frequency associated with an interferer.

10. The method of claim 8 or 9 comprising tuning the tunable matching network (1608) in a closed loop manner utilizing an operational parameter obtained from a directional coupler (1605) coupled between the tunable matching network (1608) and a transceiver (1609), wherein the directional coupler has a forward detector (1606) and a reverse detector (1607).

11. The method any one of claims 8 to 10 comprising tuning the first tunable element (1602) based on the desired VSWR such that a transmitter output power is in a range that can be matched by the tunable matching network (1608).

12. The method any one of claims 8 to 11 comprising tuning the second tunable element (1610) based on

the attenuation of the undesired frequency in an open-loop manner to maximize attenuation at the unwanted frequency while maintaining the VSWR at a fundamental frequency in a range that can be matched by tunable matching network (1608). 5

13. The method any one of claims 8 to 12 comprising estimating the desired VSWR from metrics of a detector (1603) and with knowledge of the transmitter output power. 10

14. The method any one of claims 8 to 13 comprising tuning the first tunable element (1602) in an open-loop manner based on a use case, wherein the use case comprises position information obtained from at least one of an accelerometer or a proximity detector of the communication device (1600). 15

15. A machine-readable medium storing instructions for causing a processor (1902) of a communication device (1600) to perform any one of the methods of claim 8 to 15. 20

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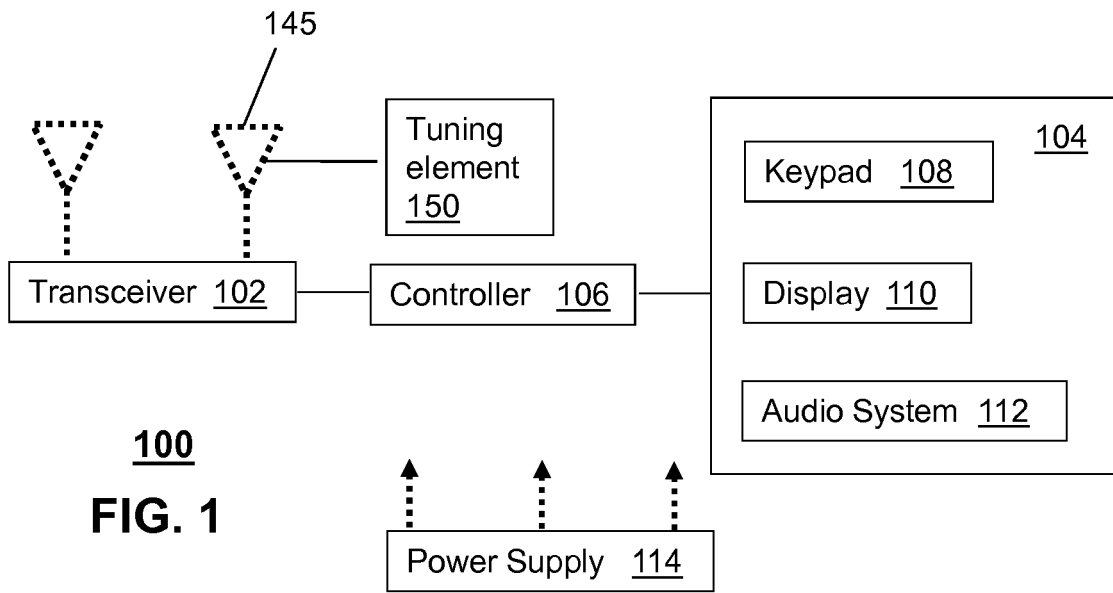
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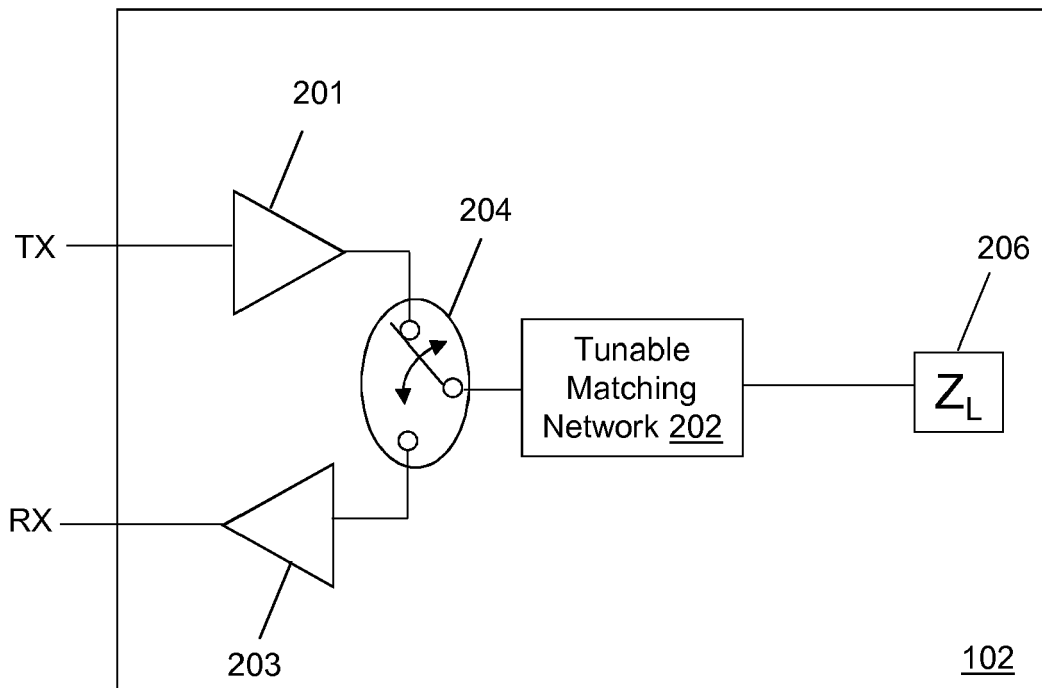
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100
FIG. 1



200
FIG. 2

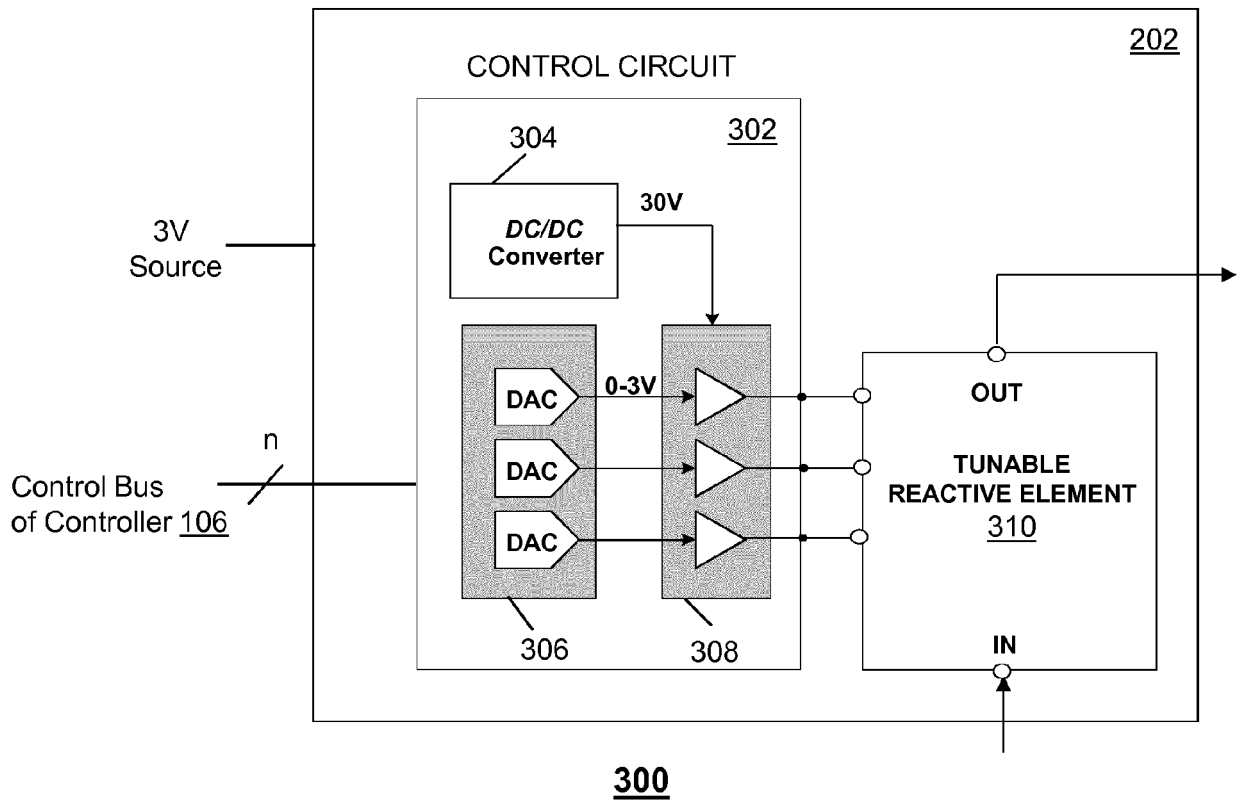


FIG. 3

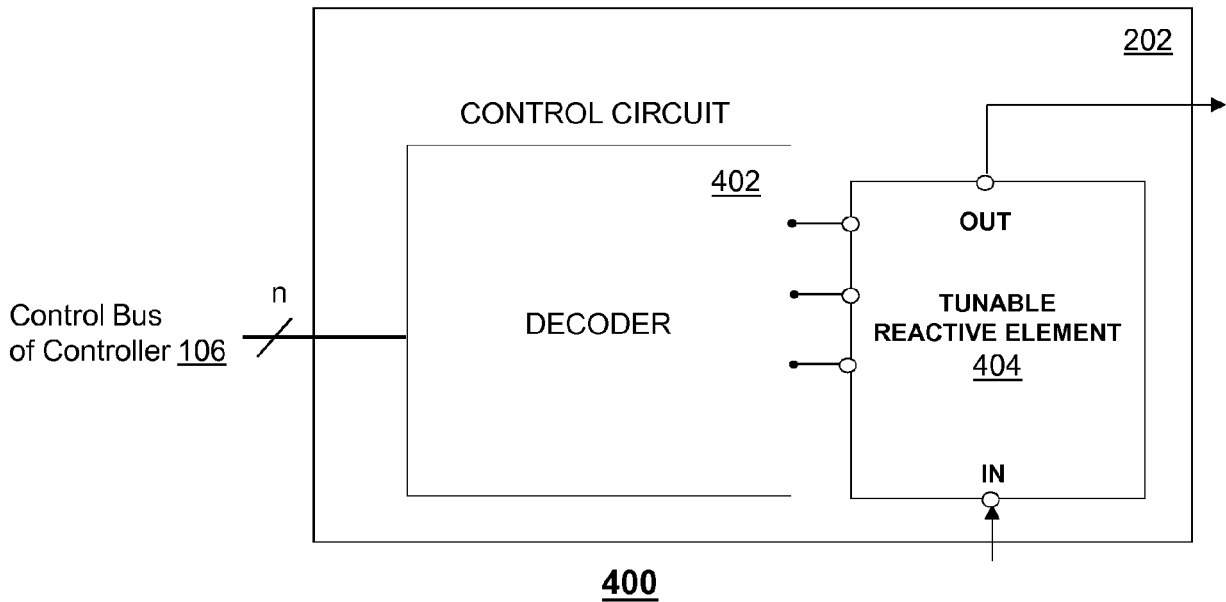
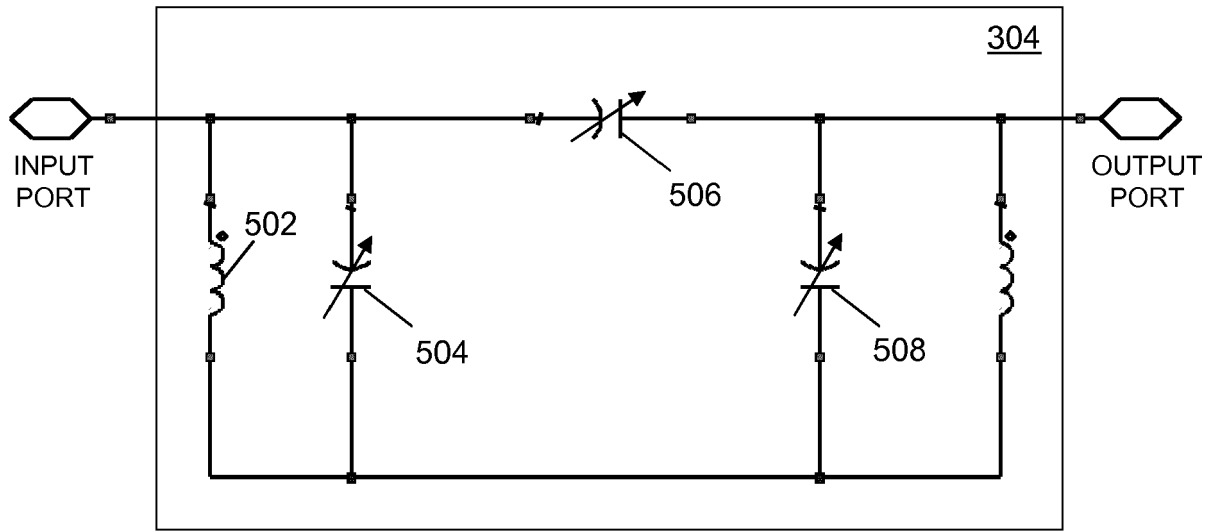
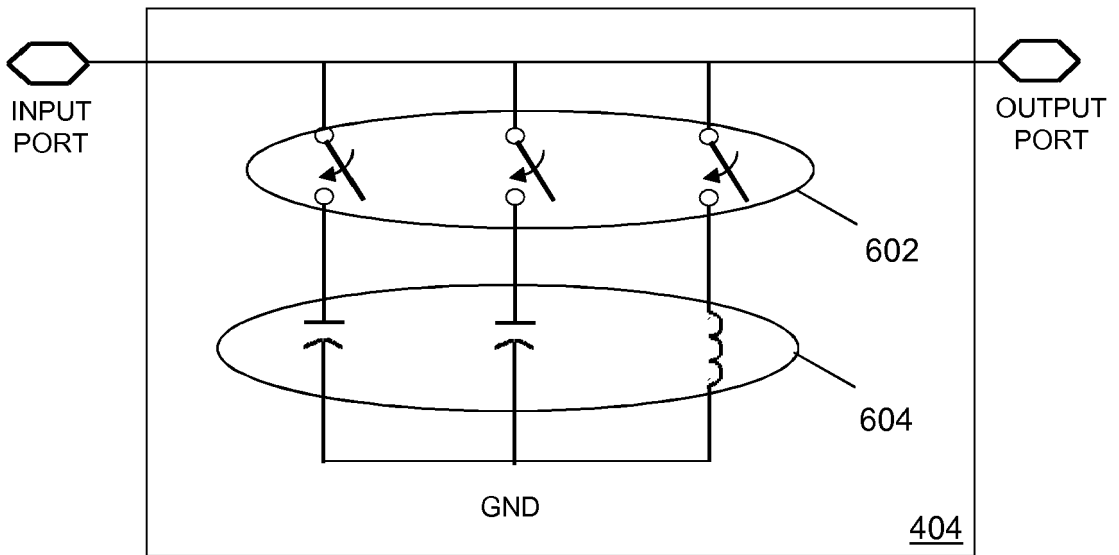


FIG. 4



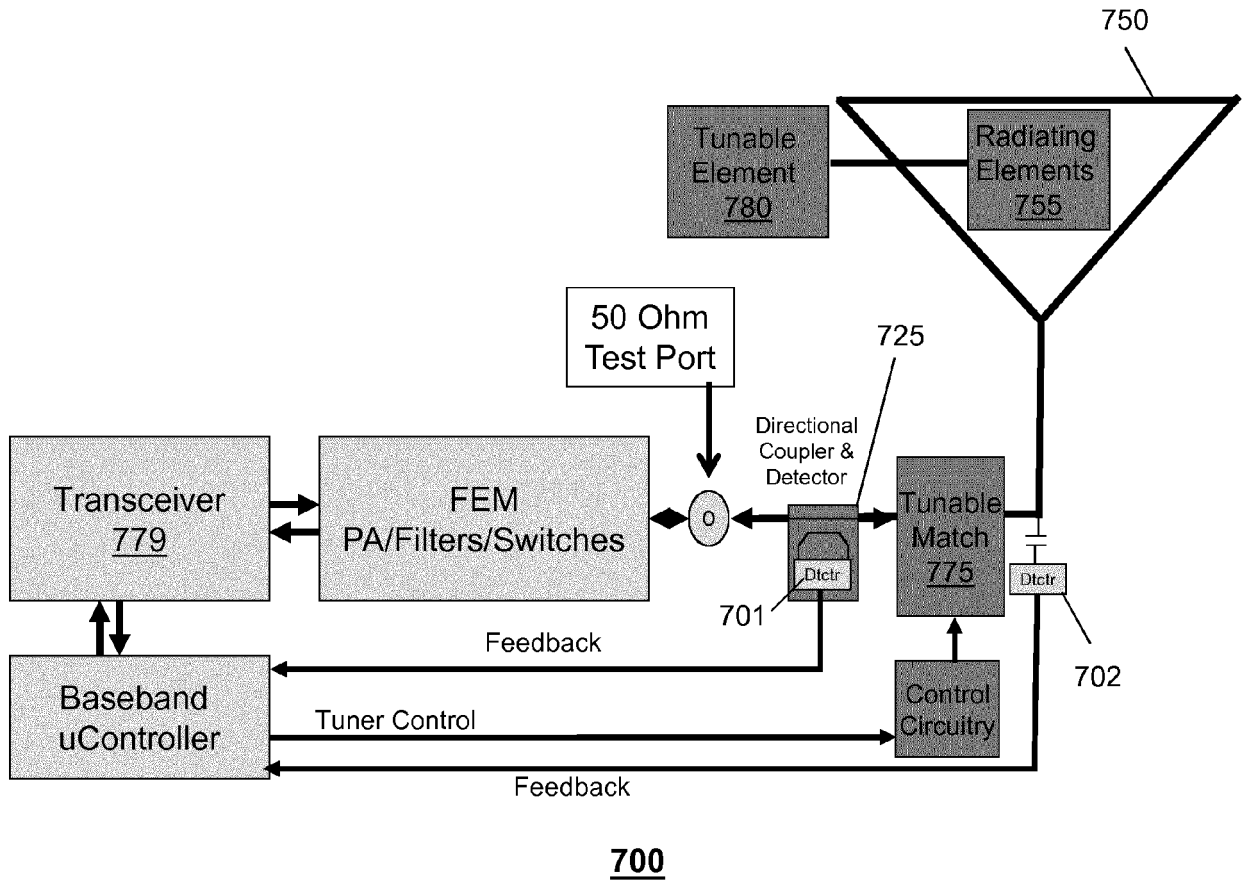
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FIG. 5



600

FIG. 6



700
FIG. 7A

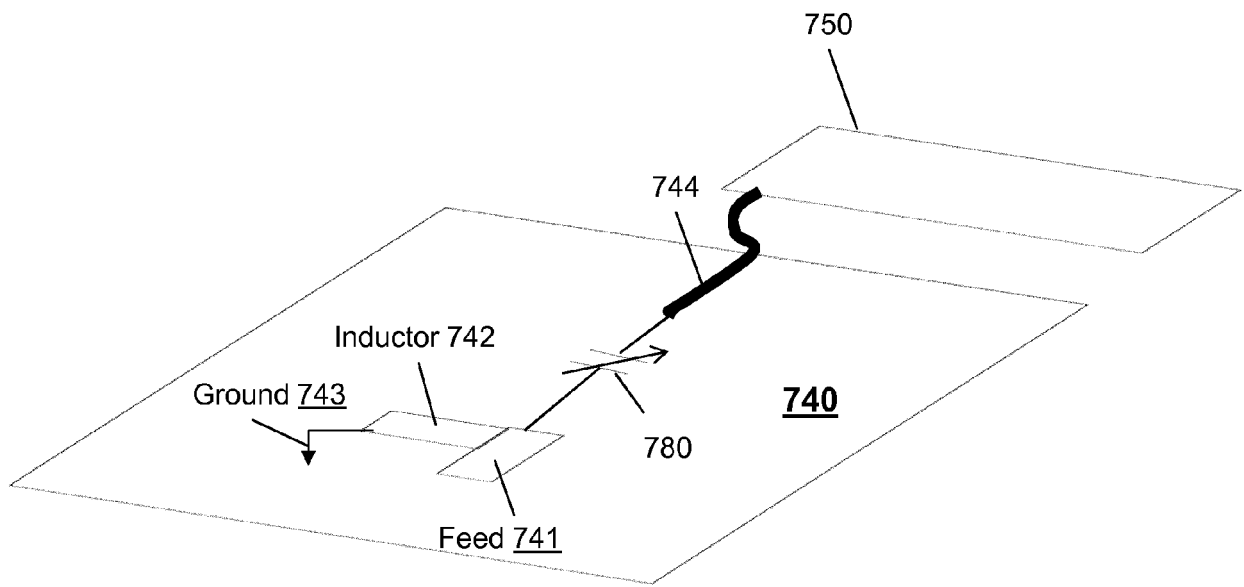


FIG. 7B

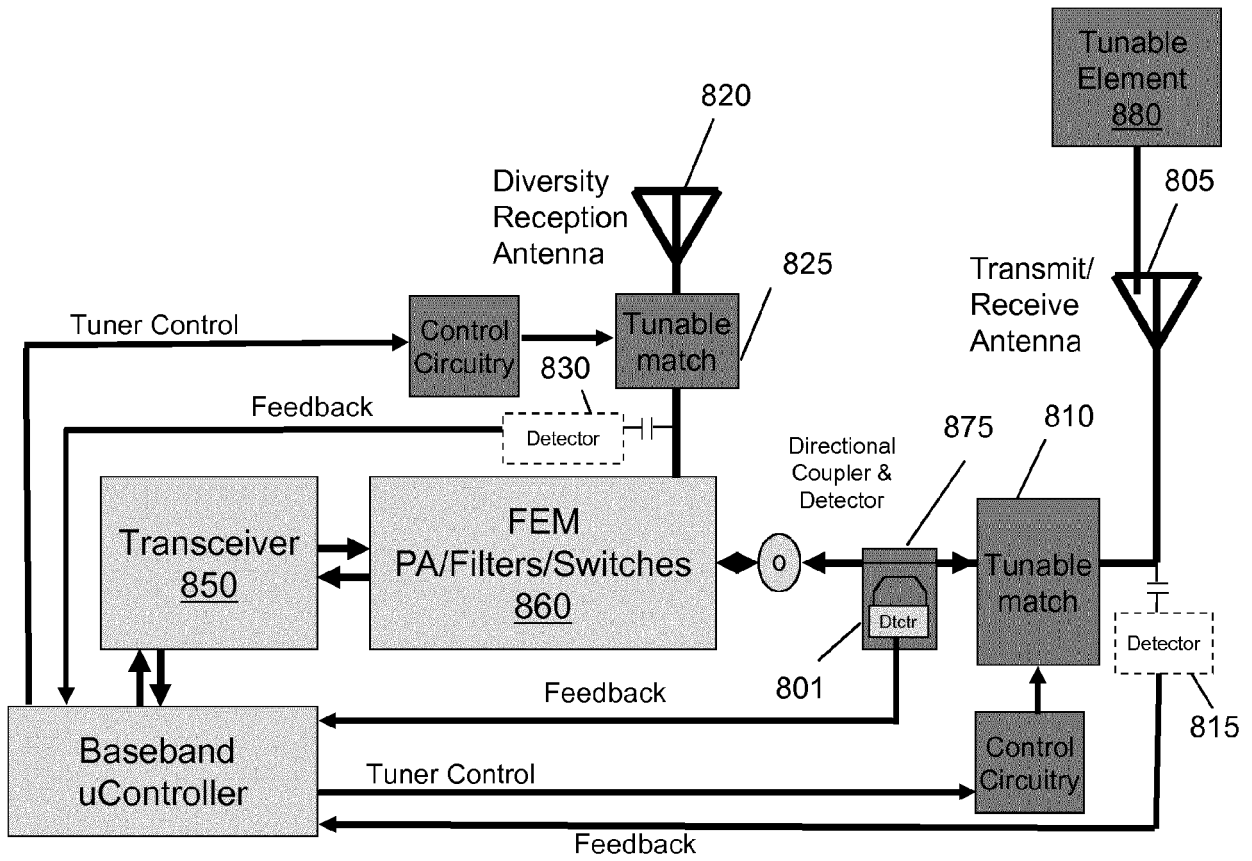


FIG. 8A

800

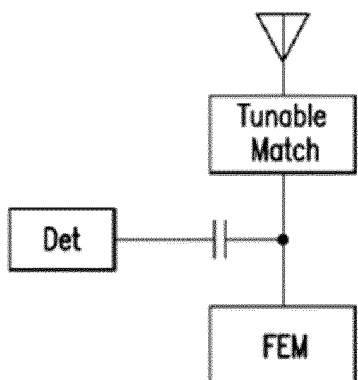


FIG. 8B

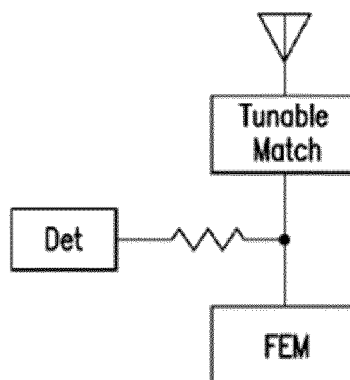


FIG. 8C

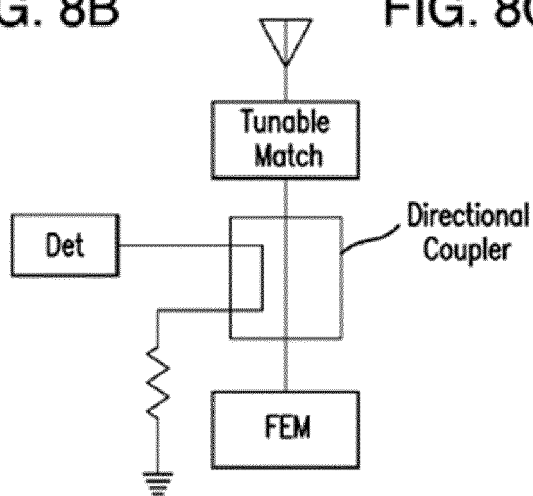


FIG. 8D

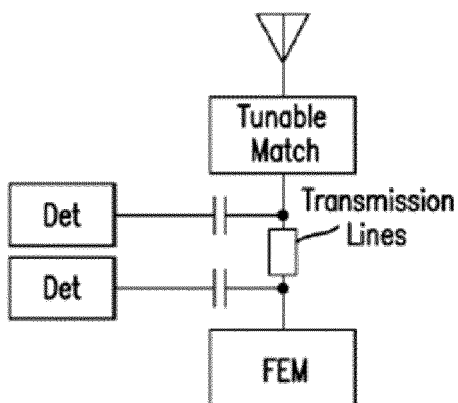


FIG. 8E

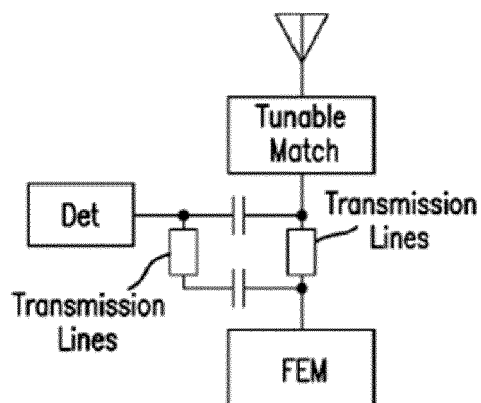


FIG. 8F

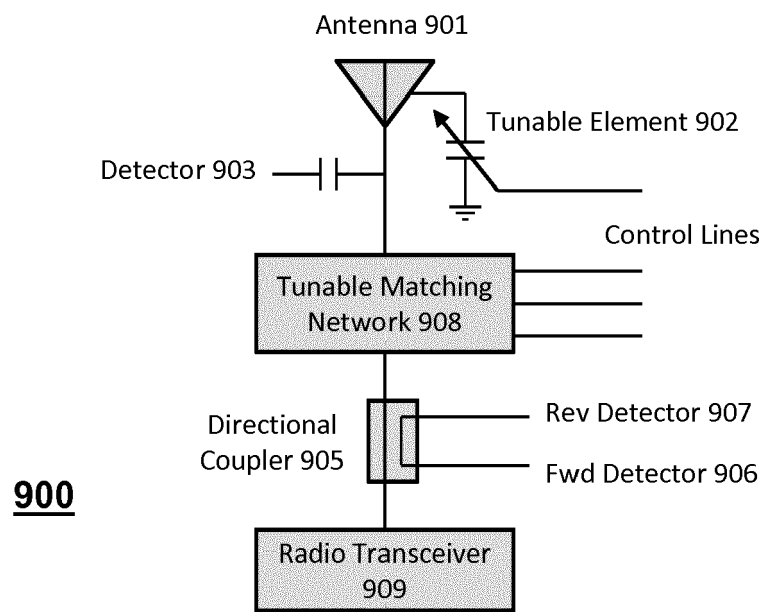
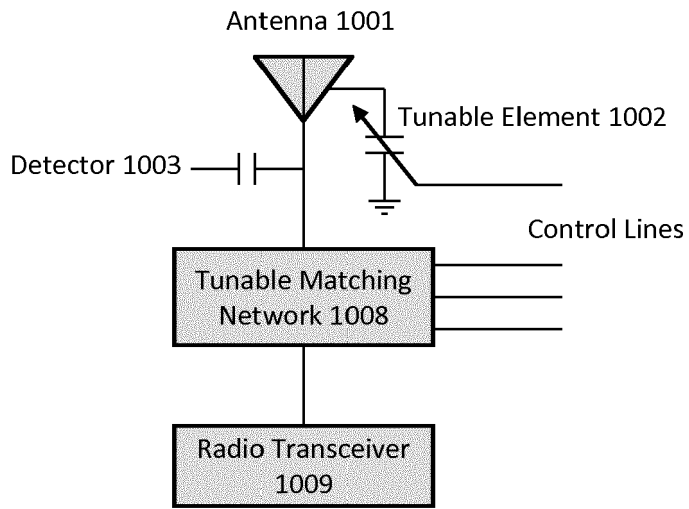
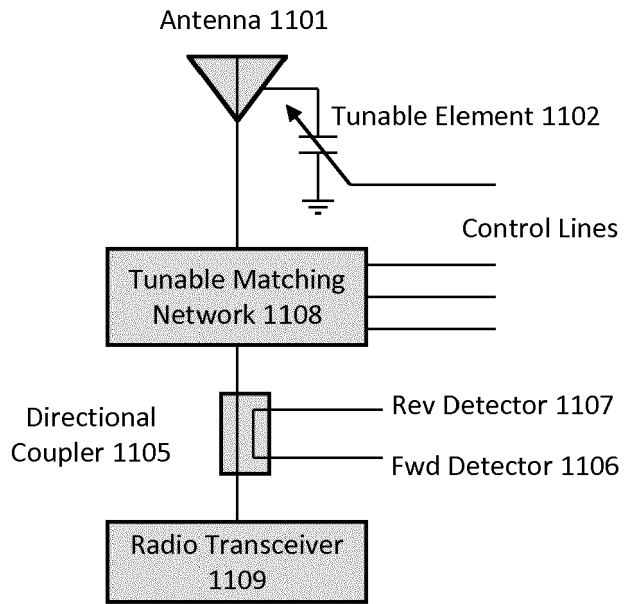


FIG. 9



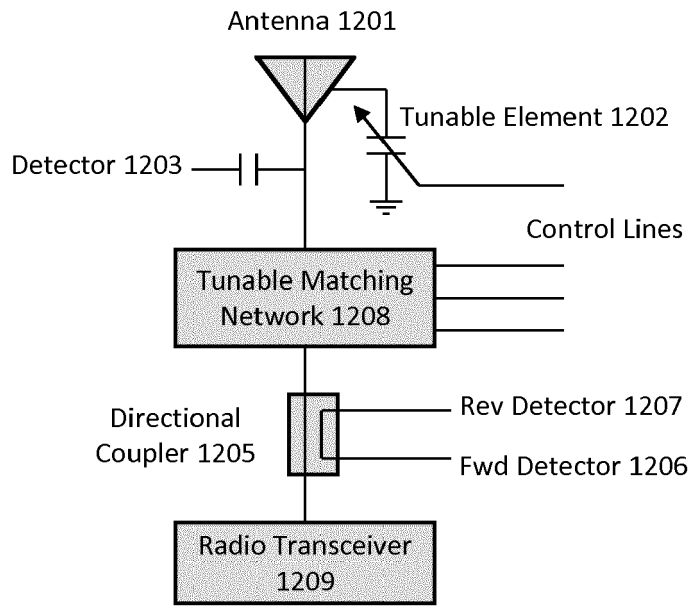
1000

FIG. 10



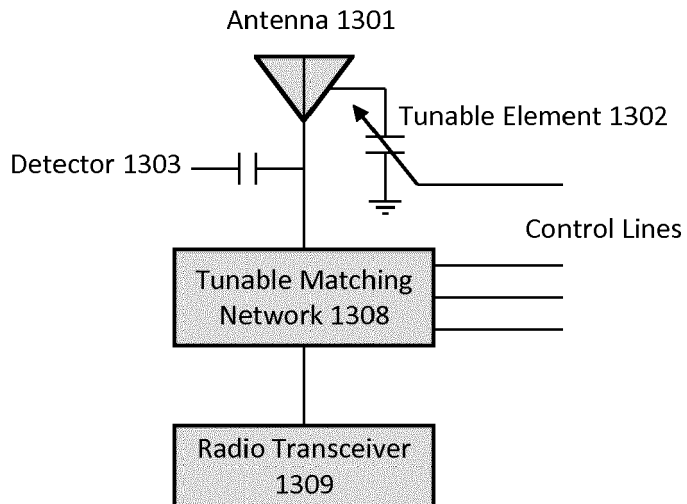
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FIG. 11



1200

FIG. 12



1300

FIG. 13

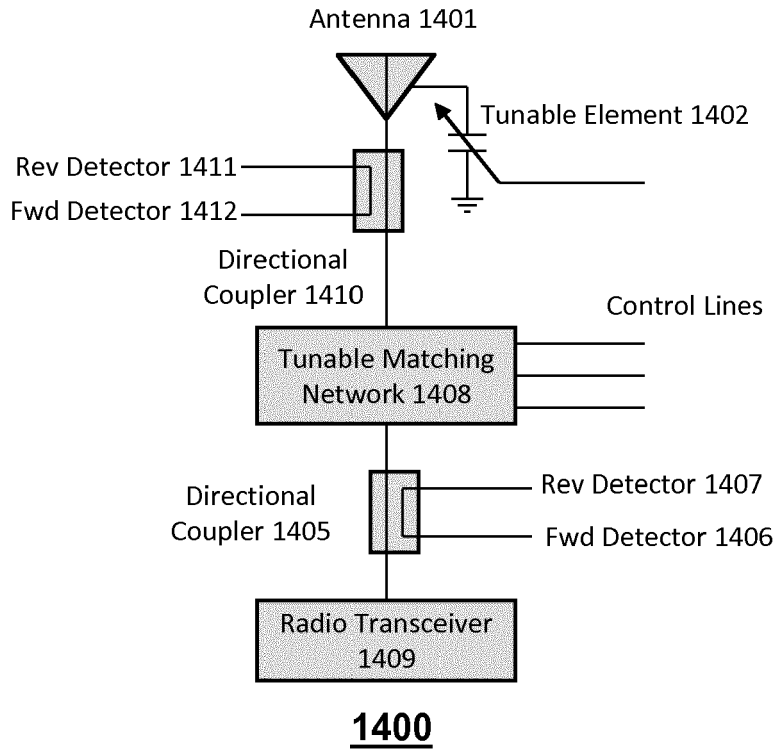


FIG. 14

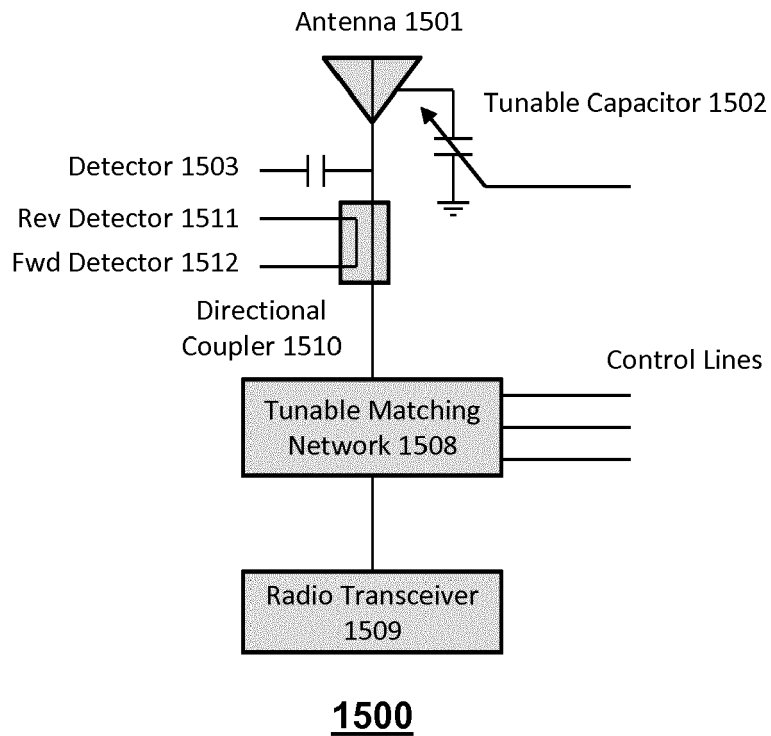
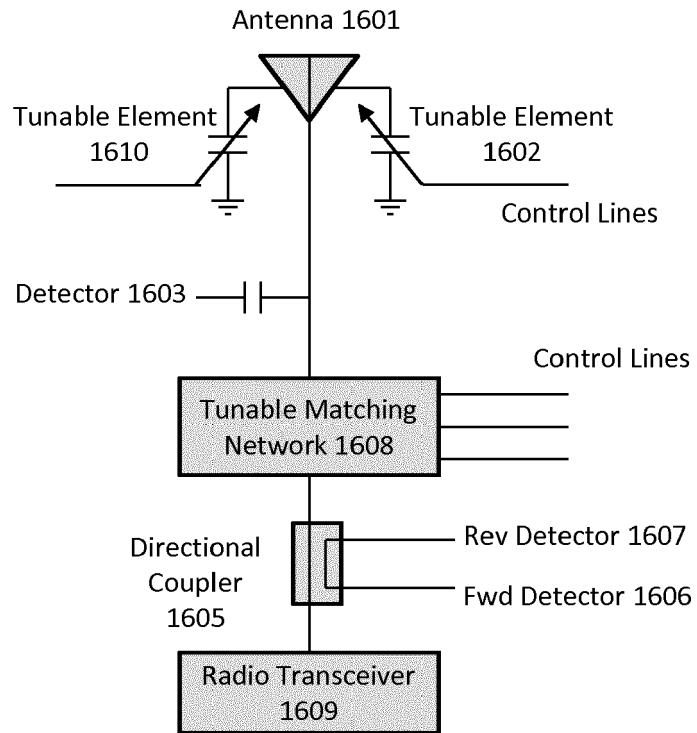
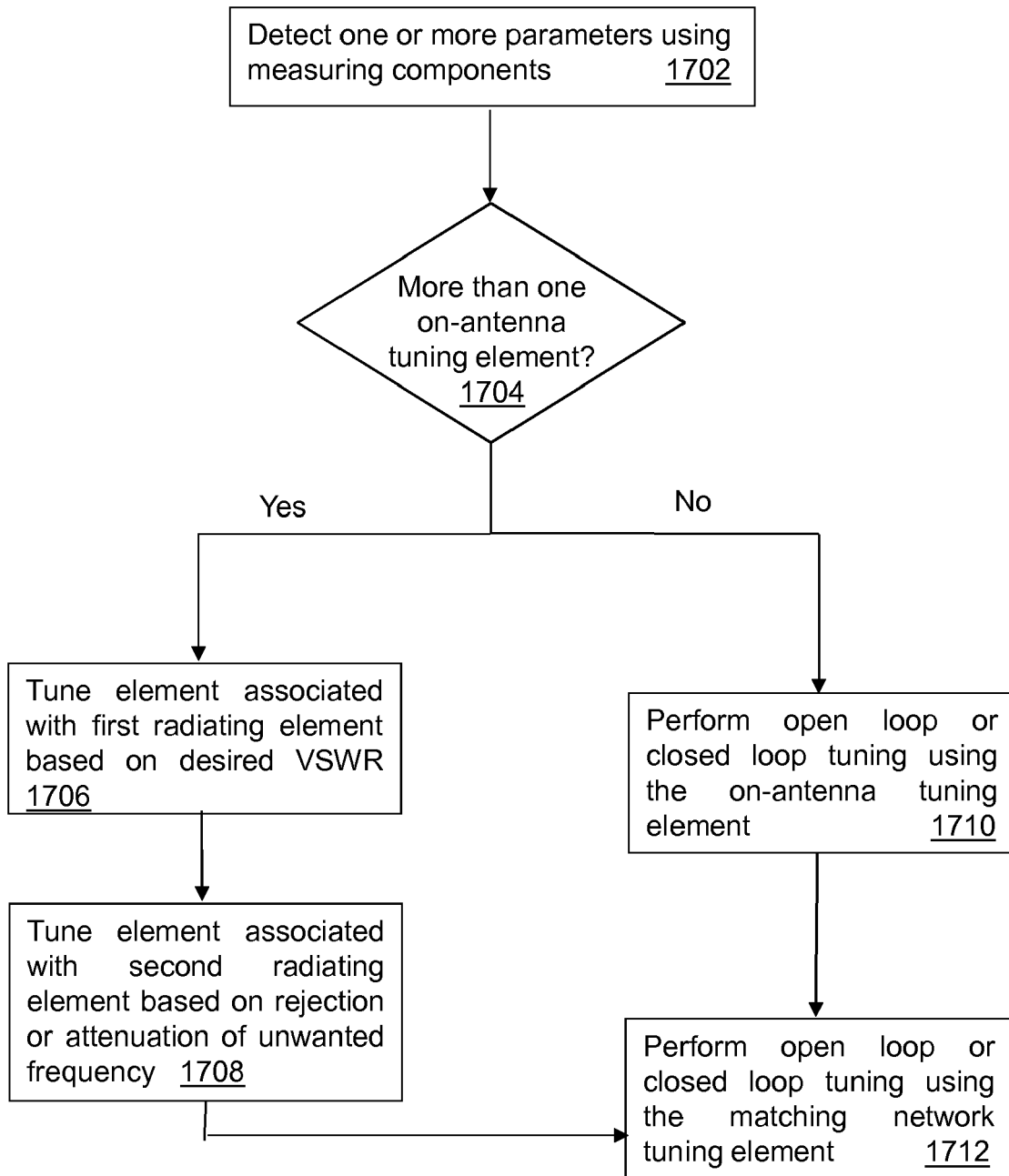


FIG. 15



1600

FIG. 16



1700

FIG. 17

LOOK-UP TABLE

Band 1; Use Case 1; Desired tuning state
Band 1; Use Case 2; Desired tuning state
● ● ●
Band 1; Use Case n; Desired tuning state
Band 2; Use Case 1; Desired tuning state
Band 2; Use Case 2; Desired tuning state
● ● ●
Band 2; Use Case n; Desired tuning state
Band N; Use Case 1; Desired tuning state
Band N; Use Case 2; Desired tuning state
● ● ●
Band N; Use Case n; Desired tuning state

1800

FIG. 18

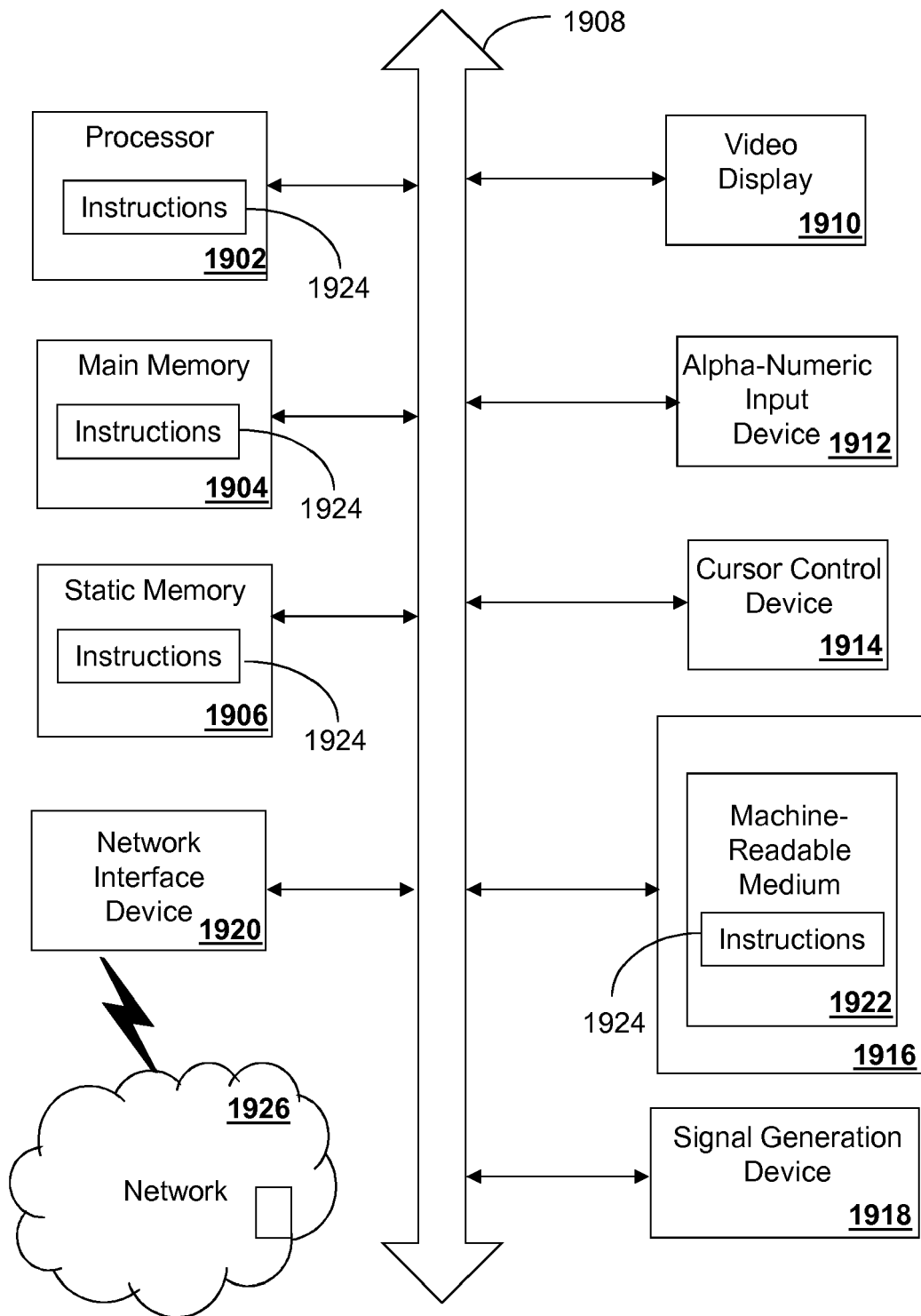


FIG. 19 1900



EUROPEAN SEARCH REPORT

Application Number
EP 17 15 5774

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Y	* figures 1,5 * * paragraphs [0013], [0014], [0020] - [0022] *	3,10	
X	US 2004/125027 A1 (RUBINSHTEYN BORIS [US] ET AL) 1 July 2004 (2004-07-01)	1,2,4-9, 11-15	
X	* abstract; figure 1 * * paragraphs [0028] - [0031] *		
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Y	* paragraphs [0023] - [0028], [0042]; figures 2,3 *		
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	* figure 1 * * paragraphs [0017] - [0020], [0040] *		
A	US 2008/266190 A1 (OHBA ISAO [JP] ET AL) 30 October 2008 (2008-10-30)	1-15	TECHNICAL FIELDS SEARCHED (IPC)
	* figures 1-4 * * paragraphs [0025] - [0043] *		H01Q
A	US 2011/012792 A1 (KRENZ ERIC [US] ET AL) 20 January 2011 (2011-01-20)	1-15	
	* figure 1 * * paragraphs [0016], [0017] *		
The present search report has been drawn up for all claims			
Place of search Munich		Date of completion of the search 3 May 2017	Examiner Unterberger, Michael
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ON EUROPEAN PATENT APPLICATION NO.

EP 17 15 5774

5 This annex lists the patent family members relating to the patent documents cited in the above-mentioned European search report.
The members are as contained in the European Patent Office EDP file on
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