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(54) **ANTENNA TUNING CIRCUITRY WITH REDUCED INTERFERENCE**

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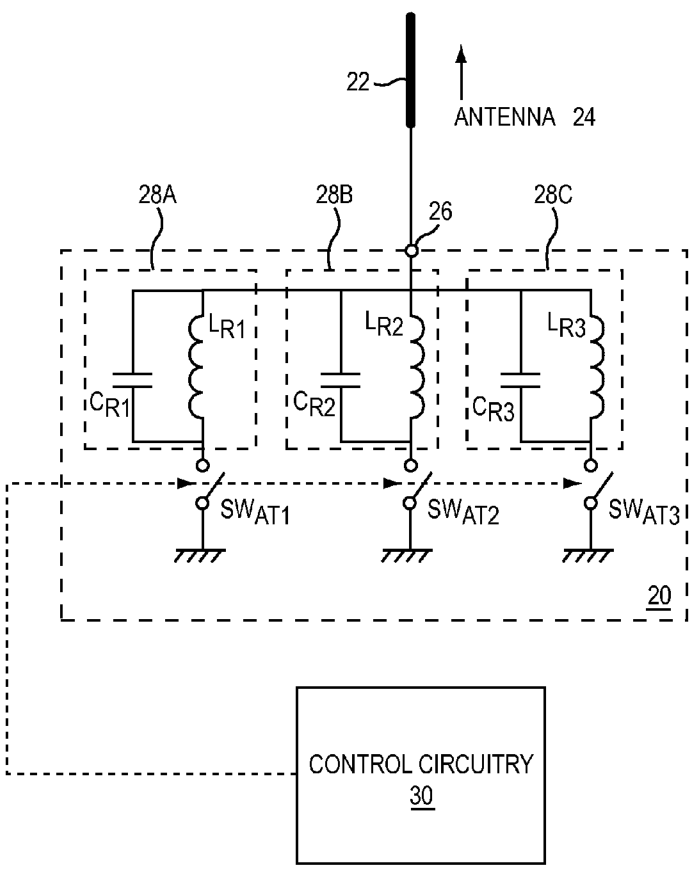
(57) **ABSTRACT**

Antenna tuning circuitry includes an antenna tuning node, an antenna tuning switch, and a resonant tuning circuit. The antenna tuning node is coupled to a resonant conduction element of an antenna. The antenna tuning switch and the resonant tuning circuit are coupled in series between the antenna tuning switch and the antenna tuning node, such that the resonant tuning circuit is between the antenna tuning node and the antenna tuning switch. The resonant tuning circuit is configured to resonate at one or more harmonic frequencies generated by the antenna tuning switch such that a high impedance path is formed between the antenna tuning switch and the antenna tuning node at harmonic frequencies generated by the antenna tuning switch. Accordingly, harmonic interference generated by the antenna tuning switch is prevented from reaching the antenna, while simultaneously allowing for tuning of the antenna.



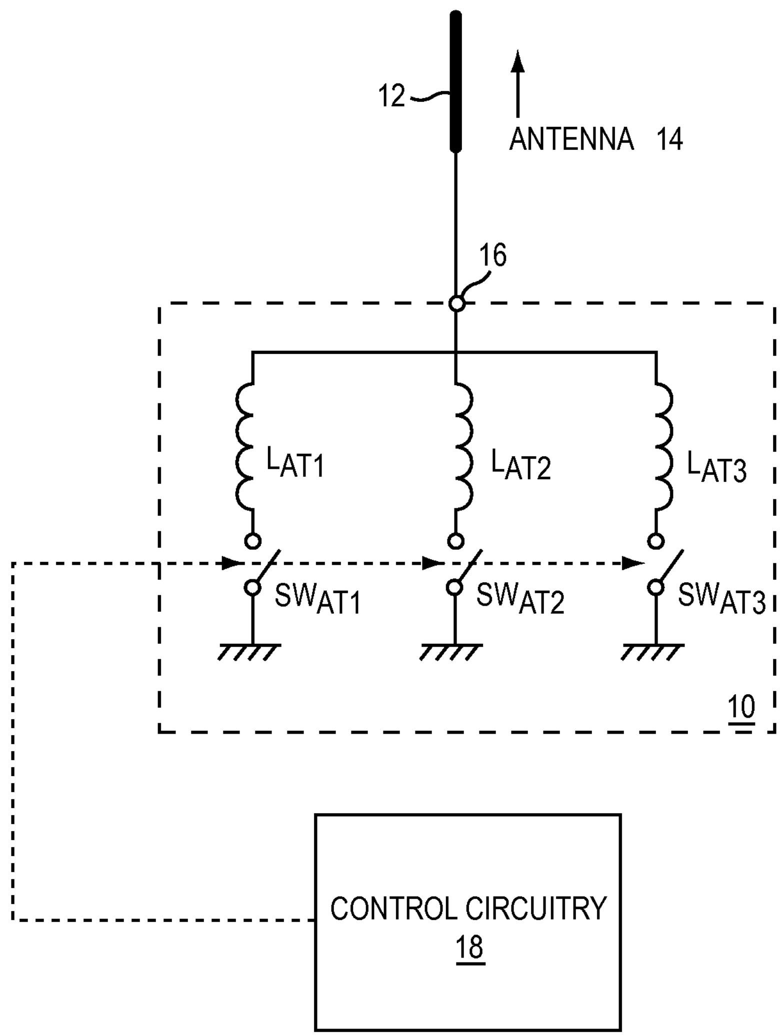


FIG. 1
(RELATED ART)

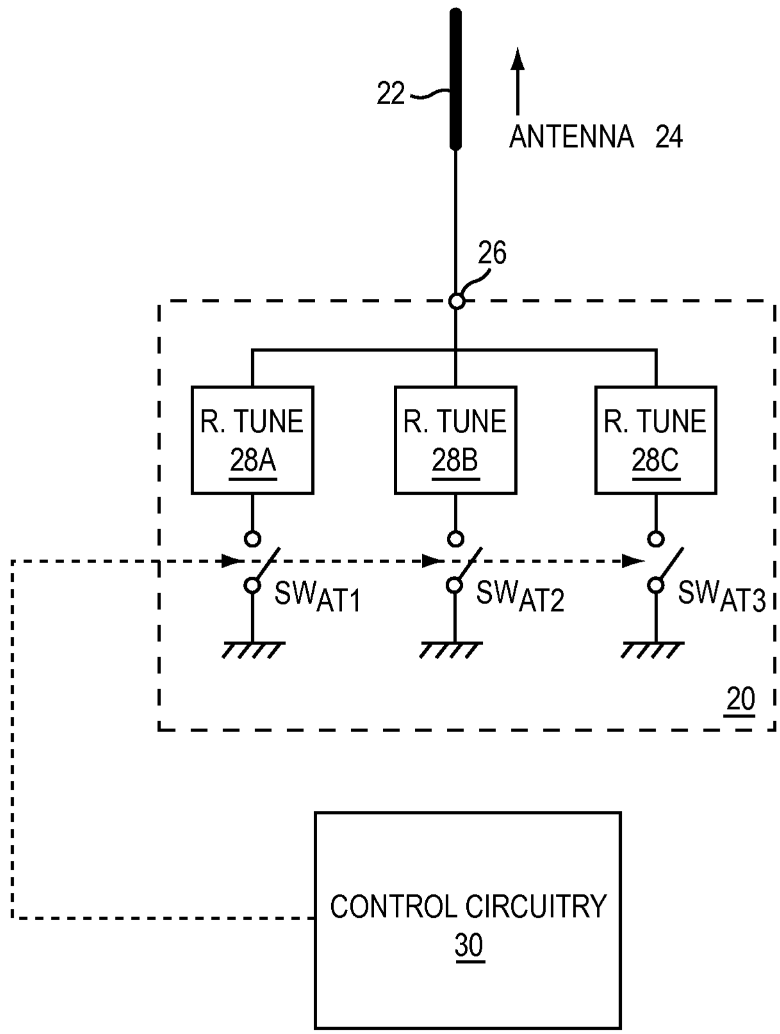

22
ANTENNA 24
26
R. TUNE
28A
R. TUNE
28B
R. TUNE
28C
SWAT1
SWAT2
SWAT3
20
CONTROL CIRCUITRY
30

FIG. 2

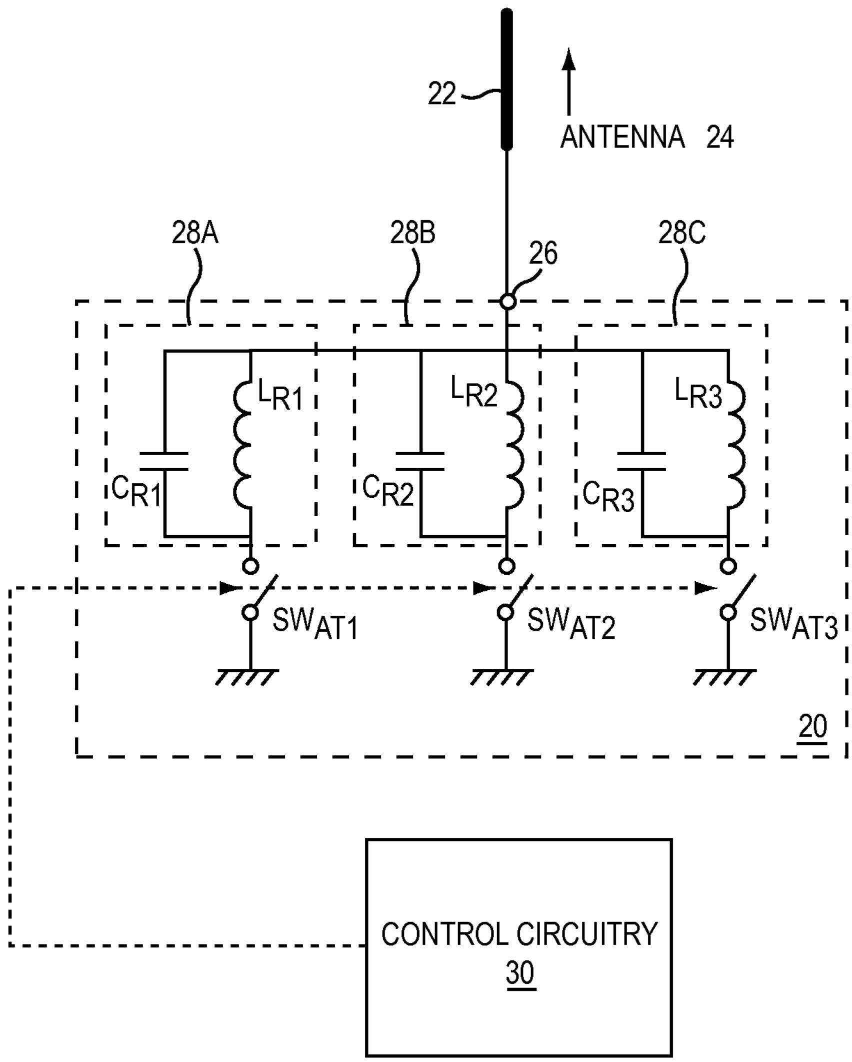

22
ANTENNA 24
28A
28B
26
28C
LR1
LR2
LR3
CR1
CR2
CR3
SWAT1
SWAT2
SWAT3
20
CONTROL CIRCUITRY
30

FIG. 3

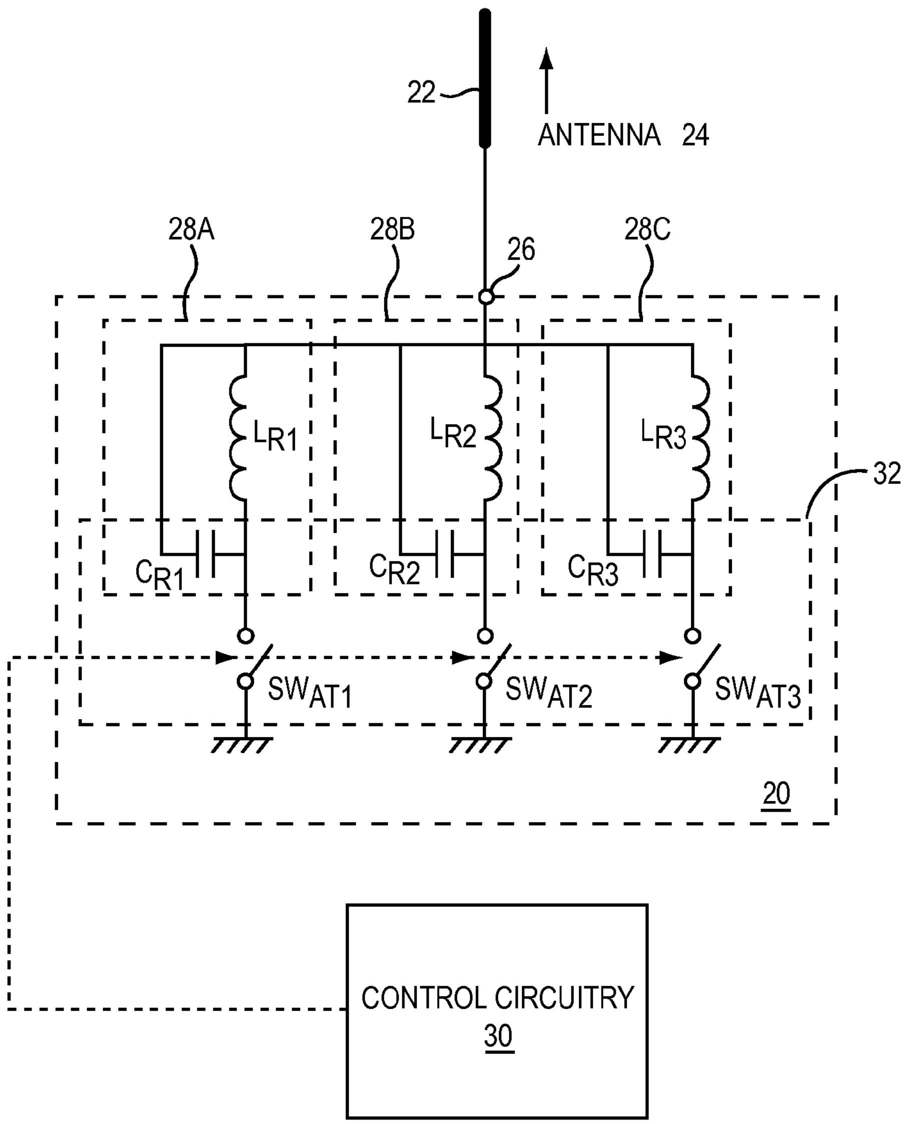

22
ANTENNA 24
28A
28B
26
28C
L_{R1}
L_{R2}
L_{R3}
32
C_{R1}
C_{R2}
C_{R3}
SW_{AT1}
SW_{AT2}
SW_{AT3}
20
CONTROL CIRCUITRY
30

FIG. 4

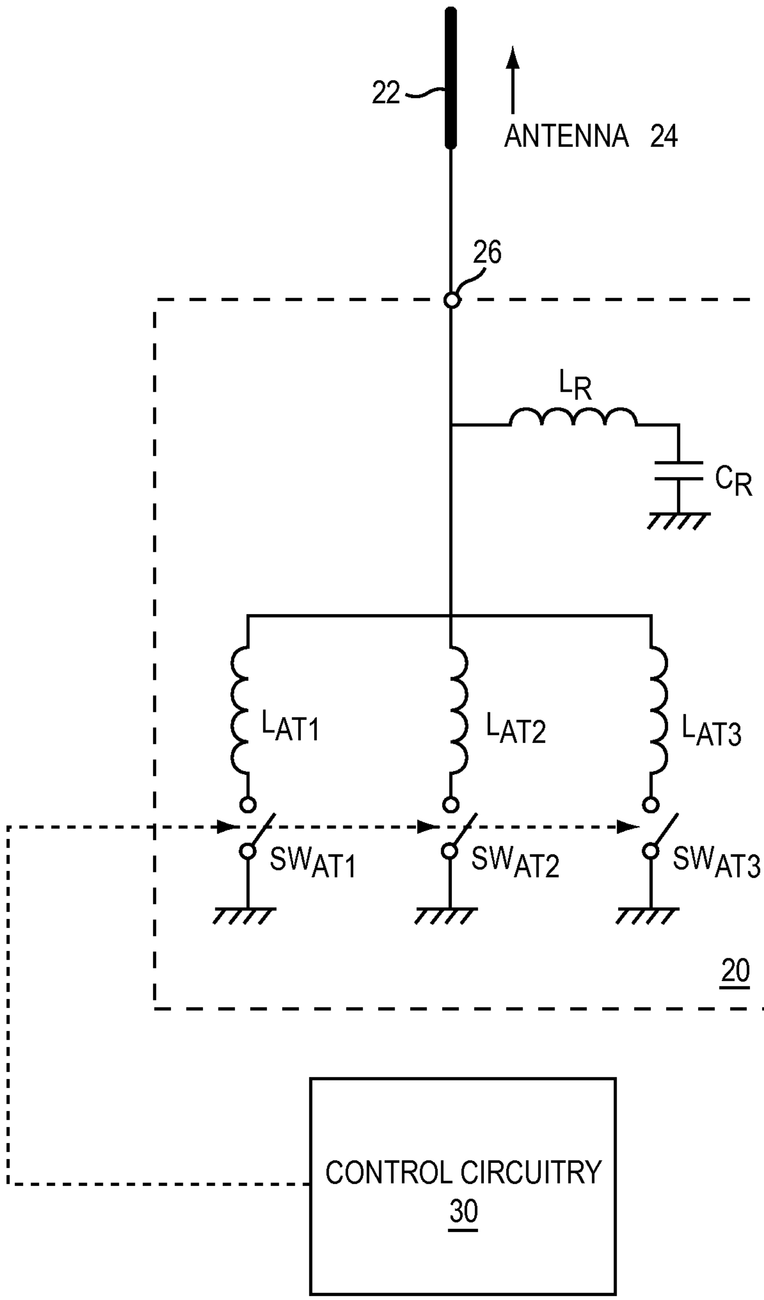

22
ANTENNA 24
26
L_R
C_R
L_{AT1}
L_{AT2}
L_{AT3}
SW_{AT1}
SW_{AT2}
SW_{AT3}
20
CONTROL CIRCUITRY
30

FIG. 5

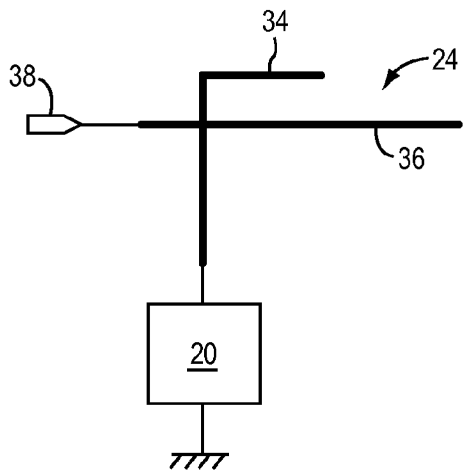


FIG. 6A

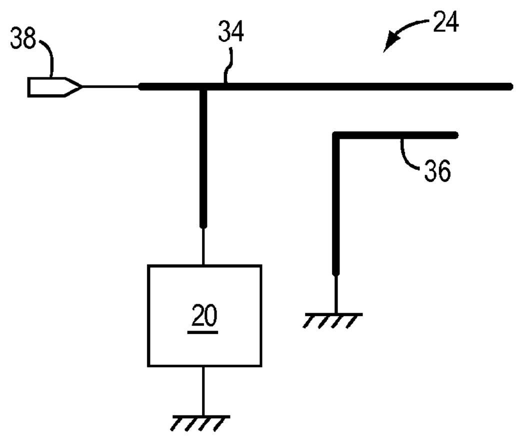


FIG. 6B

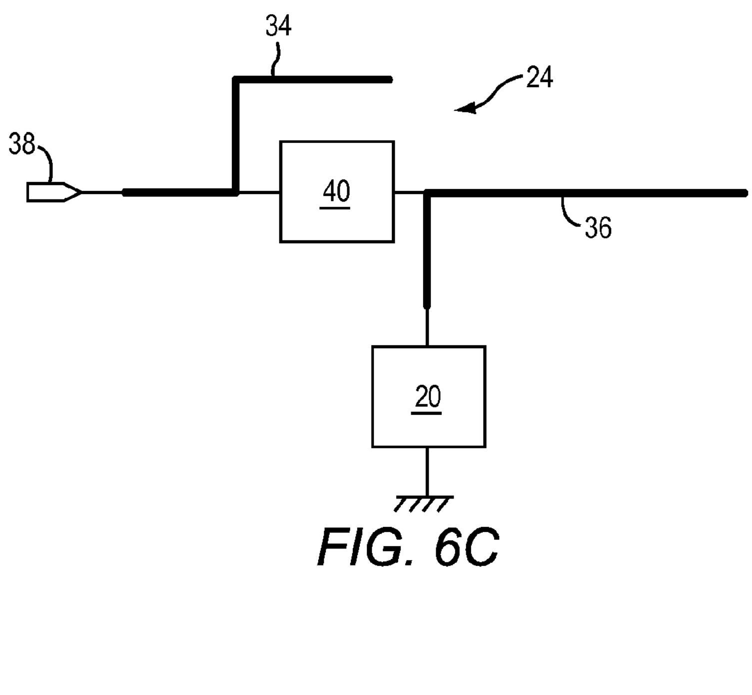


FIG. 6C

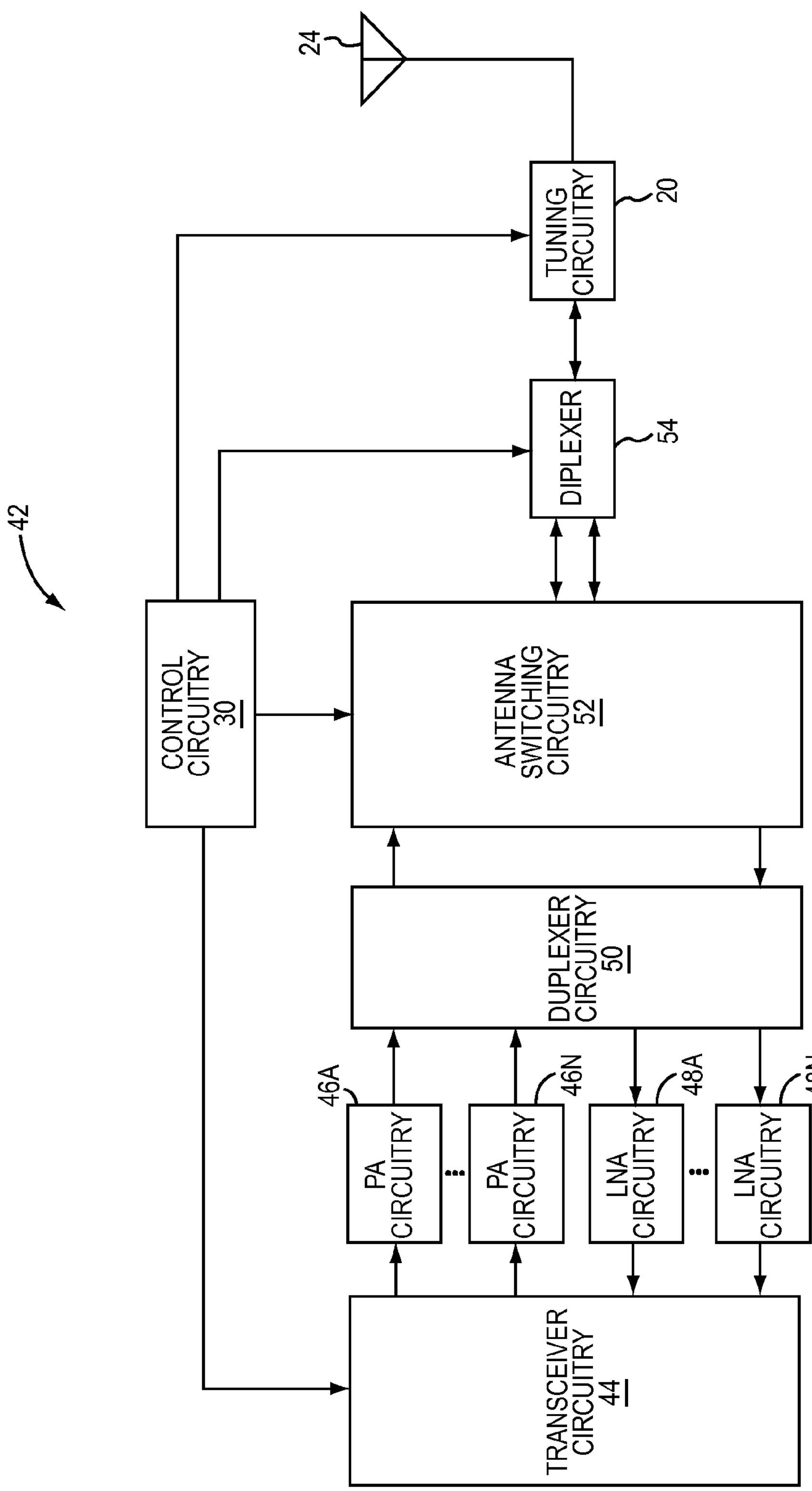

42
24
TUNING CIRCUITRY
20
DIPLEXER
54
CONTROL CIRCUITRY 30
ANTENNA SWITCHING CIRCUITRY 52
DUPLEXER CIRCUITRY 50
46A
46N
48A
48N
PA CIRCUITRY
PA CIRCUITRY
LNA CIRCUITRY
LNA CIRCUITRY
TRANSCEIVER CIRCUITRY 44

FIG. 7

ANTENNA TUNING CIRCUITRY WITH REDUCED INTERFERENCE

RELATED APPLICATIONS

[0001] This application claims the benefit of U.S. provisional patent application Ser. No. 61/868,154, filed Aug. 21, 2013, the disclosure of which is incorporated herein by reference in its entirety.

FIELD OF THE DISCLOSURE

[0002] The present disclosure relates to antenna tuning circuitry. Specifically, the present disclosure relates to antenna tuning circuitry including filtering circuitry configured to reduce harmonic distortion generated by switching elements in the antenna tuning circuitry.

BACKGROUND

[0003] Evolving wireless communications standards continue to demand extremely high performance from the antennas used in mobile handsets. Modern antennas are expected to be compact while maintaining a high quality factor and a broad operating bandwidth. Due to carrier aggregation applications, a single antenna may be required to simultaneously send and/or receive signals at five or more different bands. For example, in one carrier aggregation application, an antenna may be expected to simultaneously transmit a band **17** uplink signal, receive a band **17** downlink signal, receive a band **1** downlink signal, receive a global positioning system (GPS) signal, and send and receive WiFi signals. Generally, a standalone antenna cannot meet the demanding performance standards dictated by the wireless standards when transmitting and receiving multiple signals. Accordingly, antenna tuning circuitry is often coupled to an antenna in order to improve the performance of the antenna. Specifically, the antenna tuning circuitry is generally configured to selectively couple one or more impedances to a resonant conducting element in the antenna in order to alter the resonant frequency of the resonant conducting element. The antenna may thus be “tuned” to a specific frequency or group of frequencies, which may increase the performance of the antenna in certain operating conditions.

[0004] FIG. **1** shows conventional antenna tuning circuitry **10**. The antenna tuning circuitry **10** is coupled to a resonant conducting element **12** of an antenna **14** via an antenna tuning node **16**. The conventional antenna tuning circuitry **10** includes a first antenna tuning inductor L_{AT1}, a second antenna tuning inductor L_{AT2}, a third antenna tuning inductor L_{AT3}, a first antenna tuning switch SW_{AT1}, a second antenna tuning switch SW_{AT2}, and a third antenna tuning switch SW_{AT3}. The first antenna tuning inductor L_{AT1} is coupled in series with the first antenna tuning switch SW_{AT1} between the antenna tuning node **16** and ground. The second antenna tuning inductor L_{AT2} is coupled in series with the second antenna tuning switch SW_{AT2} between the antenna tuning node **16** and ground. Finally, the third antenna tuning inductor L_{AT3} is coupled in series with the third antenna tuning switch SW_{AT3} between the antenna tuning node **16** and ground. Control circuitry **18** is coupled to the first antenna tuning switch SW_{AT1}, the second antenna tuning switch SW_{AT2}, and the third antenna tuning switch SW_{AT3} in order to control the state of the antenna tuning switches SW_{AT}.

[0005] In operation, the control circuitry **18** opens or closes the first antenna tuning switch SW_{AT1}, the second antenna tuning switch SW_{AT2}, and/or the third antenna tuning switch SW_{AT3}, either separately or together, in order to alter the impedance of the resonant conducting element **12** of the antenna **14**. Changing the impedance of the resonant conducting element **12** effectively changes the resonant frequency thereof, thereby “tuning” the antenna **14** to a desired frequency or frequencies. Accordingly, the antenna **14** may more easily transmit or receive signals about a desired frequency or frequencies.

[0006] Although effective at “tuning” the antenna **14**, the switching components present in the conventional antenna tuning circuitry **10** may degrade the performance of the antenna **14** in certain operating conditions. Specifically, the first antenna tuning switch SW_{AT1}, the second antenna tuning switch SW_{AT2}, and/or the third antenna tuning switch SW_{AT3} may generate harmonic signals, which are subsequently delivered to receive circuitry attached to the antenna **14** and/or transmitted from the antenna **14**. Because the harmonic signals may be generated in response to a high-power transmit signal, such harmonic signals may cause desensitization of the receive circuitry, particularly when operating in a carrier aggregation configuration in which a receive frequency band includes one or more harmonic frequencies of a transmit signal. For example, a carrier aggregation configuration in which signals are simultaneously transmitted and received about bands **4** and **17** may be problematic, as the third harmonic of the band **17** uplink frequency range (704-716 MHz) falls squarely within the band **4** downlink frequency range (2110-2155 MHz).

[0007] Accordingly, there is a need for antenna tuning circuitry capable of altering the impedance and thus the resonant frequency of one or more resonant conducting elements in an antenna, while simultaneously avoiding or mitigating the generation of harmonic interference by the antenna tuning circuitry.

SUMMARY

[0008] The present disclosure relates to antenna tuning circuitry. In one embodiment, antenna tuning circuitry includes an antenna tuning node, an antenna tuning switch, and a resonant tuning circuit. The antenna tuning node is coupled to a resonant conduction element of an antenna. The antenna tuning switch and the resonant tuning circuit are coupled in series between the antenna tuning switch and the antenna tuning node, such that the resonant tuning circuit is between the antenna tuning node and the antenna tuning switch. The resonant tuning circuit is configured to resonate at one or more harmonic frequencies generated by the antenna tuning switch such that a high impedance path is formed between the antenna tuning switch and the antenna tuning node at harmonic frequencies generated by the antenna tuning switch. Accordingly, harmonic interference generated by the antenna tuning switch is prevented from reaching the antenna, while simultaneously allowing for tuning of the antenna.

[0009] In one embodiment, antenna tuning circuitry includes an antenna tuning node, an antenna tuning switch, a fixed tuning impedance, and a resonant tuning circuit. The antenna tuning node is coupled to a resonant conduction element of an antenna. The antenna tuning switch is coupled in series with the fixed tuning impedance between the antenna tuning node and ground. The resonant tuning circuit is coupled between the antenna tuning node and ground, and is configured to resonate at one or more harmonic frequencies generated by the antenna tuning switch such that a low imped-

ance path is formed between the antenna tuning switch and ground. Accordingly, harmonic interference generated by the antenna tuning switch is shorted to ground, thereby preventing the harmonic interference from reaching the antenna, while simultaneously allowing for tuning of the antenna.

[0010] In one embodiment, an antenna comprises a low-band resonant conduction element, a high-band resonant conduction element, and antenna tuning circuitry. The antenna tuning circuitry includes an antenna tuning node, an antenna tuning switch, and a resonant tuning circuit. The antenna tuning node is coupled to the high-band resonant conduction element and the low-band resonant conduction element of the antenna. The antenna tuning switch and the resonant tuning circuit are coupled in series between the antenna tuning switch and the antenna tuning node, such that the resonant tuning circuit is between the antenna tuning node and the antenna tuning switch. The resonant tuning circuit is configured to resonate at one or more harmonic frequencies generated by the antenna tuning switch such that a high impedance path is formed between the antenna tuning switch and the antenna tuning node at harmonic frequencies generated by the antenna tuning switch. Accordingly, harmonic interference generated by the antenna tuning switch is prevented from reaching the antenna, while simultaneously allowing for tuning of the antenna.

[0011] In one embodiment, an antenna comprises a low-band resonant conduction element, a high-band resonant conduction element, and antenna tuning circuitry. The antenna tuning circuitry includes an antenna tuning node, an antenna tuning switch, a fixed tuning impedance, and a resonant tuning circuit. The antenna tuning node is coupled to a resonant conduction element of an antenna. The antenna tuning switch is coupled in series with the fixed tuning impedance between the antenna tuning node and ground. The resonant tuning circuit is coupled between the antenna tuning node and ground, and is configured to resonate at one or more harmonic frequencies generated by the antenna tuning switch such that a low impedance path is formed between the antenna tuning node and ground. Accordingly, harmonic interference generated by the antenna tuning switch is shorted to ground, thereby preventing the harmonic interference from reaching the antenna, while simultaneously allowing for tuning of the antenna.

[0012] Those skilled in the art will appreciate the scope of the disclosure and realize additional aspects thereof after reading the following detailed description in association with the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

[0013] The accompanying drawings incorporated in and forming a part of this specification illustrate several aspects of the disclosure, and together with the description serve to explain the principles of the disclosure.

[0014] FIG. **1** is a schematic representation of conventional antenna tuning circuitry.

[0015] FIG. **2** is a schematic representation of antenna tuning circuitry according to one embodiment of the present disclosure.

[0016] FIG. **3** is a schematic representation of antenna tuning circuitry according to an additional embodiment of the present disclosure.

[0017] FIG. **4** is a schematic representation of antenna tuning circuitry according to an additional embodiment of the present disclosure.

[0018] FIG. **5** is a schematic representation of antenna tuning circuitry according to an additional embodiment of the present disclosure.

[0019] FIGS. **6A-6C** are schematic representations of antennas including antenna tuning circuitry according to various embodiments of the present disclosure.

[0020] FIG. **7** is a block diagram showing radio frequency front end circuitry according to one embodiment of the present disclosure.

DETAILED DESCRIPTION

[0021] The embodiments set forth below represent the necessary information to enable those skilled in the art to practice the disclosure and illustrate the best mode of practicing the disclosure. Upon reading the following description in light of the accompanying drawings, those skilled in the art will understand the concepts of the disclosure and will recognize applications of these concepts not particularly addressed herein. It should be understood that these concepts and applications fall within the scope of the disclosure and the accompanying claims.

[0022] It will be understood that, although the terms first, second, etc. may be used herein to describe various elements, these elements should not be limited by these terms. These terms are only used to distinguish one element from another. For example, a first element could be termed a second element, and, similarly, a second element could be termed a first element, without departing from the scope of the present disclosure. As used herein, the term “and/or” includes any and all combinations of one or more of the associated listed items.

[0023] Relative terms such as “below” or “above” or “upper” or “lower” or “horizontal” or “vertical” may be used herein to describe a relationship of one element, layer, or region to another element, layer, or region as illustrated in the Figures. It will be understood that these terms and those discussed above are intended to encompass different orientations of the device in addition to the orientation depicted in the Figures.

[0024] The terminology used herein is for the purpose of describing particular embodiments only and is not intended to be limiting of the disclosure. As used herein, the singular forms “a,” “an,” and “the” are intended to include the plural forms as well, unless the context clearly indicates otherwise. It will be further understood that the terms “comprises,” “comprising,” “includes,” and/or “including” when used herein specify the presence of stated features, integers, steps, operations, elements, and/or components, but do not preclude the presence or addition of one or more other features, integers, steps, operations, elements, components, and/or groups thereof.

[0025] Unless otherwise defined, all terms (including technical and scientific terms) used herein have the same meaning as commonly understood by one of ordinary skill in the art to which this disclosure belongs. It will be further understood that terms used herein should be interpreted as having a meaning that is consistent with their meaning in the context of this specification and the relevant art and will not be interpreted in an idealized or overly formal sense unless expressly so defined herein.

[0026] Turning now to FIG. **2**, antenna tuning circuitry **20** is shown according to one embodiment of the present disclosure. The antenna tuning circuitry **20** is coupled to a resonant conducting element **22** of an antenna **24** through an antenna tuning node **26**. The antenna tuning circuitry **20** includes a first resonant tuning circuit **28**A, a second resonant tuning circuit **28**B, a third resonant tuning circuit **28**C, a first antenna tuning switch SW_{AT1}, a second antenna tuning switch SW_{AT2}, and a third antenna tuning switch SW_{AT3}. The first resonant tuning circuit **28**A is coupled in series with the first antenna tuning switch SW_{AT1} between the antenna tuning node **26** and ground. The second resonant tuning circuit **28**B is coupled in series with the second antenna tuning switch SW_{AT2} and ground. The third resonant tuning circuit **28**C is coupled in series with the third antenna tuning switch SW_{AT3} between the antenna tuning node **26** and ground. Control circuitry **30** is coupled to each one of the first antenna tuning switch SW_{AT1}, the second antenna tuning switch SW_{AT2}, and the third antenna tuning switch SW_{AT3}, in order to control the state of each one of the antenna tuning switches SW_{AT}.

[0027] The first resonant tuning circuit **28**A, the second resonant tuning circuit **28**B, and the third resonant tuning circuit **28**C are each associated with a particular impedance, which may be the same or different from one to the next. In operation, the control circuitry **30** opens and closes the first antenna tuning switch SW_{AT1}, the second antenna tuning switch SW_{AT2}, and/or the third antenna tuning switch SW_{AT3}, either separately or together, in order to alter the impedance of the resonant conducting element **22** of the antenna **24**. Changing the impedance of the resonant conducting element **22** effectively changes the resonant frequency thereof, thereby "tuning" the antenna **24** to a desired frequency or frequencies. Accordingly, the antenna **24** may more easily transmit or receive signals about a desired frequency or frequencies. Additionally, the first resonant tuning circuit **28**A, the second resonant tuning circuit **28**B, and the third resonant tuning circuit **28**C are each configured to resonate at one or more harmonic frequencies generated by the antenna tuning switch SW_{AT} to which they are attached, as discussed in further detail below. When the first resonant tuning circuit **28**A, the second resonant tuning circuit **28**B, and the third resonant tuning circuit **28**C resonate, they each produce a substantially high impedance, thereby blocking harmonic signals generated by the antenna tuning switch SW_{AT} coupled to the circuitry from reaching the antenna tuning node **26** and thus the antenna **24**. Accordingly, the antenna **24** may be tuned while simultaneously avoiding problematic harmonic distortion.

[0028] Although three resonant tuning circuits **28** coupled in series with three antenna tuning switches SW_{AT} are shown in FIG. **2**, any number of antenna tuning switches SW_{AT} and corresponding resonant tuning circuits **28** may be used without departing from the principles of the present disclosure. Further, one or more static impedance elements, for example, a tuning inductor or a tuning capacitor (not shown), may additionally be coupled between the antenna tuning node **26** and ground in some embodiments. Since the static impedance elements do not contain switching elements that may generate problematic harmonic signals, a resonant tuning circuit **28** is not required to be coupled in series with these elements. The control circuitry **30** may store one or more antenna tuning switch configuration presets, such that a particular configuration of the antenna tuning switches SW_{AT} is associated with transmitting or receiving a particular signal, and thus is implemented in that scenario. Each one of the resonant tuning circuits **28** may comprise any suitable components capable of providing a desired impedance while also resonating at one or more harmonic frequencies of the antenna tuning switch SW_{AT} to which the resonant tuning circuit **28** is coupled. The antenna tuning switches SW_{AT} may be field-effect transistors (FETs), metal-oxide-semiconductor field-effect transistors (MOSFETs), insulated gate bipolar-junction transistors (IGBTs), high electron mobility transistors (HEMTs), bipolar junction transistors (BJTs), or the like. Further, the antenna tuning switches SW_{AT} may be fabricated in a variety of material systems, for example, silicon (Si), semiconductor on insulator (SOI), gallium arsenide (GaAs), gallium nitride (GaN), and the like. In one embodiment, one or more portions of the resonant tuning circuits **28** are monolithically integrated on a semiconductor die with the antenna tuning switches SW_{AT}, as discussed in further detail below.

[0029] FIG. **3** shows details of the antenna tuning circuitry **20** according to one embodiment of the present disclosure. As shown in FIG. **3**, the first resonant tuning circuit **28**A includes a first resonant capacitor C_{R1} coupled in parallel with a first resonant inductor L_{R1} between the antenna tuning node **26** and the first antenna tuning switch SW_{AT1}. The second resonant tuning circuit **28**B includes a second resonant capacitor C_{R2} coupled in parallel with a second resonant inductor L_{R2} between the antenna tuning node **26** and the second antenna tuning switch SW_{AT2}. The third resonant tuning circuit **28**C includes a third resonant capacitor C_{R3} coupled in parallel with a third resonant inductor L_{R3} between the antenna tuning node **26** and the third antenna tuning switch SW_{AT3}.

[0030] As discussed above, the values of the first resonant capacitor C_{R1} and the first resonant inductor L_{R1} are chosen such that the parallel combination of the first resonant capacitor C_{R1} and the first resonant inductor L_{R1} provides a desirable impedance value for presenting to the antenna tuning node **26** in order to tune the resonant conducting element **22** of the antenna **24**, while simultaneously resonating at one or more harmonic frequencies generated by the first antenna tuning switch SW_{AT1} in order to block harmonic signals generated by the first antenna tuning switch SW_{AT1} from reaching the antenna tuning node **26** and thus the resonant conducting element **22** of the antenna **24**. The values of the second resonant capacitor C_{R2}, the second resonant inductor L_{R2}, the third resonant capacitor C_{R3}, and the third resonant inductor L_{R3} are chosen similarly, such that the combination of the second resonant capacitor C_{R2} and the second resonant inductor L_{R2} and the combination of the third resonant capacitor C_{R3} and the third resonant inductor L_{R3} provide a desirable impedance value for presenting to the antenna tuning node **26** in order to tune the resonant conducting element **22** of the antenna **24**, while simultaneously resonating at one or more harmonic frequencies generated by the second antenna tuning switch SW_{AT2} and the third antenna tuning switch SW_{AT3}, respectively in order to block harmonic signals generated by the second antenna tuning switch SW_{AT2} and the third antenna tuning switch SW_{AT3} from reaching the antenna tuning node **26** and thus the resonant conducting element **22** of the antenna **24**.

[0031] FIG. **4** shows details of the antenna tuning circuitry **20** according to an additional embodiment of the present disclosure. The antenna tuning circuitry **20** shown in FIG. **4** is substantially similar to that shown in FIG. **3**, but illustrates that each one of the first resonant capacitor C_{R1}, the second resonant capacitor C_{R2}, the third resonant capacitor C_{R3}, the first antenna tuning switch SW_{AT1}, the second antenna tuning switch SW_{AT2}, and the third antenna tuning switch SW_{AT3}, may be monolithically integrated on a semiconductor die, as illustrated by the dashed box **32**. Monolithically integrating the first resonant capacitor C_{R1}, the second resonant capacitor C_{R2}, the third resonant capacitor C_{R3}, the first antenna tuning switch SW_{AT1}, the second antenna tuning switch SW_{AT2}, and the third antenna tuning switch SW_{AT3} on a semiconductor die saves space in the antenna tuning circuitry **20**, and further may reduce interference generated by trace inductances from connections between the various components.

[0032] FIG. **5** shows the antenna tuning circuitry **20** according to an additional embodiment of the present disclosure. The antenna tuning circuitry **20** is coupled to the resonant conducting element **22** of the antenna **24** through the antenna tuning node **26**. The antenna tuning circuitry **20** includes a resonant capacitor C_R coupled in series with a resonant inductor L_R between the antenna tuning node **26** and ground. Further, the antenna tuning circuitry **20** includes a first fixed tuning impedance (e.g., a first antenna tuning inductor L_{AT1}) coupled in series with a first antenna tuning switch SW_{AT1} between the antenna tuning node **26** and ground, a second fixed tuning impedance (e.g., a second antenna tuning inductor L_{AT2}) coupled in series with a second antenna tuning switch SW_{AT2} between the antenna tuning node **26** and ground, and a third fixed tuning impedance (e.g., a third antenna tuning inductor L_{ATS}) coupled in series with a third antenna tuning switch SW_{AT3} between the antenna tuning node **26** and ground. Although the fixed antenna tuning impedances are shown in FIG. **5** as antenna tuning inductors L_{AT}, any suitable fixed impedance components may be used for the fixed tuning impedances without departing from the principles of the present disclosure. The control circuitry **30** is coupled to each one of the first antenna tuning switch SW_{AT1}, the second antenna tuning switch SW_{AT2}, and the third antenna tuning switch SW_{AT3}, in order to control the state of each one of the antenna tuning switches SW_{AT}.

[0033] The resonant capacitor C_R and the resonant inductor L_R are configured to resonate at one or more harmonic frequencies generated by the first antenna tuning switch SW_{AT1}, the second antenna tuning switch SW_{AT2}, and the third antenna tuning switch SW_{AT3}. When the resonant capacitor C_R and the resonant inductor L_R resonate, they produce a substantially low impedance path from the antenna tuning node **26** to ground, thereby shorting harmonic signals generated by the first antenna tuning switch SW_{AT1}, the second antenna tuning switch SW_{AT2}, and the third antenna tuning switch SW_{AT3} to ground and preventing harmonic distortion from reaching the antenna **24**. Accordingly, the antenna **24** may be tuned while simultaneously avoiding problematic harmonic distortion.

[0034] FIGS. **6**A through **6**C show various configurations of the antenna **24** including antenna tuning circuitry **20**. In FIG. **6**A, the antenna **24** includes a high-band resonant conducting element **34**, a low-band resonant conducting element **36**, an antenna feed **38**, and the antenna tuning circuitry **20**. The antenna **24** may be a microstrip antenna, and the high-band resonant conducting element **34** and the low-band resonant conducting element **36** may each be "inverted-L" elements. The antenna tuning circuitry **20** is coupled to the high-band resonant conducting element **34** and the low-band resonant conducting element **36** through the antenna tuning node **26**. The control circuitry **30** may be coupled to the antenna tuning circuitry **20** in order to control when each one of the switches therein is opened or closed.

[0035] FIG. **6**B shows an alternative configuration of the antenna **24**. The antenna **24** shown in FIG. **6**B is substantially similar to that shown in FIG. **6**A, except that the high-band resonant conducting element **34** is not attached to the low-band resonant conducting element **36**, but rather is left floating as a non-coupled element. In this case, the antenna tuning circuitry **20** may be coupled only to the low-band resonant conducting element **36**, rather than both the high-band resonant conducting element **34** and the low-band resonant conducting element **36**.

[0036] FIG. **6**C shows yet another configuration of the antenna **24**. The antenna **24** shown in FIG. **6**C is substantially similar to that shown in FIG. **6**A and FIG. **6**B, except that the high-band resonant conducting element **34** is separated from the low-band resonant conducting element **36** by coupling circuitry **40**, such that the high-band resonant conducting element **34** is coupled to the antenna feed **38**. In this case, the antenna tuning circuitry **20** may be coupled to the low-band resonant conducting element **36**, and in turn coupled to the high-band resonant conducting element **34** via the coupling circuitry **40**. In some embodiments, the coupling circuitry **40** may also be the antenna tuning circuitry **20** discussed above.

[0037] FIG. **7** shows radio frequency (RF) front end circuitry **42** including antenna tuning circuitry **20** according to one embodiment of the present disclosure. The basic architecture of the RF front end circuitry **42** includes transceiver circuitry **44**, a plurality of power amplifiers **46**A-**46**N, a plurality of low noise amplifiers **48**A-**48**N, duplexer circuitry **50**, antenna switching circuitry **52**, a diplexer **54**, the antenna tuning circuitry **20**, the antenna **24**, and the control circuitry **30**. When receiving a signal, the antenna **24** of the RF front end circuitry **42** receives information bearing radio frequency signals at a receive frequency from one or more remote transmitters provided by a base station (not shown). The radio frequency signals pass through the antenna tuning circuitry **20**, which may have previously set the impedance of the antenna **24** in order to optimize reception of signals about a desired receive frequency, to the diplexer **54**, where the signals are filtered into their low band and high band components and delivered to the antenna switching circuitry **52**. The antenna switching circuitry **52** selectively couples one or more terminals of the diplexer **54** to one or more of the plurality of low noise amplifiers **48**A-**48**N through the duplexer circuitry **50**.

[0038] One or more of the plurality of low noise amplifiers **48**A-**48**N amplify the received components of the radio frequency signals and deliver them to the transceiver circuitry **44**, where they may be subsequently processed and used by the RF front end circuitry **42**.

[0039] On the transmit side, the transceiver circuitry **44** receives digitized data, which may represent voice, data, or control information. The encoded data is modulated to produce a carrier signal at a desired transmit frequency. The carrier signal is then delivered to one or more of the plurality of power amplifiers **46**A-**46**N, where it is amplified and delivered to the antenna switching circuitry **52**, which may have previously set the impedance of the antenna **24** in order to optimize transmission of signals about a desired frequency, through the duplexer circuitry **50**. The antenna switching circuitry **52** selectively couples one or more output terminals of the plurality of power amplifiers **46**A-**46**N to the diplexer **54**. The carrier signal is then filtered by the diplexer **54**, and delivered through the antenna tuning circuitry **20** to the antenna **24**. As discussed above, the antenna tuning circuitry **20** is configured to ensure optimal operation of the antenna **24** over a wide bandwidth, thereby increasing the performance of the RF front end circuitry **42**. The control circuitry **30** may be configured to control not only the antenna tuning circuitry

20, but also one or more additional operating parameters of the transceiver circuitry 44, the antenna switching circuitry 52, and/or the diplexer 54.

[0040] Those skilled in the art will recognize improvements and modifications to the embodiments of the present disclosure. All such improvements and modifications are considered within the scope of the concepts disclosed herein and the claims that follow.

What is claimed is:

1. Antenna tuning circuitry comprising:
an antenna tuning node coupled to a resonant conduction element of an antenna;
an antenna tuning switch; and
a resonant tuning circuit coupled between the antenna tuning switch and the antenna tuning node and configured to resonate at one or more harmonic frequencies generated by the antenna tuning switch such that a high impedance path is formed between the antenna tuning switch and the antenna tuning node at the one or more harmonic frequencies generated by the antenna tuning switch.

2. The antenna tuning circuitry of claim 1 wherein the resonant tuning circuit comprises a resonant capacitor coupled in parallel with a resonant inductor.

3. The antenna tuning circuitry of claim 2 wherein the resonant capacitor and the antenna tuning switch are monolithically integrated on a semiconductor die.

4. The antenna tuning circuitry of claim 3 wherein the semiconductor die is a silicon-on-insulator (SOI) semiconductor die.

5. The antenna tuning circuitry of claim 1 wherein the antenna tuning circuitry further comprises:
an additional antenna tuning switch; and
an additional resonant tuning circuit coupled between the additional antenna tuning switch and the antenna tuning node and configured to resonate at one or more harmonic frequencies of the additional antenna tuning switch such that a high impedance path is formed between the additional antenna tuning switch and the antenna tuning node at the one or more harmonic frequencies generated by the antenna tuning switch.

6. The antenna tuning circuitry of claim 5 wherein the resonant tuning circuit and the additional resonant tuning circuit each comprise a resonant capacitor coupled in parallel with a resonant inductor.

7. The antenna tuning circuitry of claim 6 wherein each one of the resonant tuning capacitors in the resonant tuning circuit and the additional resonant tuning circuit, the antenna tuning switch, and the additional antenna tuning switch, are monolithically integrated on a semiconductor die.

8. The antenna tuning circuitry of claim 7 wherein the semiconductor die is a silicon-on-insulator (SOI) semiconductor die.

9. Antenna tuning circuitry comprising:
an antenna tuning node coupled to a resonant conduction element of an antenna;
an antenna tuning switch coupled in series with a fixed tuning impedance between the antenna tuning node and ground; and
a resonant tuning circuit coupled between the antenna tuning node and ground and configured to resonate at one or more harmonic frequencies of the antenna tuning switch such that a low impedance path is formed between the antenna tuning node and ground at the one or more harmonic frequencies generated by the antenna tuning switch.

10. The antenna tuning circuitry of claim 9 wherein the resonant tuning circuit comprises a resonant capacitor coupled in series with a resonant inductor.

11. The antenna tuning circuitry of claim 10 wherein the resonant capacitor and the antenna tuning switch are monolithically integrated on a semiconductor die.

12. The antenna tuning circuitry of claim 11 wherein the semiconductor die is a silicon-on-insulator (SOI) semiconductor die.

13. The antenna tuning circuitry of claim 9 wherein the antenna tuning circuitry further comprises an additional antenna tuning switch and an additional fixed tuning impedance coupled in series between the antenna tuning node and ground.

14. An antenna comprising:
a low-band resonant conduction element;
a high-band resonant conduction element; and
antenna tuning circuitry comprising:
an antenna tuning node coupled to a resonant conduction element of an antenna;
an antenna tuning switch; and
a resonant tuning circuit coupled between the antenna tuning switch and the antenna tuning node and configured to resonate at one or more harmonic frequencies of the antenna tuning switch such that a high impedance path is formed between the antenna tuning switch and the antenna tuning node at the one or more harmonic frequencies generated by the antenna tuning switch.

15. The antenna of claim 14 wherein the resonant tuning circuit comprises a resonant capacitor coupled in parallel with a resonant inductor.

16. The antenna of claim 15 wherein the resonant capacitor and the antenna tuning switch are monolithically integrated on a semiconductor die.

17. The antenna of claim 16 wherein the semiconductor die is a silicon-on-insulator (SOI) semiconductor die.

18. The antenna of claim 14 wherein the antenna tuning circuitry further comprises:
an additional antenna tuning switch; and
an additional resonant tuning circuit coupled between the additional antenna tuning switch and the antenna tuning node and configured to resonate at one or more harmonic frequencies of the additional antenna tuning switch such that a high impedance path is formed between the additional antenna tuning switch and the antenna tuning node at the one or more harmonic frequencies generated by the antenna tuning switch.

19. The antenna of claim 18 wherein the resonant tuning circuit and the additional resonant tuning circuit each comprise a resonant capacitor coupled in parallel with a resonant inductor.

20. The antenna of claim 19 wherein each one of the resonant tuning capacitors in the resonant tuning circuit and the additional resonant tuning circuit, the antenna tuning switch, and the additional antenna tuning switch, are monolithically integrated on a semiconductor die.

21. The antenna of claim 20 wherein the semiconductor die is a silicon-on-insulator (SOI) semiconductor die.

22. The antenna of claim 14 wherein the antenna is configured to simultaneously:

receive a high-band receive signal via the high-band resonant conduction element; and

transmit a low-band transmit signal via the low-band resonant conduction element.

23. The antenna of claim **22** wherein the resonant tuning circuit is configured to resonate at one or more harmonic frequencies of the low-band transmit signal.

24. The antenna of claim **23** wherein the low-band transmit signal is a band **17** uplink signal with a frequency range between about 704-716 MHz and the high-band receive signal is a band **4** downlink signal with a frequency range between about 2110-2155 MHz.

25. The antenna of claim **24** wherein the resonant tuning circuit is configured to resonate at a third harmonic frequency of the low-band transmit signal.

26. An antenna comprising:

a low-band resonant conduction element;

a high-band resonant conduction element; and

antenna tuning circuitry comprising:

an antenna tuning node coupled to a resonant conduction element of the antenna;

an antenna tuning switch coupled in series with a fixed tuning impedance between the antenna tuning node and ground; and

a resonant tuning circuit coupled between the antenna tuning node and ground and configured to resonate at one or more harmonic frequencies of the antenna tuning switch such that a low impedance path is formed between the antenna tuning node and ground at the one or more harmonic frequencies generated by the antenna tuning switch.

27. The antenna of claim **26** wherein the resonant tuning circuit comprises a resonant capacitor coupled in series with a resonant inductor.

28. The antenna of claim **27** wherein the resonant capacitor and the antenna tuning switch are monolithically integrated on a semiconductor die.

29. The antenna of claim **28** wherein the semiconductor die is a silicon-on-insulator (SOI) semiconductor die.

30. The antenna of claim **26** wherein the antenna tuning circuitry further comprises an additional antenna tuning switch and an additional fixed tuning impedance coupled in series between the antenna tuning node and ground.

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