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(54) Title: APPARATUS AND METHOD FOR ANTENNA MATCHING

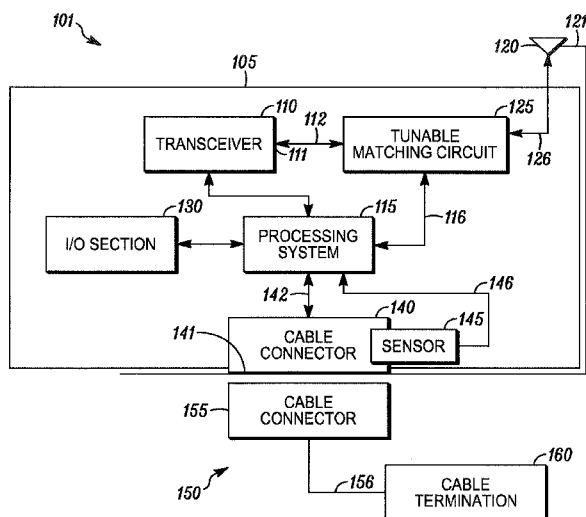


FIG. 1

(57) Abstract: A method and apparatus are for performing antenna matching and include determining a cable connection state of a cable connector, generating a cable detection signal that indicates the cable connection state, and modifying impedance transform of a tunable matching circuit in response to the cable detection signal. The cable detection signal indicates one of a presence and an absence of a cable connector. The tunable matching circuit couples a transceiver and an antenna. The tunable matching circuit couples the selected impedance transform between the transceiver and the antenna. The apparatus is a radio communication device that includes a transceiver, a processing system, an antenna, a tunable matching circuit, an input/output section, a cable connector, and a sensor.

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APPARATUS AND METHOD FOR ANTENNA MATCHING

FIELD OF THE INVENTION

[0001] The present invention relates generally to radio communication devices, and more specifically to antenna systems used in handheld radio communication devices.

BACKGROUND

[0002] Radio communication devices typically employ antennas that optimize radio signal transmission and reception. The antennas are often coupled to the transmitter output signal and/or the receiver input signal connector through impedance matching circuits so that the transmitters and receivers can be designed and tested to a specified value. The impedance matching circuits can then be designed or adjusted for differing antennas or differing antenna environments, which vary the impedances of the antennas that may be coupled to the transmitters and/or receivers. Antenna matching circuits may have different impedance matching states that are selectable according to a radio channel and environmental conditions. In the case of handheld electronic devices, such environmental conditions include the presence of a user's hands in a variety of positions relative to an antenna or an antenna element.

BRIEF DESCRIPTION OF THE DRAWINGS

[0003] The accompanying figures, where like reference numerals refer to identical or functionally similar elements throughout the separate views, together with the detailed description below, are incorporated in and form part of the specification, and serve to further illustrate embodiments of concepts that include the claimed invention, and explain various principles and advantages of those embodiments.

The description is meant to be taken in conjunction with the accompanying drawings in which:

[0004] **FIG. 1** is an electrical block diagram that shows a radio communication device and a cable, in accordance with certain embodiments.

[0005] **FIG. 2** is a three dimensional drawing that shows some parts of the antenna described with reference to **FIG. 1**, in accordance with certain embodiments.

[0006] **FIGS. 3-5** are three dimensional drawings, each showing a cable connector described with reference to **FIG. 1** an antenna element, in accordance with certain embodiments.

[0007] **FIG. 6** is a graph that shows plots of antenna return loss for a particular radio communication device in the presence and absence of a particular cable.

[0008] **FIG. 7** is a graph that shows plots of radiation efficiencies and system efficiencies for different situations of the cellular telephone and the presence and absence of a USB cable, in accordance with certain embodiments.

[0009] **FIG. 8** is a flow chart that shows some steps of a method for tuning a tunable matching circuit, in accordance with certain embodiments.

[0010] Skilled artisans will appreciate that elements in the figures are illustrated for simplicity and clarity and have not necessarily been drawn to scale. For example, the dimensions of some of the elements in the figures may be exaggerated relative to other elements to help to improve understanding of the embodiments...

DETAILED DESCRIPTION

[0011] In the description below, like reference numerals are used to describe the same, similar or corresponding parts in the several views of the drawings.

[0012] Embodiments described herein generally relate to radio communication devices that are designed with an antenna that has an element through which a cable connection is formed. One example of such a radio communication device is

a cellular telephone. One example of such an antenna element is an antenna element that is positioned on the narrow dimension of the radio communication device – i.e., around part of the edge of a thin rectangular shaped radio communication device.

[0013] Referring to **FIG. 1**, an electrical block diagram 100 of a radio communication device 101 and a cable 150 is shown, in accordance with certain embodiments. The radio communication device 101 may be any radio communication device having at least one antenna element near to or through which a cable is connected to the radio communication device 101. Embodiments in which the antenna element has been modified to allow passage of the cable connector by removing more of the conductive material of the element typically provide more improvement. Some benefits may still be obtained for situations in which the cable connector is proximate the antenna element, and for which there is no reduction of the antenna element material proximate the cable connector. These relationships will be described in more detail with reference to **FIGS. 3-5**. The radio communication device 101 comprises a housing 105, a transceiver 110, a processing system 115, an antenna 120, a tunable matching circuit 125, an input/output section 130, a cable connector 140, and a sensor 145. The radio communication device 101 may be, for example, a cellular telephone, an electronic tablet, an electronic pad, a monitoring device, a vehicular communication device, just to name a few. The cable 150 comprises a compatible cable connector 155 designed to mate with cable connector 140, a cable that is designed to include wires that carry electrical signals that may be DC or AC. The AC signals may include analog or digital signals, and may include audio, video, and/or radio frequency bandwidths. Certain wires may be shielded. The cable 156 is terminated in a cable termination 160 that may be another cable connector or an electronic device.

[0014] The transceiver 110 is a radio transceiver 110. The transceiver 110 may be one of one or more transceivers in the radio communication device 101. For example, if the radio communication device 101 is cellular communication device, the radio communication device 101 may have a cellular transceiver and a Wi-Fi

hotspot transceiver. The transceiver 110 represents any one transceiver when there are multiple transceivers in the radio communication device 101. The transceiver 110 may provide transmitting and receiving functions (e.g., a cellular system transmitter-receiver), or a transmitting only function (e.g., a sign-post transmitter), or a receiving only function (e.g., a global positioning system (GPS) receiver). The transceiver 110 may comprise one or more processors and associated memories for controlling the operation of the transceiver 110.

[0015] The transceiver 110 is coupled to the antenna 120. The manner in which the antenna 120 is drawn is intended to indicate that it may comprise one or more antenna elements that are outside of the housing 105, or on the housing 105, or within the housing 105, as well as an antenna signal 126 that couples the antenna elements to the tunable matching circuit 125. The antenna 120 is illustrated to show one particular antenna element 121 that is a conductive material, such as a metal alloy, disposed on the surface of the housing 105. It may be disposed by plating techniques or mechanical attachment techniques. The cable connector 140 of the radio communication device 101 has a connector insertion cavity with a face 141 that is approximately flush with the surface of the housing 105 and the antenna element 121. "Approximately flush" includes situations in which the cable connector 140 either protrudes from or is recessed from the surface of the antenna element 121. For example, the cable connector 140 may be printed circuit board mounted and/or may have a flange, resulting in a disposition of the face 141 such that it is recessed from or protrudes from the antenna element 121 by a distance that is small in comparison to the size of the antenna element 121. Although the illustration of the antenna element 121 indicates that it is disposed on three sides of the housing 105, the antenna element 121 need not be so disposed. That is, the antenna element 121 may alternatively be disposed along only part of one side of the housing and may be plated on either the inner or outer surface of the housing 105. In some embodiments the antenna element 121 may be implemented as an independent structure that is located with reference to the radio communication device 101 and the cable connector 140 such that the antenna element 121 has a hole or cutout where the cable connector 140 passes through the antenna element

121. For example, the antenna element 121 may be a bent or flat punched metal piece that is mounted to a printed circuit board inside the housing 105 of the radio communication device 101.

[0016] The tunable matching circuit 125 is coupled to the transceiver 110. When the transceiver has both a radio frequency (RF) transmitter and an RF receiver the tunable matching circuit 125 is coupled to a RF output port and an RF input port of the transceiver 110, which may be a common RF port 111. When the transceiver 110 has only one of a transmitter or receiver, the tunable matching circuit 125 is coupled to the RF port 111 that is one of an RF output port or RF input port of the transceiver 110. The RF transmitter of the transceiver 110 is designed to generate an RF signal at a selected power at a designed output impedance of the RF transmitter. The signal is coupled through the tunable matching circuit 125 to the antenna 120. The RF receiver of the transceiver 110 is designed to receive an RF signal within a designated power range at a designed input impedance of the RF receiver, wherein the RF signal is coupled from antenna 120 through the tunable matching circuit 125 to the RF input port 111.

[0017] The tunable matching circuit 125 is also coupled to the processing system 115. The tunable matching circuit 125 is a circuit that provides a selected impedance transform, or matching state, selected by control signals 116 from the processing system 115. The processing system 115 is also coupled to the sensor 145. The processing system generates the control signals 116 in response to a cable detection signal 146 generated by the sensor 145 and other parameters, such as the selected radio channel and an environmental state of the radio communication device 101. Each particular impedance transform that is selected by the control signals 116 is designed to match the impedance of the antenna 120 to the impedance of the RF port or ports 111. The impedance of the antenna may change for different states of the transceiver 110, the environment of the radio communication device 101, and the cable connection state signal. Selecting an impedance transform optimizes the transfer of signal power between the transceiver 110 and the antenna 120. The states, the environment, and the cable connection state are indicated by the control signals 116. The selected impedance

transforms are mapped to the control signals 116, for example by a table stored in a memory. The action of selecting an impedance transform or matching state using the mapping function is called tuning the tunable matching circuit 125. Each impedance transform may comprise stages of passive impedance devices, each stage able to be set to one of a plurality of gains and/or phases primarily within a narrow frequency band. The narrow frequency bands of the sets are combined to provide an impedance transform over a wide frequency band. The selection may involve the use of transistor switches. The selected impedance transform may provide an impedance at the antenna coupling which is the complex conjugate of the antenna impedance, and an impedance at the transceiver coupling which is the complex conjugate of the designed transceiver impedance, thereby maximizing the transfer of signal power between the transceiver and the antenna. Other known methods of providing a set of impedance transforms in a tunable matching circuit may alternatively be used. Advantageously, by adjusting the impedance transform one or more aspect of communication device 101 performance may be improved, such as transmitter radiated power, receiver sensitivity, communication range or distance, data rate, error rate, or energy efficiency.

[0018] Transceiver 110 is also coupled to the processing system 115. The processing system 115 is coupled to an input/output section 130, which includes human interface functions such as indicators, buttons, a graphical display, touch screen sensors as well as other sensor, such as position, orientation, and acceleration. The processing system 115 may be coupled to one or more other transceivers (not shown in **FIG. 1**) of the radio communication device 101 and other circuits (not shown in **FIG. 1**), of which just one example is a battery control circuits. There are alternative embodiments of the radio communication device 101 that relate to the configuration of the processing system 115 and the transceiver 110 and provide the same benefits. In the embodiments shown in **FIG. 1**, the control signals 116 that indicate the states, environment, and cable connection state are generated by processing system 115. In some embodiments the processing system 115 may be controlling the channel selection and other parameters (e.g., power output) of the transceiver 110 and the processing system 115 may also determine

the environment of the radio communication device 101. Examples of the environment of the radio communication device 101 are a user's head proximity to the radio communication device 101 and a location of a user's hand holding the radio communication device 101. In these embodiments, the control signals 116 may originate in the processing system 115. In other embodiments, the transceiver 110 may have its own processing system that controls the channel selection and other parameters of the transceiver, largely based on channel control messages that are exchanged between a processing system 115 of the transceiver 110 and a fixed network radio station. These signals may be passed to the processing system 115, which generates control signals 116 from them and the cable detection signal 146.

[0019] In some embodiments the transceiver 110 has its own processing system and the signals that indicate the channel selection and other parameters of the transceiver 110 are coupled directly to the tunable matching circuit by signals 112, while the processing system 115 couples the cable connection state to the tunable matching circuit in the control signals 116. In these embodiments, the determination of the environment of the radio communication device 101 may be determined either by the processing system 115 or the processing system of the transceiver.

[0020] The mapping of the states, the environment, and the cable connection state to a particular impedance transform may be a memory based mapping function performed in the tunable matching circuit 125. Other configurations may provide the same benefits. For example, the mapping function could be done in the transceiver 110, and the transceiver 110 would then directly control the switching of the impedance stages of the tunable matching circuit 125. In this example, the cable connection state may be coupled to the transceiver 110 either directly from the sensor 145 or through the processing system 115. In some embodiments, the cable connection state may be coupled by cable detection signal 146 directly to a control circuit of the tunable matching circuit 125. The control circuit may be the mapping function. In some embodiments, the processing system 115 may be referred to as a control circuit.

[0021] As noted above, the processing system 115 is also coupled to the cable connector 140. When the cable connector 140 is mated with a cable 150 having a compatible cable connector 155, cable signals 142 may be passed between the processing system 115 and the termination of the cable 160. Also, when the cable connector 140 is mated with a cable 150 having a compatible cable connector 155, the sensor 145 changes a cable connection state that in some embodiments is coupled by cable detection signal 146 to the processing system 115. The cable connection state in this case changes from a cable absent state to a cable present state. The sensor 145 may comprise an electrical contact moved by the insertion or extraction of the compatible cable connector 155, a pull up resistor coupled to a DC voltage, and a ground, arranged in a manner known in the art. This type of sensor may be characterized as a contact switch, reflecting the fact that a moving contact is used with electronic parts and two voltage sources to cause two voltage states. Other types of switches could be used. One example is a magnetic sensor, known as a Hall effect sensor. Another example is an optical detector. The cable 150 may be, for example, a universal serial bus (USB) cable having a micro USB cable connector 155.

[0022] In some embodiments, the cable connection state is generated in response to a detection of one or more signals of the cable signals 142. The detection may be performed by the processing system 115. The sensor 145 in this case is a combination of input/output circuits of the processing system 115 that are connected to the cable signals 142, and additional logic circuits and/or execution of input/output driver instructions by the processing system 115. For example, the cable connection state may be generated by the processing system 115 in response to a sensing that +5V has occurred on a +5V circuit line in the cable signals 142. It will be appreciated that, given the physical proximity of the cable connector 140 to the antenna element 121, and particularly when the antenna element has a hole or a cutout for the cable connector 140, the presence of the compatible cable connector 155 and the wires in the cable 150 and other metallic parts of the compatible cable connector may significantly degrade the efficiency of signal coupling between the antenna element 121 and the transceiver 110 from that

which existed when the compatible cable connector 155 is not present. When the compatible cable connector 155 is present, the cable connection state that indicates that the compatible cable connector 155 is present modifies the tunable matching circuit 125 to optimize the energy coupled between the antenna 120 and the transceiver 115. The transfer function that results from the modification will typically be different depending on the state of the transceiver, and therefore the transfer function, that exists when the compatible cable connector is inserted into the cable connector 140, which is determined by the control signals 116. An example of the improvement achieved by this modification is provided with reference to **FIG. 7**.

[0023] Referring to **FIG. 2**, a three dimensional drawing 200 shows some parts of the antenna 120 described with reference to **FIG. 1**, disposed on a housing for a radio communication device such as radio communication device 101, in accordance with certain embodiments. The antenna 120 comprises a sectioned metal band 202 about a perimeter edge of the housing 105 of radio communication device 101. The inner contents of the radio communication device 101 are not specifically shown for clarity. The sectioned metal band 202 may have multiple antenna elements. In this example there are a top antenna element 206 and a bottom antenna element 204. There are two metal grounded sections, being a first grounded section 208 and a second grounded section 210. Four metal corner sections, being first, second, third and fourth corner sections (212, 214, 216, 218) are provided to reduce the capacitive coupling between the antenna elements 204, 206 and the electrical ground sections 208, 210 by providing distance between the antenna elements 204, 206 and ground. The reduction of coupling (i.e., decoupling) between the antenna elements 204, 206 and the grounded sections 208, 210 improves the antenna efficiency. The four metal sections (212, 214, 216, and 218) may be referred to as parasitic sections, electrically floating sections and/or floating sections. The four metal sections (212, 214, 216, 218) are each positioned on the sectioned metal band 202 between an antenna section and a ground section. In an alternative embodiment, the number of floating segments can be reduced from four to two by eliminating the gaps 234, 226, 232, 224.

[0024] In various embodiments, the sectioned metal band 202 comprises insulative or high impedance gaps between the various metal sections of the sectioned metal band 202. For example, the bottom antenna element 204 is defined between a first gap 220 and a second gap 222. The first corner section 212 is adjacent to and separated from a first side of the bottom antenna element 204 by the first gap 220. The first grounded section 208 is adjacent to and separated from the first corner section 212 by a third gap 224. The second corner section 214 is adjacent to and separated from a second side of the top antenna 204 by the second gap 222. The second grounded section 210 is adjacent to and separated from the second corner section 214 by a fourth gap 226.

[0025] The top antenna element 206 is positioned between a fifth gap 228 and a sixth gap 230. The third corner section 216 is adjacent to and separated from a first side of the top antenna element 206 by the fifth gap 228. The first grounded section 208 is adjacent to and separated from the third corner section 216 by a seventh gap 232. The fourth corner section 218 is adjacent to and separated from a second side of the top antenna element 206 by the sixth gap 230. The second grounded section 210 is adjacent to and separated from the fourth corner section 218 by an eighth gap 234. Thus, each metal section or element of the sectioned metal band 202 is defined and separated from each of the other metal sections by gaps. In other words, each one of the plurality of conductive metal sections and elements is interposed between the plurality of gaps such that two gaps define the ends of each conductive section or element in the slotted or sectioned metal band 102. It is understood that the gaps may be made of an insulative polymer, ceramic, plastic, epoxy, rubber, glass or other substantially equivalent insulative material, or by an absence of material.

[0026] The top and bottom antenna elements 206, 204 are both driven elements, which comprise radiating antenna elements. In some embodiments the top antenna element 206 is a diversity antenna for receiving only, while the bottom antenna element 204 is for both transmitting and receiving radio communication

signals. In other embodiments, both antenna elements 204, 206 are configured to transmit or receive RF signals. In certain embodiments, antenna element 204 includes a connector hole 250, which provides for use of the cable connector 140 described with reference to **FIG. 1**.

[0027] The corner sections 212, 214, 216 and 218 are provided to reduce capacitive coupling between the driven top and bottom antenna elements 204, 206 and the electrical ground sections 208, 210. Since any electrical coupling between the antenna elements and the ground sections reduces the efficiency of each antenna respectively, then any improvement that reduces or helps reduce coupling or the potential for coupling between a driven antenna element and the ground sections improves the overall transceiving operation of an embodiment.

[0028] Additionally, the metal corner sections 212, 214, 216 and 218 do not function as active antenna elements. As mentioned previously, the corner sections 212, 214, 216 and 218 are provided to decrease the probability that a user's finger or hand, while holding the UE, will couple or complete a circuit between a driven antenna element, for example bottom antenna element 204, and one or more of the ground sections 208, 210. This is important because when a user's finger or hand bridges or completes the circuit between a driven antenna element and a ground section, there can be a strong capacitive coupling between the driven antenna element and ground section, thereby requiring retuning of an impedance matching circuit connected between the antenna and a transceiver.

[0029] Referring to **FIG. 3**, a three dimensional drawing 300 shows the cable connector 140 (**FIG. 1**) and a portion 310 of housing 105 (**FIG. 1**), in accordance with certain embodiments. Antenna element 204 (**FIG. 2**) is disposed on the portion 310 of the housing 105. A cable 320 is shown in FIG.3, which includes wires (not shown in **FIG. 3**) for coupling cable signals 142 (FIG.1) to the processing system 115 (**FIG. 1**). The signals may be conveyed by other means. For example, cable connector 140 could be a printed circuit board mounted connector and the cable signals 142 would then be coupled by printed circuit board conductors. In some embodiments a separate wire 315 conveys the cable detection signal 146 to the

processing system 115. In some embodiments, the separate wire 315 is not used. In the case of a printed circuit board mounted cable connector 140, the cable detection signal may alternatively be coupled by a printed circuit board conductor to the processing system 115. The antenna element 204 includes the hole 250 (**FIG. 2**) for a shell of the cable connector 140, which in these embodiments is shown as having shell edges 335, 340 that are flush with the antenna element 204. The outer surface of the cable connector 140, having shell edge 335, is referred in this document as the periphery of the cable connector 140. The shell edges of the cable connector 140 do not touch the antenna element 204 and are separated or isolated by a non-conductive material such as a plastic resin material for the housing. In the embodiments described with reference to **FIG. 3**, the periphery of the cable connector 140 is wholly within the antenna element 204. It will be appreciated that the mating of the compatible cable connector 155 with the cable connector 140 may negatively alter the impedance characteristics and radiation efficiency of the antenna element 204 and the radiation system efficiency of the antenna system comprising the antenna 120, the transceiver 110 and the tunable matching circuit 125. The use of the sensor 145 to detect the presence of the compatible cable connector 155 can trigger an adjustment of the tuning state of tunable matching circuit 125, and thereby substantially improve the radiation system efficiency of the antenna system comprising antenna 120, the transceiver 110, and tunable matching circuit 125. This improvement is achieved by adjusting the matching state of the tunable matching circuit 125 to improve the signal transfer between the transceiver 110 and antenna 120 when the antenna impedance 120 is altered due to the presence of a cable 160.

[0030] Referring to **FIG. 4** a three dimensional drawing 400 shows the cable connector 140 (**FIG. 1**) and a portion 410 of housing 105 (**FIG. 1**), in accordance with certain embodiments. An antenna element 404 (**FIG. 4**) is disposed on the portion 410 of the housing 105 in approximately the same position as antenna element 204 (**FIG. 2**). The cable 320 and wire 315 and possible alternative conductors for the cable 320 and wire 315 are as described with reference to **FIG. 3**. The antenna element 404 includes a cutout 430 for a shell of the cable connector

140, which in these embodiments is shown as having shell edges 335, 340 that are flush with the antenna element 404. In the embodiments described with reference to **FIG. 4**, the periphery of the cable connector 140 is partially within the antenna element 204. It will be appreciated that the mating of the compatible cable connector 155 with the cable connector 140 may negatively alter the impedance characteristics and radiation efficiency of the antenna element 404 and the radiation system efficiency of the system comprising the antenna 120, the transceiver 110 and the tunable matching circuit 125. The use of the sensor 145 to detect the presence of the compatible cable connector 155 can trigger an adjustment of the tuning state of tunable matching circuit 125, and thereby substantially improve the radiation system efficiency of the antenna system comprising antenna 120 and tunable matching circuit 125.

[0031] Referring to **FIG. 5** a three dimensional drawing 500 shows the cable connector 140 (**FIG. 1**) and a portion 510 of housing 105 (**FIG. 1**), in accordance with certain embodiments. An antenna element 504 (**FIG. 5**) is disposed on the portion 510 of the housing 105 in approximately the same position as antenna element 204 (**FIG. 2**). The cable 320 and wire 315 and possible alternatives for the cable 320 and wire 315 are as described with reference to FIG 3. The antenna element 504 is proximate the shell of the cable connector 140, which in these embodiments is shown as having shell edges 335, 340 that are flush with the housing 510. In the embodiments described with reference to **FIG. 5**, the periphery of the cable connector 140 is described as being proximate or adjacent to the antenna element 504. It will be appreciated that the mating of the compatible cable connector 155 with the cable connector 140 may negatively alter the impedance characteristics and radiation efficiency of the antenna element 504 and the radiation system efficiency of the system comprising the antenna 120, the transceiver 110 and the tunable matching circuit 125. The use of the sensor 145 to detect the presence of the compatible cable connector 155 can trigger an adjustment of the tuning state of tunable matching circuit 125, and thereby improve the radiation system efficiency of the antenna system comprising the antenna 120, the transceiver 110 and the tunable matching circuit 125. .

[0032] Referring to **FIG. 6**, a graph 600 shows plots of antenna return loss for a particular radio communication device in the presence and absence of a particular cable. The particular radio communication device is a specific model of a cellular telephone, with its associated cellular antenna. The cellular antenna is similar to antenna 120 described with reference to **FIGS. 1-3** that is disposed on a housing of the cellular telephone that is similar to that described with reference to **FIG. 1**. The particular cable connector is a micro USB cable connector of a selected USB cable that is compatible with the USB cable connector of the particular cellular telephone model. The vertical axis 605 of the graph 600 shows return loss in dB. The horizontal axis 610 of the graph 600 shows frequency in GHz. The antenna return loss is plotted for frequencies from 0.6 GHz to 0.8GHz, which is a frequency range that includes the transceiver operating frequencies. In this frequency range the antenna return loss is affected by the absence and presence of a micro USB connector that is positioned relative to the antenna element in the manner described with reference to **FIGS. 2-3**. The tunable matching circuit setting is selected for a test environment and for no USB cable connector being inserted in the female USB connector that is a permanent part of the cellular radio. Plot 615 shows the return loss without the USB cable connector being inserted in the female USB connector. Plot 620 shows the return loss with the USB cable connector being inserted in the female USB connector. It can be seen that the resonant frequency of the antennas shifts approximately 53 MHz and the return loss at the resonant frequency of about 745 MHz degrades by about 9 dB. If the benefits of embodiments are not used, this degradation causes a substantial loss of system efficiency, as described below.

[0033] Referring to **FIG. 7**, a graph 700 shows plots of radiation efficiencies and system efficiencies for different situations of the cellular telephone and the presence and absence of the USB cable described above with reference to **FIG. 3** and **FIG. 6**, in accordance with certain embodiments. The vertical axis 705 shows the values of radiation and system efficiencies with reference to a maximum of 0 dB (zero decibels of power) over a range of frequencies of interest, in GHz, for the cellular telephone, for the presence or absence of the USB cable connector, and for

particular settings of the tunable matching circuit of the particular radio communication device. The horizontal axis 710 shows frequency in GHz. Antenna efficiency is defined as the power radiated from the particular antenna divided by the power delivered to the antenna, e.g., the power of the antenna signal 126 that is delivered into antenna 120 and not reflected back into matching circuit 125 (**FIG. 1**). System efficiency is defined as the power radiated from the particular antenna divided by the power available from the source e.g., the power of the antenna signal 126 that would be delivered into antenna 120 if the antenna impedance were the complex conjugate of the matching circuit 125 output impedance (**FIG. 1**).

[0034] Plot 715 shows the radiation efficiency for the cellular antenna without the USB cable connector being present, and with the tunable circuit setting that has been selected for initial testing. Plot 720 shows the system efficiency under the same circumstances.

[0035] Plots 725 and 730 show, respectively, the radiation efficiency and system efficiency when the USB cable connector is present under the same circumstances. It can be seen that the antenna efficiency degrades by approximately 5 dB at the center frequency, shown by arrow 735, and that the system efficiency degrades by approximately 11 dB at the center frequency, shown by arrow 740.

[0036] By modifying the tunable matching circuit settings to minimize the antenna impedance mismatch, as described above, the degradation of the system efficiency can be substantially improved. In simulation of a cellular telephone in which the impedance transform of tunable matching circuit was selected for a transmit band of 0.704-0.716 GHz in a test environment, improvements across the transmit band of up to 5dB of system efficiency were achieved by selecting the setting of the tunable matching circuit to optimize the antenna matching for the situations when the USB connector was present and not present.

[0037] It will be appreciated that the positioning and dimensions of the antenna element and the cable connector will affect the degradation caused by the insertion of the compatible cable connector, and therefore affect the amount of improvement that can be achieved by changing the setting of the tunable matching circuit. For

different embodiments in which the antenna section is the same width and length, a same cable connector that is positioned in the cutout situation shown in **FIG. 4** (such that less of the antenna section is removed) will have less degradation, and thus less improvement than for the situation described with reference to **FIG. 3**. For the situation shown in **FIG. 5**, and if the antenna section 504 were the same width as the antenna section 204 (**FIG. 3**), the degradation and improvement are predicted to be even less than for the cutout situation described with reference to **FIG. 4**. The embodiments can provide substantial improvements for these situations in which the cable connector periphery is disposed in a cutout of the antenna element or is disposed proximate the antenna element, in some cases providing more than 5 dB of system efficiency improvement.

[0038] Referring to **FIG. 8**, a flow chart 800 shows some steps of a method for tuning a tunable matching circuit, in accordance with certain embodiments. At step 805, a cable connection state of a cable connector is determined. At step 810, a cable detection signal is generated that indicates the cable connection state. At step 815 an impedance transform of a tunable matching circuit is modified in response to the cable detection signal. The cable detection signal indicates one of a presence and an absence of a cable attached to the cable connector. The tunable matching circuit couples the modified impedance transform between a transceiver and an antenna. A periphery of the cable connector is disposed at least partially within an antenna element of the antenna. A first system efficiency that exists while the tunable matching circuit is modified for the presence of the cable and the cable is connected provides a substantial increase above a second system efficiency that exists while the tunable matching circuit is not modified for the presence of the cable and the cable is connected. A substantial increase in this context means at least 2 dB.

[0039] In accordance with the above descriptions, some embodiments may be described as an apparatus including a transceiver 110, an antenna 120, a tunable matching circuit 125, a cable connector 140, a sensor 145, and a control circuit. The tunable matching circuit 125 is responsive to a tuning input to modify an impedance transform of the tunable matching circuit 125. The tunable matching

circuit 125 couples the selected impedance transform between the transceiver 110 and the antenna 120. The sensor 145 determines a cable connection state of the cable connector 140 and generates a cable detection signal that indicates the cable connection state. The control circuit is coupled to the cable detection signal and the tuning input of the matching circuit. The control circuit modifies the tunable matching circuit in response to an indication of the cable connection state that a cable 150 is present in the connector. In some embodiments, the control circuit may physically be integrated with the tunable matching circuit 125. In other embodiments, the control circuit may be a portion of a processing system 115. A first system efficiency that exists while the tunable matching circuit 125 is modified for the presence of the cable 150 and the cable 150 is connected (by cable connector 155 to cable connector 140) provides a substantial increase above a second system efficiency that exists while the cable detection signal is uncoupled from the control circuit and the tunable matching circuit 125 is not modified for the presence of the cable 150 and the cable 150 is connected (by cable connector 155 to cable connector 140).

[0040] In accordance with the above descriptions, some embodiments may be described as an apparatus that includes a transceiver 110, an antenna 120, a tunable matching circuit 125, a cable connector 140, and a processing system 115. The tunable matching circuit 125 is responsive to a tuning input to select an impedance transform of the tunable matching circuit 125. The tunable matching circuit 125 couples the selected impedance transform between the transceiver 110 and the antenna 120. The sensor 145 determines a cable connection state of the cable connector 140. The cable connection state is one of present and absent. The sensor 145 generates a cable detection signal 146 that indicates the cable connection state. The processing system 115 is coupled to the cable detection signal and the tuning input of the tunable matching circuit 125. The processing system 115 tunes the tunable matching circuit 125 in response to the cable connection state. A first impedance transform is selected when the cable connection state is present and a second impedance transform is selected when the cable connection state is absent. A first system efficiency that exists while a

cable connection state of present is coupled to the tuning input and a cable 150 is connected (by cable connector 155 to cable connector 140) provides a substantial increase above a second system efficiency that exists while the coupling of the cable detection signal from the sensor to the processing system is removed and a cable connection state of absent is coupled to the tuning input and the cable 150 is connected (by cable connector 155 to cable connector 140).

[0041] It should be apparent to those of ordinary skill in the art that for the methods described herein other steps may be added or existing steps may be removed, modified or rearranged without departing from the scope of the methods. Also, the methods are described with respect to the apparatuses described herein by way of example and not limitation, and the methods may be used in other systems.

[0042] In this document, relational terms such as first and second, top and bottom, and the like may be used solely to distinguish one entity or action from another entity or action without necessarily requiring or implying any actual such relationship or order between such entities or actions. The terms "comprises," "comprising," or any other variation thereof, are intended to cover a non-exclusive inclusion, such that a process, method, article, or apparatus that comprises a list of elements does not include only those elements but may include other elements not expressly listed or inherent to such process, method, article, or apparatus. An element preceded by "comprises ...a" does not, without more constraints, preclude the existence of additional identical elements in the process, method, article, or apparatus that comprises the element. The term "coupled" as used herein is defined as connected, although not necessarily directly and not necessarily mechanically.

[0043] Reference throughout this document are made to "one embodiment", "certain embodiments", "an embodiment" or similar terms. The appearances of such phrases or in various places throughout this specification are not necessarily all referring to the same embodiment. Furthermore, the particular features, structures, or characteristics attributed to any of the embodiments referred to herein may be combined in any suitable manner in one or more embodiments without limitation.

[0044] The term "or" as used herein is to be interpreted as an inclusive or meaning any one or any combination. Therefore, "A, B or C" means "any of the following: A; B; C; A and B; A and C; B and C; A, B and C". An exception to this definition will occur only when a combination of elements, functions, steps or acts are in some way inherently mutually exclusive.

[0045] The processes illustrated in this document, for example (but not limited to) the method steps described in **FIG. 8**, may be performed using programmed instructions contained on a computer readable medium which may be read by a processor of a CPU. A computer readable medium may be any tangible medium capable of storing instructions to be performed by a microprocessor. The medium may be one of or include one or more of a CD disc, DVD disc, magnetic or optical disc, tape, and semiconductor based removable or non-removable memory. The programming instructions may also be carried in the intangible form of packetized or non-packetized wire line or wireless transmission signals.

[0046] In the foregoing specification, specific embodiments have been described. However, one of ordinary skill in the art appreciates that various modifications and changes can be made without departing from the scope of the present invention as set forth in the claims below. Accordingly, the specification and figures are to be regarded in an illustrative rather than a restrictive sense, and all such modifications are intended to be included within the scope of present invention. The benefits, advantages, solutions to problems, and any element(s) that may cause any benefit, advantage, or solution to occur or become more pronounced are not to be construed as a critical, required, or essential features or elements of any or all the claims. The invention is defined solely by the appended claims including any amendments made during the pendency of this application and all equivalents of those claims as issued.

What is claimed is:

1. An apparatus, comprising:

A transceiver;

An antenna;

a tunable matching circuit that is responsive to a tuning input to modify an impedance transform of the tunable matching circuit, wherein the tunable matching circuit couples the selected impedance transform between the transceiver and the antenna;

A cable connector;

A sensor that determines a cable connection state of the cable connector and generates a cable detection signal that indicates the cable connection state; and

A control circuit coupled to the cable detection signal and the tuning input of the tunable matching circuit, wherein the control circuit modifies the tunable matching circuit in response to an indication of the cable connection state that a cable is present in the connector.

2. The apparatus according to claim 1, wherein the antenna comprises an antenna element and wherein a periphery of the cable connector is at least partially within the antenna element.

3. The apparatus according to claim 1, wherein a first system efficiency that exists while the tunable matching circuit is modified for the presence of the cable and the cable is connected provides a substantial increase above a second system efficiency that exists while the cable detection signal is uncoupled from the control circuit and the tunable matching circuit is not modified for the presence of the cable and the cable is connected.

4. The apparatus according to claim 3, wherein the tunable matching circuit has a frequency range and a substantial improvement is an improvement of at least 5 dB for at least one frequency in the frequency range.

5. The apparatus according to claim 4, wherein the frequency range includes a frequency range within frequency limits 0.60 GHz and 0.80 GHz.
6. The apparatus according to claim 1, wherein the sensor uses one of a contact switch and a magnetic switch.
7. The apparatus according to claim 1, wherein the apparatus is a handheld cellular communication device.
8. The apparatus according to claim 1, wherein the modification of the tunable matching circuit is achieved by switching passive electronic components that are coupled between the transceiver and the antenna.
9. An apparatus, comprising:
 - A transceiver;
 - An antenna;
 - a tunable matching circuit that is responsive to a tuning input to select an impedance transform of the tunable matching circuit, wherein the tunable matching circuit couples the selected impedance transform between the transceiver and the antenna;
 - A cable connector;
 - a sensor that determines a cable connection state of the cable connector, the cable connection state being one of present and absent, and generates a cable detection signal that indicates the cable connection state; and
 - A processing system coupled to the cable detection signal and the tuning input of the tunable matching circuit, wherein the processing system tunes the tunable matching circuit in response to the cable connection state.
10. The apparatus according to claim 9, wherein the antenna comprises an antenna element and wherein a periphery of the cable connector is at least partially within the antenna element.

11. The apparatus according to claim 9, wherein a first system efficiency that exists while a cable connection state of present is coupled to the tuning input and a cable is connected provides a substantial increase above a second system efficiency that exists while the coupling between the sensor and the processing system is removed and a cable connection state of absent is coupled to the tuning input and the cable is connected.

12. The apparatus according to claim 11, wherein the tunable matching circuit has a frequency range and a substantial improvement is an improvement of at least 5 dB for at least one frequency in the frequency range.

13. The apparatus according to claim 12, wherein the frequency range includes a frequency range within frequency limits 0.60 GHz and 0.80 GHz.

14. The apparatus according to claim 9, wherein the sensor uses one of a contact switch and a magnetic switch.

15. The apparatus according to claim 9, wherein the apparatus is a handheld cellular communication device.

16. The apparatus according to claim 9, wherein the modification of the tunable matching circuit is achieved by switching passive electrical components coupled between the transceiver and the antenna.

17. A method, comprising:

Determining a cable connection state of a cable connector;

Generating a cable detection signal that indicates the cable connection state; and

modifying an impedance transform of a tunable matching circuit in response to the cable detection signal indicating a presence of the cable connector, wherein the tunable matching circuit couples the modified impedance transform between a transceiver and an antenna..

18. The apparatus according to claim 17, wherein the antenna comprises an antenna element and wherein a periphery of the cable connector is disposed at least partially within the antenna element.

19. The apparatus according to claim 17, wherein a first system efficiency that exists while the tunable matching circuit is modified for the presence of the cable and the cable is connected provides a substantial increase above a second system efficiency that exists while the tunable matching circuit is not modified for the presence of the cable and the cable is connected.

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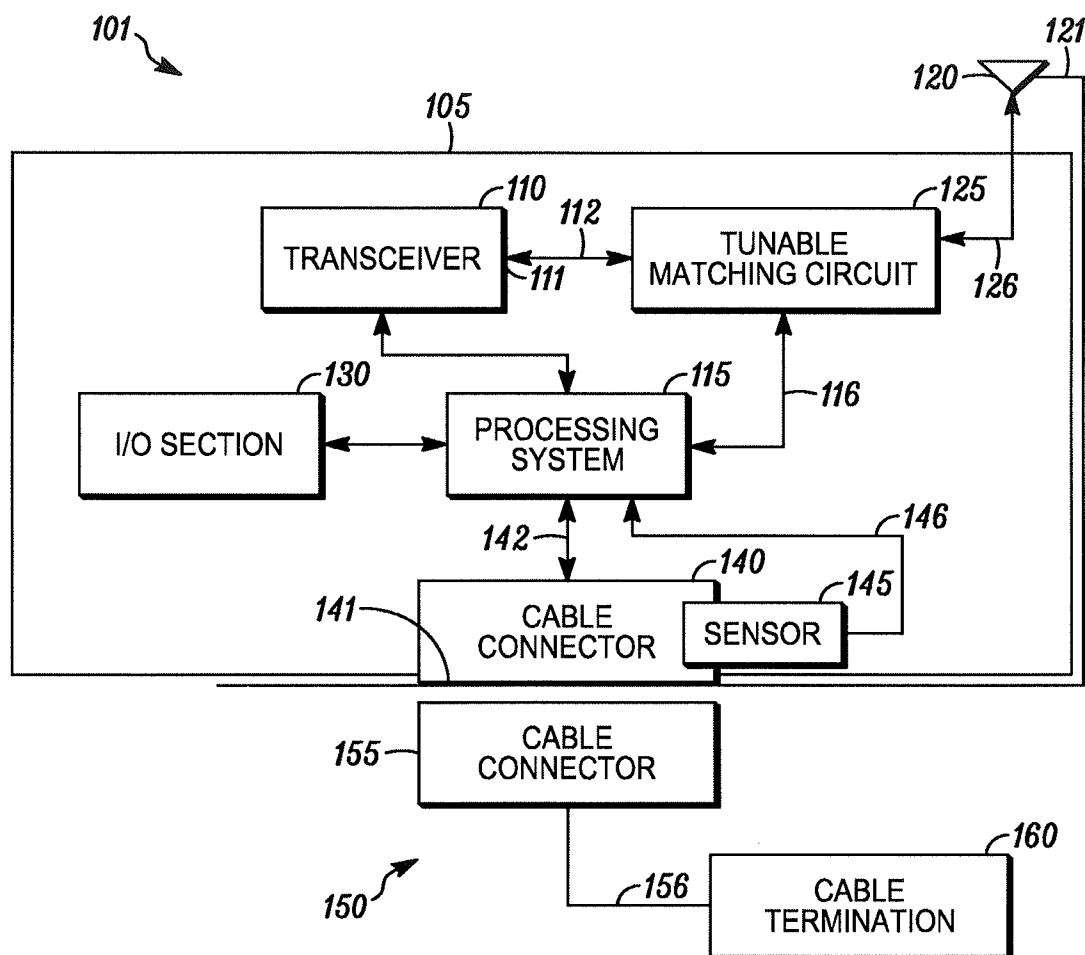
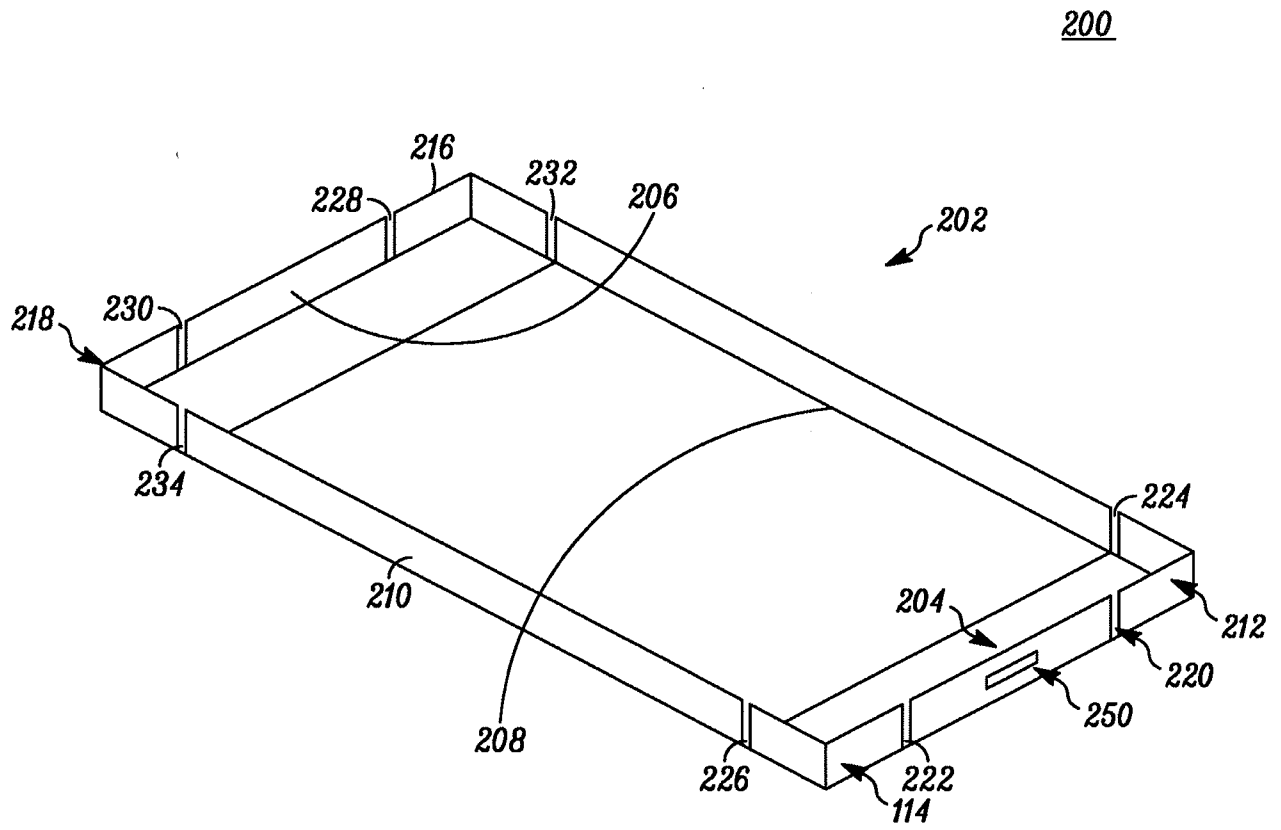


FIG. 1

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*FIG. 2*

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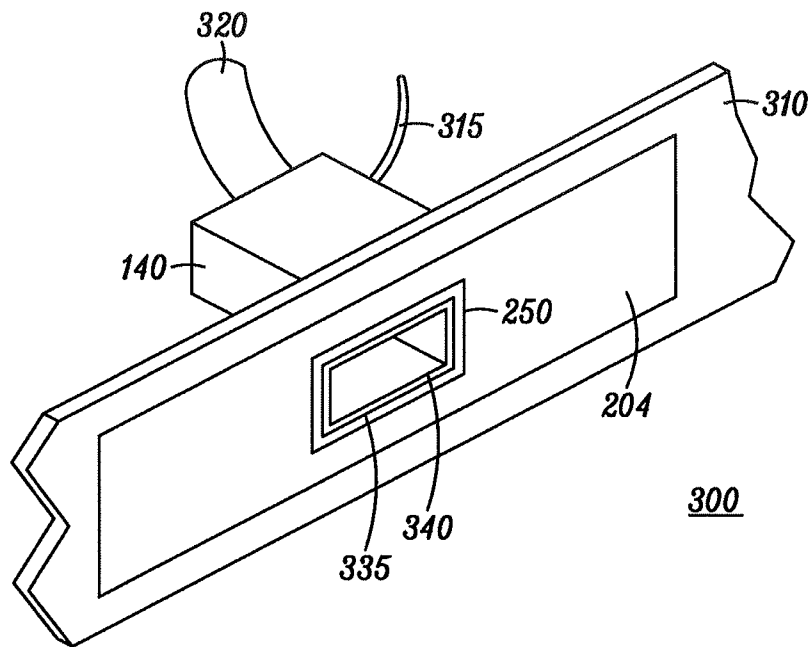


FIG. 3

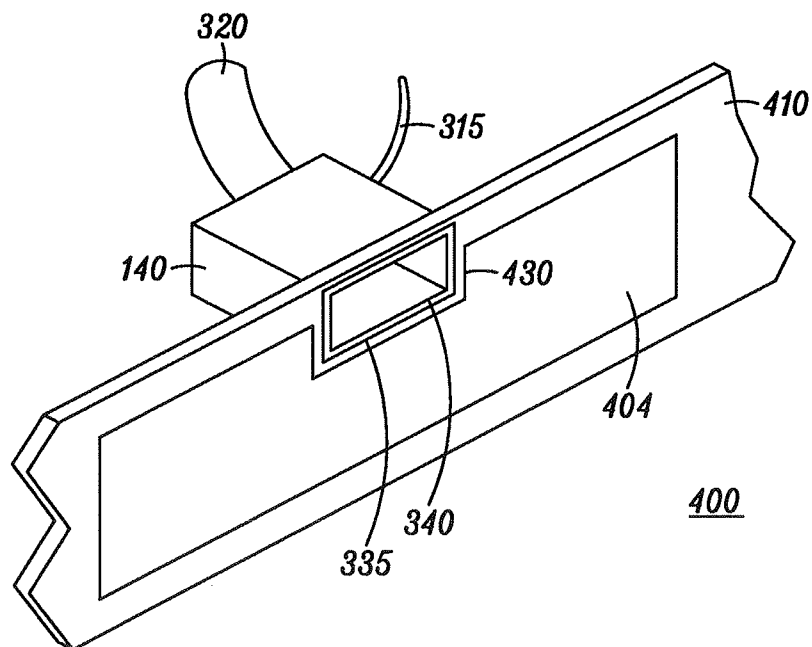
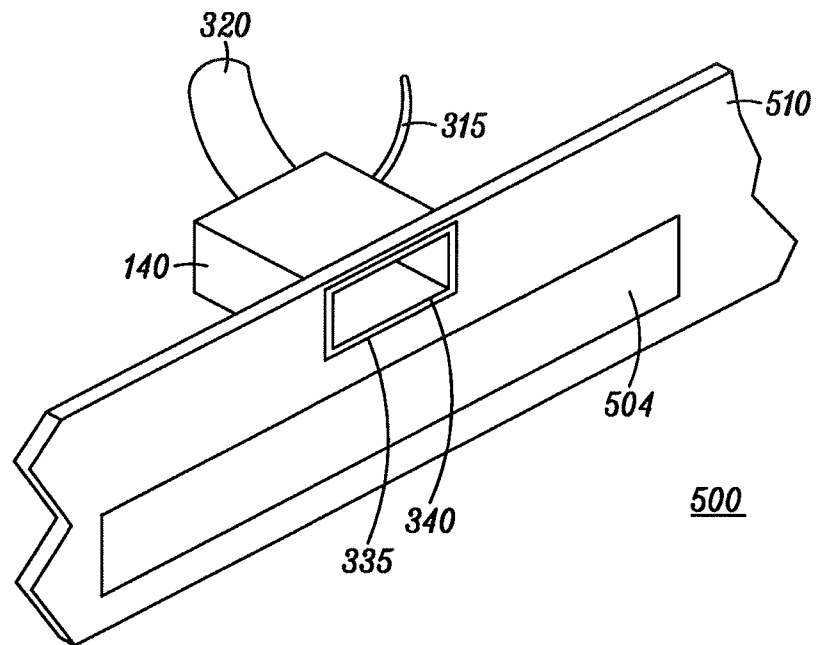


FIG. 4

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*FIG. 5*

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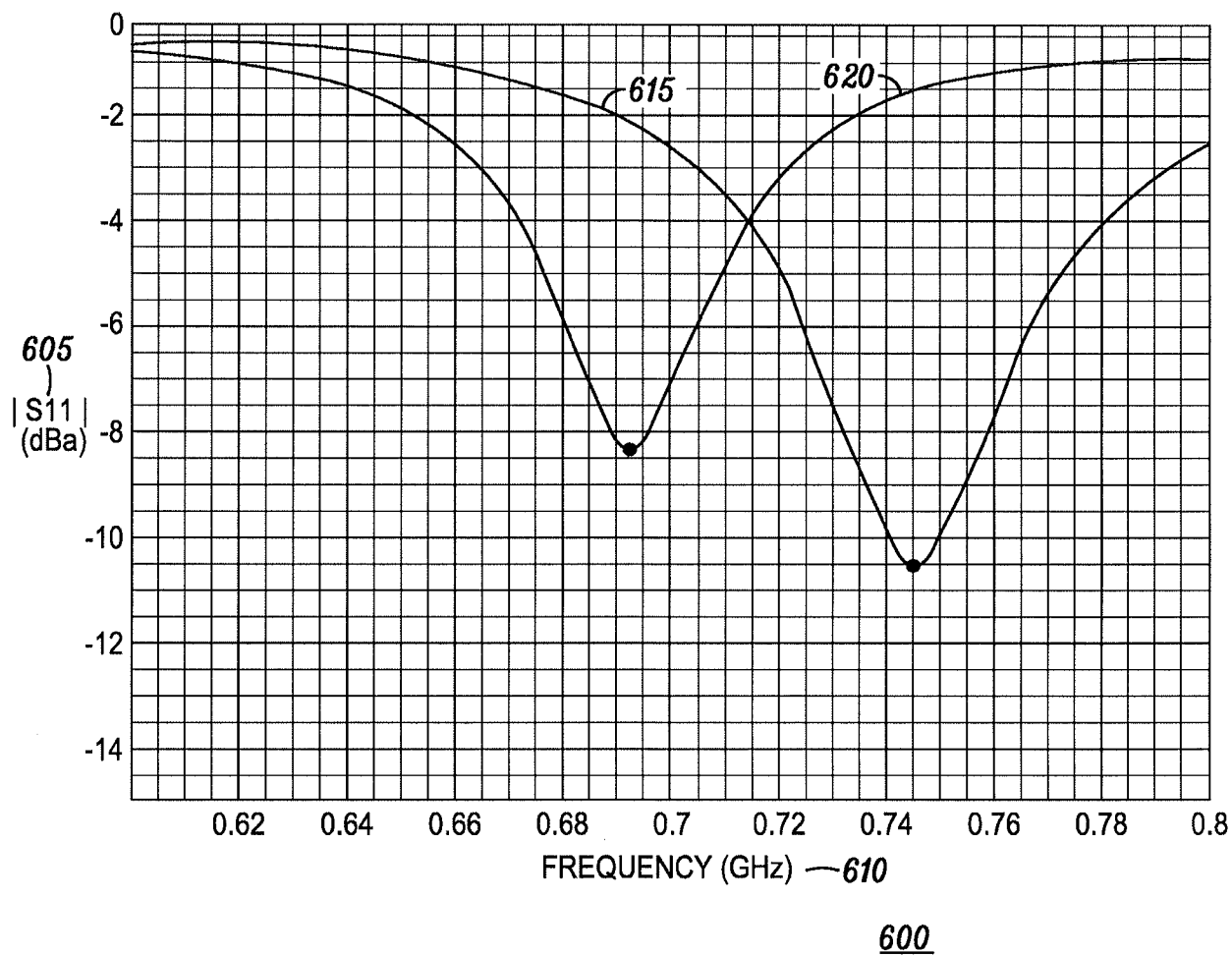


FIG. 6

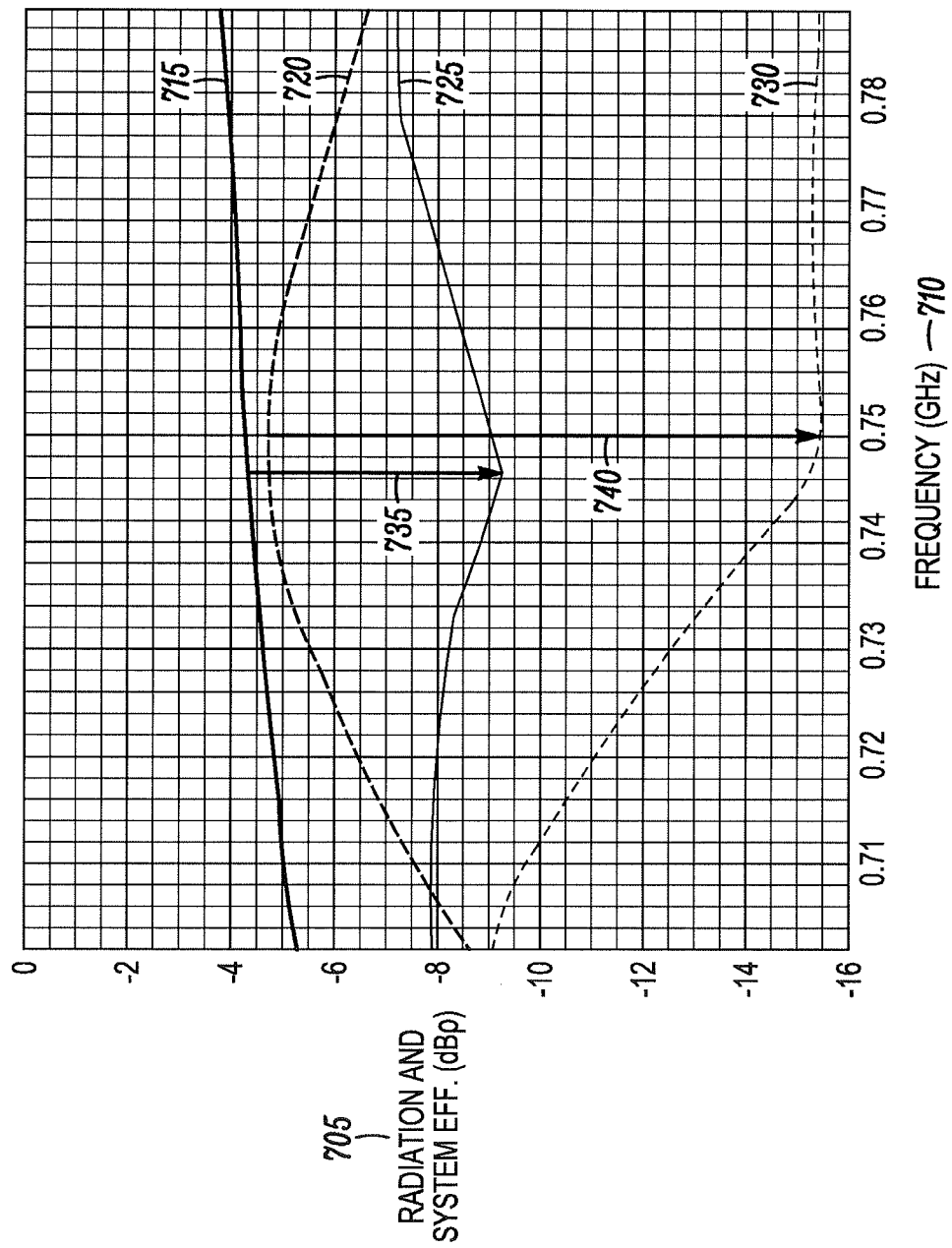
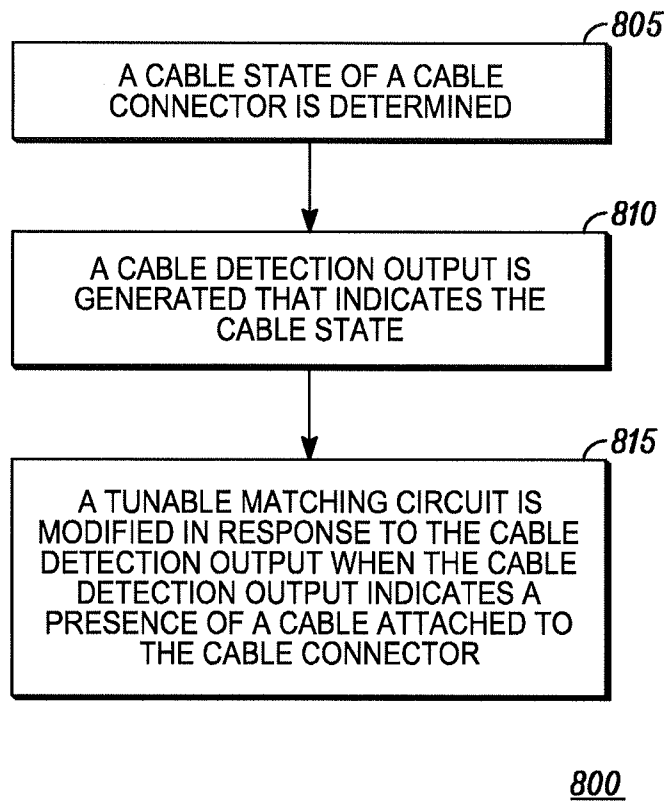


FIG. 7

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*FIG. 8*

INTERNATIONAL SEARCH REPORT

International application No

PCT/US2015/027872

A. CLASSIFICATION OF SUBJECT MATTER

INV. H01Q1/52 H01Q1/24 H01Q21/28
ADD.

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

H01Q H04B H04M

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

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

EPO-Internal, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

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Y	paragraph [0016] - paragraph [0034]; figures 1-4	2,6,10, 14,18
X	JP 2000 286924 A (BROTHER IND LTD) 13 October 2000 (2000-10-13) abstract; figure 5	1,3-5,9, 11-13, 17,19
X	US 2011/281532 A1 (SHIN YONG JOO [KR] ET AL) 17 November 2011 (2011-11-17)	1,3-5,7, 9,11-13, 15,17,19
Y	paragraph [0049] - paragraph [0069]; figures 1,2,4; table 6 ----- -/-	2,6,10, 14,18



Further documents are listed in the continuation of Box C.



See patent family annex.

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Date of the actual completion of the international search

25 June 2015

Date of mailing of the international search report

15/07/2015

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Kaleve, Abraham

INTERNATIONAL SEARCH REPORT

International application No
PCT/US2015/027872

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT		
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