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(54) **APPARATUS AND METHOD FOR ANTENNA MATCHING**

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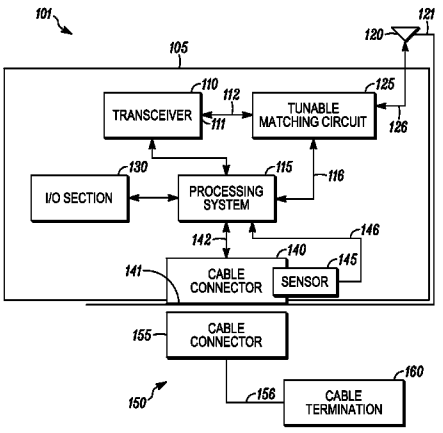
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(57) **ABSTRACT**

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.

20 Claims, 7 Drawing Sheets



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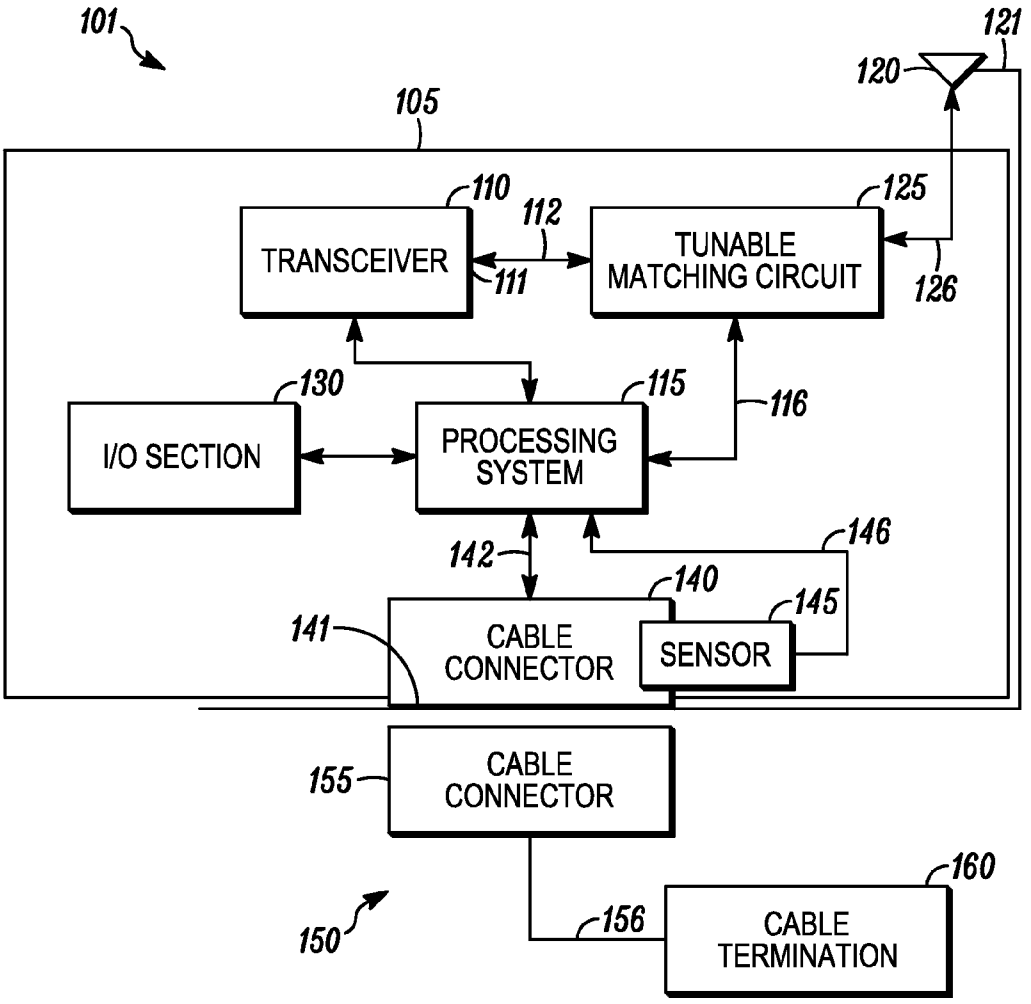

101
121
120
105
110
112
125
TRANSCEIVER
111
TUNABLE
MATCHING CIRCUIT
126
130
115
116
I/O SECTION
PROCESSING
SYSTEM
146
142
140
145
141
CABLE
CONNECTOR
SENSOR
155
CABLE
CONNECTOR
160
150
156
CABLE
TERMINATION

FIG. 1

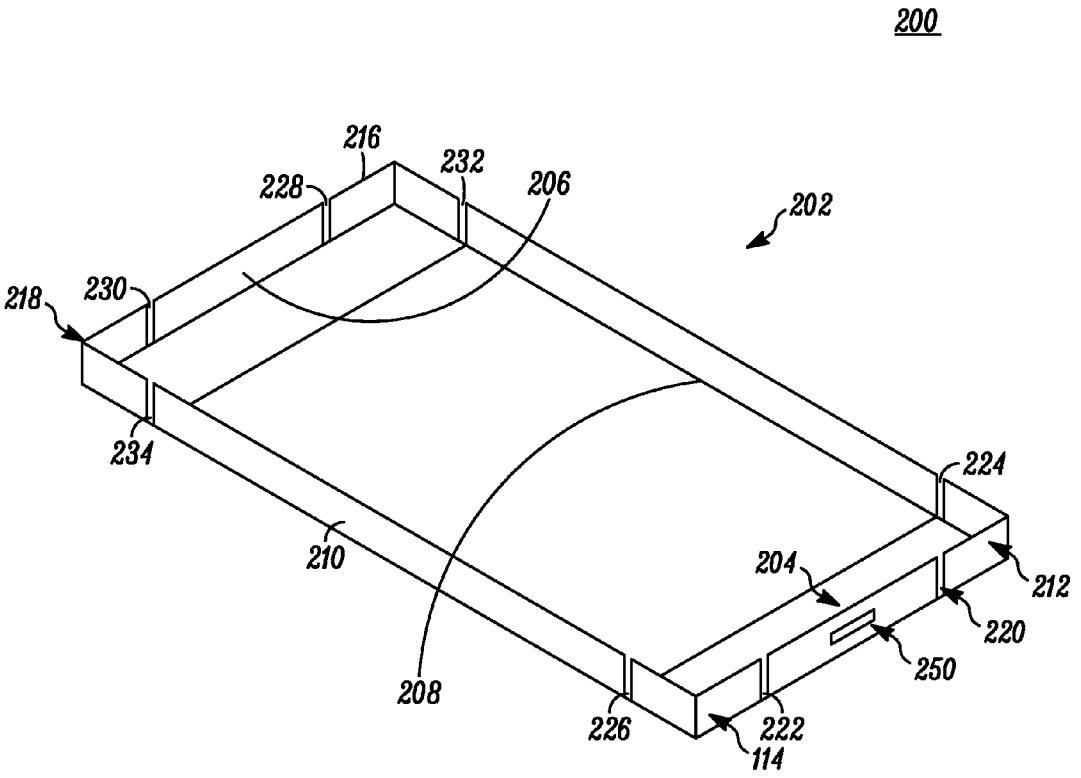

200
216
232
228
206
202
218
230
234
224
210
204
212
220
250
208
226
222
114

FIG. 2

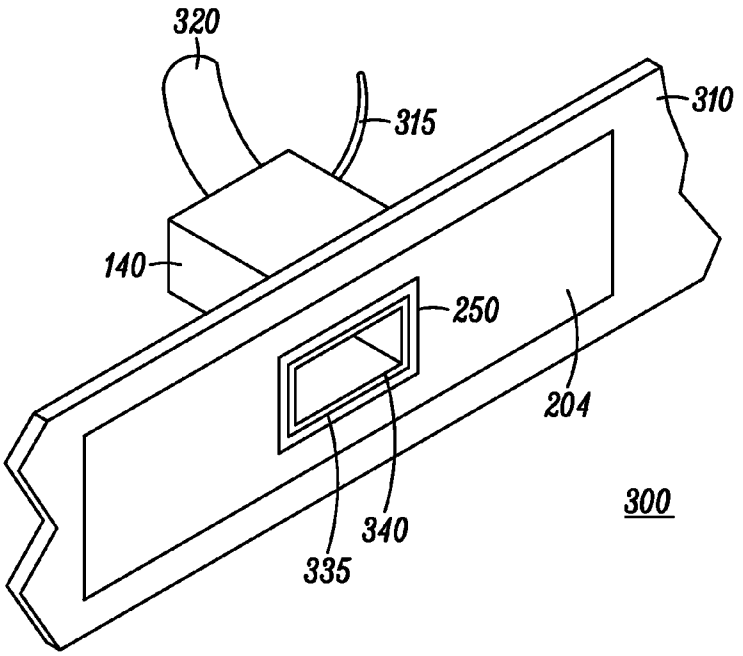


FIG. 3

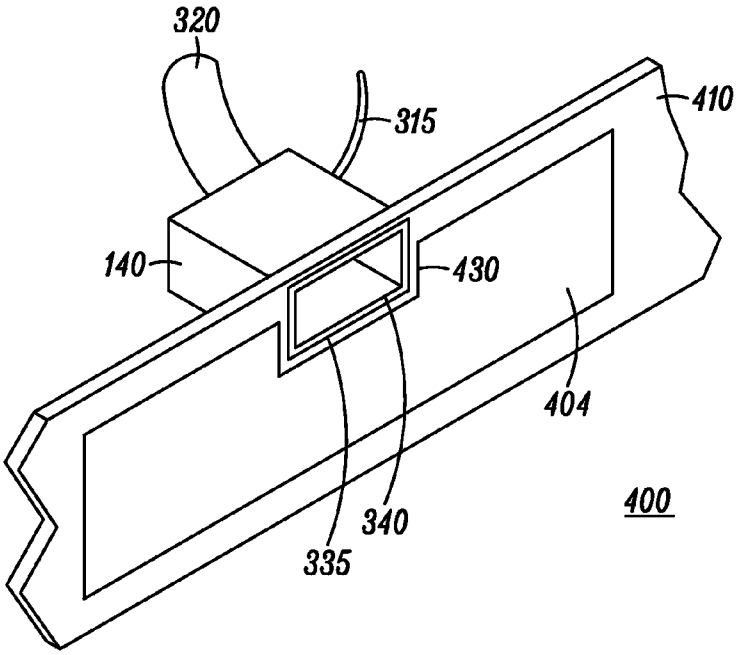


FIG. 4

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Amazon et al. v. SoundClear - IPR2025-01096

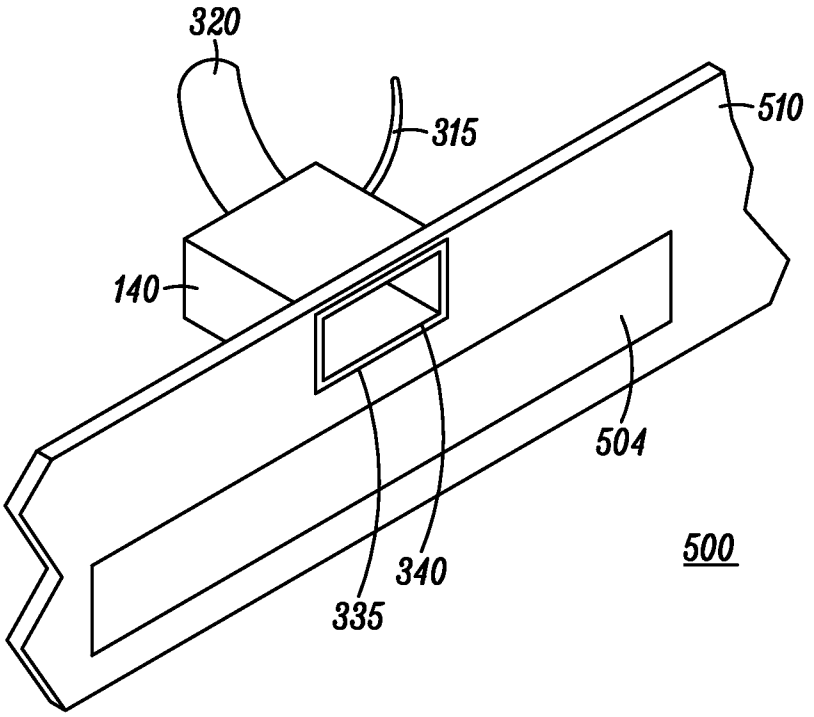


FIG. 5

SoundClear Exhibit 2021
Amazon et al. v. SoundClear - IPR2025-01096

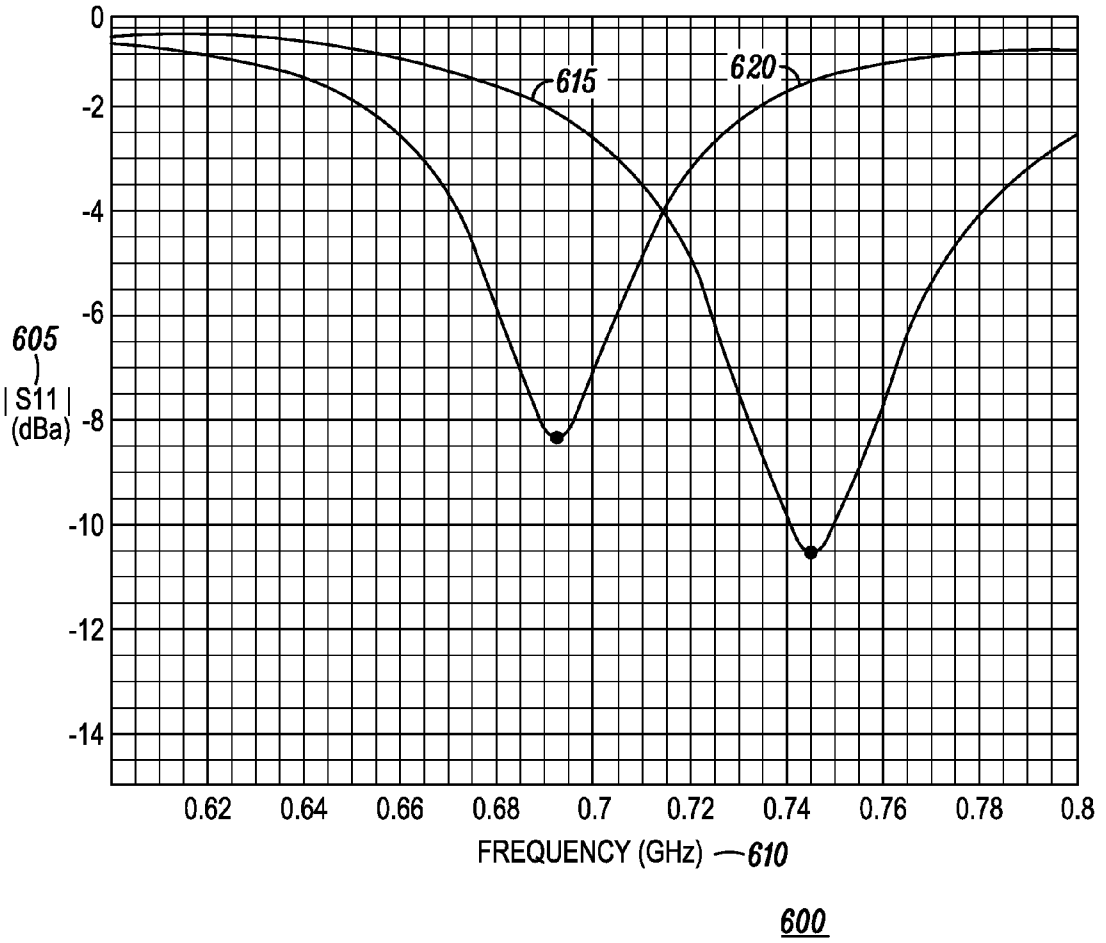


FIG. 6

SoundClear Exhibit 2021
Amazon et al. v. SoundClear - IPR2025-01096

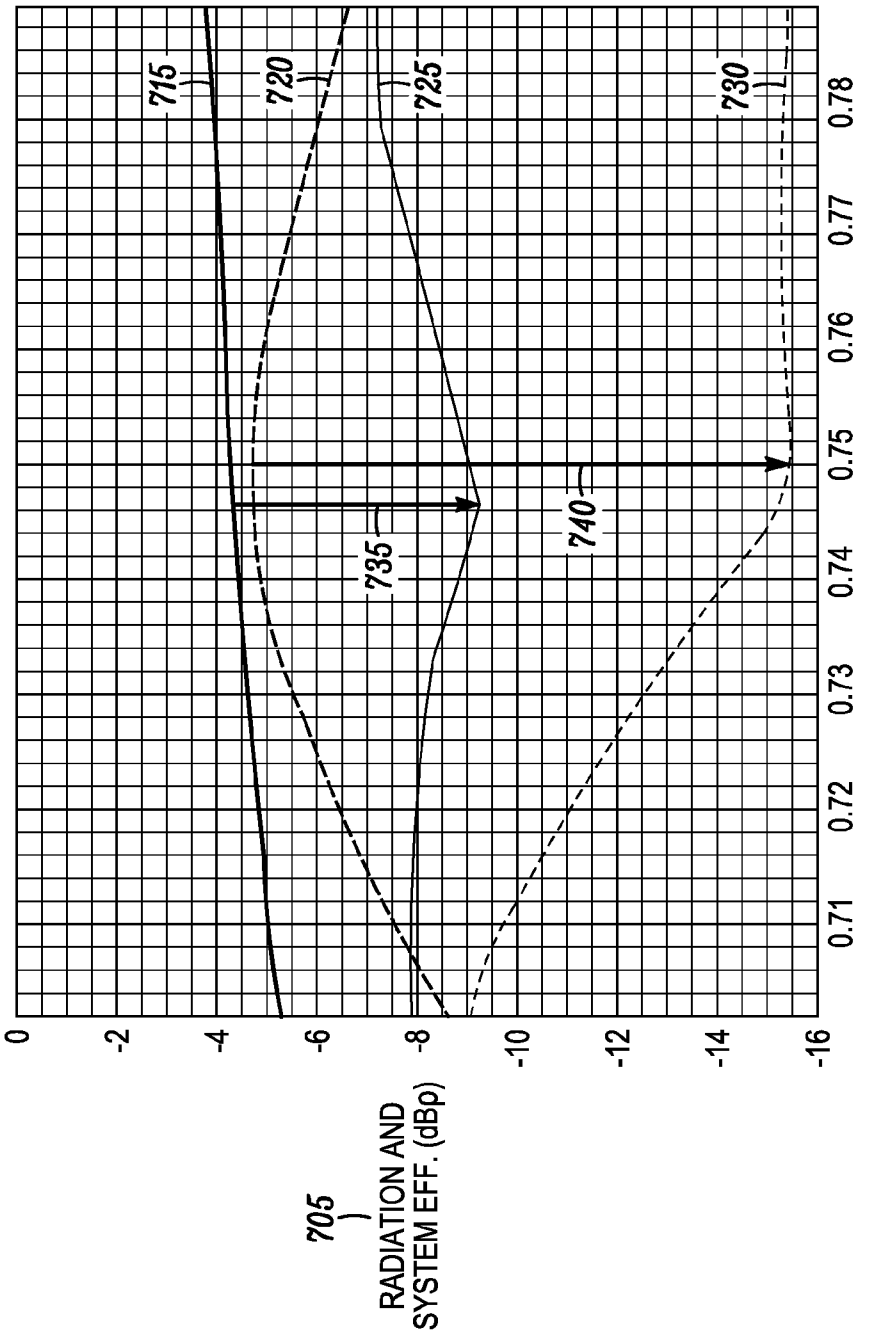


FIG. 7

SoundClear Exhibit 2021
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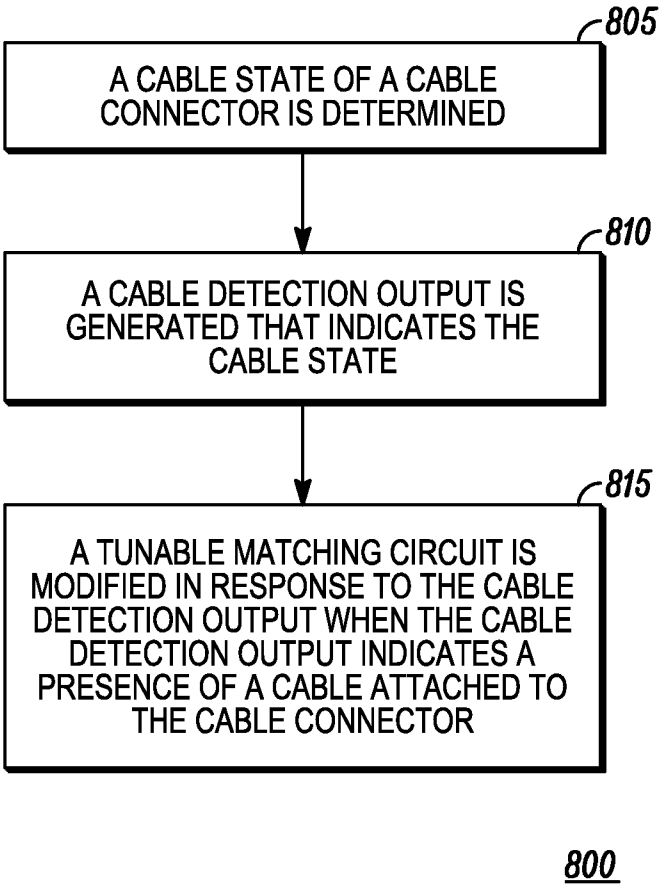


FIG. 8

SoundClear Exhibit 2021
Amazon et al. v. SoundClear - IPR2025-01096

APPARATUS AND METHOD FOR ANTENNA MATCHING

FIELD OF THE INVENTION

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

BACKGROUND

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 though 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

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:

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

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.

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.

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.

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.

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

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

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

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.

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.

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**.

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**.

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**.

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.

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**.

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.

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.

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**.

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 appreciate 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**.

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**.

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**.

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.

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**.

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.

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.

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 buy 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**.

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**.

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**.

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 0.8 GHz, 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.

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**).

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.

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**.

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 5 dB 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.

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.

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.

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**).

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**).

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.

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 proceeded 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.

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.

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.

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.

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 having a transceiver impedance;

an antenna having an antenna impedance and a cable connector element through which a cable connection is formable, the cable connector element having a location that degrades an effectiveness of an impedance transform for matching the antenna impedance with the transceiver impedance when the cable connection is formed by a cable connected to the cable connector element;

a tunable matching circuit for coupling the impedance transform between the transceiver and the antenna;

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

a control circuit coupled to the cable detection signal and a tuning input of the tunable matching circuit, the control circuit configured to:

modify, via the tuning input and in response to an indication of the cable connection state indicating that the cable is connected to the cable connector element, the impedance transform used by the tunable matching circuit to match the antenna impedance with the transceiver impedance; and

cause, via the modifying, a first system efficiency while the tunable matching circuit is modified for the presence of the cable and the cable is connected, the first system efficiency providing a substantial increase above a second system efficiency that exists

while the effectiveness of the impedance transform is degraded when a cable is connected to the cable connector.

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

3. The apparatus according to claim **1**, wherein the tunable matching circuit has a frequency range and the substantial increase is an improvement of at least 5 dB for at least one frequency in the frequency range.

4. The apparatus according to claim **3**, wherein the frequency range includes a frequency range within frequency limits 0.60 GHz and 0.80 GHz.

5. The apparatus according to claim **1**, wherein the sensor uses one of a contact switch and a magnetic switch.

6. The apparatus according to claim **1**, wherein the apparatus is a handheld cellular communication device.

7. The apparatus according to claim **1**, wherein the modification of the impedance transform used by the tunable matching circuit is achieved by switching passive electronic components that are coupled between the transceiver and the antenna.

8. An apparatus, comprising:

a transceiver having a transceiver impedance;

an antenna having an antenna impedance and a cable connector element through which a cable connection is formable, the cable connector element having a location on the apparatus that affects the antenna impedance when the cable connection is formed by a cable connected to the cable connector element;

a tunable matching circuit;

a sensor that determines a cable connection state of the cable connector element, 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 a tuning input of the tunable matching circuit, the processing system configured to:

tune, via the tuning input, the tunable matching circuit in response to the cable connection state indicating that the cable is connected to the cable connector element, the tuning causing the tunable matching circuit to select a first impedance transform and couple the selected first impedance transform between the transceiver and the antenna; and

generate, while the cable is connected, a first system efficiency, the first system efficiency providing a substantial increase above a second system efficiency, the second system efficiency existing while the cable is connected and while no cable detection signal is coupled to the processing system; or

tune the tunable matching circuit in response to the cable connection state being the state of absent, the tuning causing the tunable matching circuit to select a second impedance transform that causes the transceiver impedance to match the antenna impedance while the cable is not connected.

9. The apparatus according to claim **8**, wherein the antenna comprises an antenna element and wherein a periphery of the cable connector element is at least partially within the antenna element.

10. The apparatus according to claim **8**, wherein the tunable matching circuit has a frequency range and the substantial increase is an improvement of at least 5 dB for at least one frequency in the frequency range.

11. The apparatus according to claim **10**, wherein the frequency range includes a frequency range within frequency limits 0.60 GHz and 0.80 GHz.

12. The apparatus according to claim **8**, wherein the sensor uses one of a contact switch and a magnetic switch.

13. The apparatus according to claim **8**, wherein the apparatus is a handheld cellular communication device.

14. The apparatus according to claim **8**, wherein tuning the tunable matching circuit in response to the cable connection state is achieved by switching passive electrical components coupled between the transceiver and the antenna.

15. A method, comprising:

determining a cable connection state of a cable connector element of an antenna through which a cable connection is formable, the cable connector element degrading an effectiveness of an impedance transform of a tunable matching circuit when the cable connection is formed by a cable connected to the cable connector element;

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

modifying the impedance transform of the tunable matching circuit in response to the cable detection signal indicating a presence of the cable, the tunable matching circuit coupling the modified impedance transform between a transceiver and the antenna, the modifying causing a first system efficiency while the tunable matching circuit is modified for the presence of the cable and the cable is connected, the first system efficiency providing a substantial increase above a second system efficiency that exists while the effectiveness of the impedance transform is degraded when the cable is connected to the cable connector.

16. The method according to claim **15**, wherein the antenna comprises an antenna element and wherein a periphery of the cable connector element is disposed at least partially within the antenna element.

17. The method according to claim **15**, wherein the tunable matching circuit has a frequency range and the substantial increase is an improvement of at least 5 dB for at least one frequency in the frequency range.

18. The method according to claim **17**, wherein the frequency range includes a frequency range within frequency limits 0.60 GHz and 0.80 GHz.

19. The method according to claim **15**, wherein the cable connection state is determined by one of a contact switch and a magnetic switch.

20. The method according to claim **15**, wherein the modifying of the impedance transform of the tunable matching circuit is achieved by switching passive electrical components coupled between the transceiver and the antenna.

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