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(54) Title: MULTIFREQUENCY RECONFIGURABLE TRANSCEIVER SYSTEMS AND METHODS

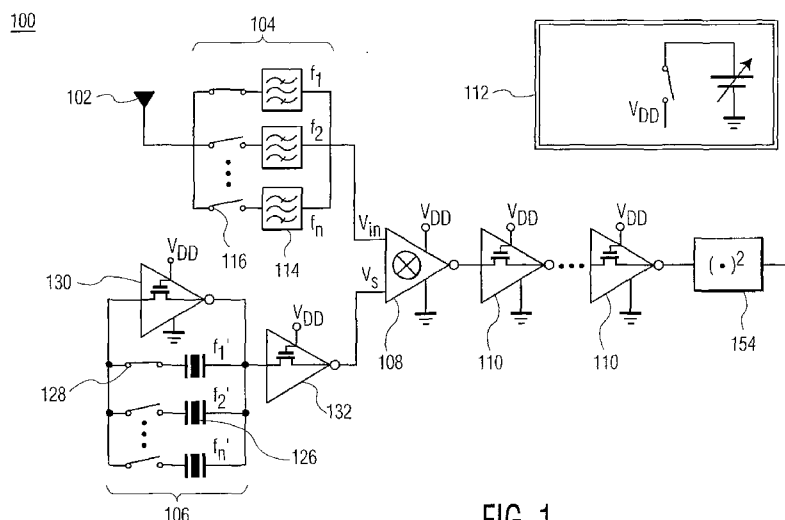


FIG. 1

(57) Abstract: Multifrequency reconfigurable communication systems and methods are disclosed. The system includes a tunable power supply, a tunable mixer, and a tunable amplifier. The tunable mixer is configured to receive a supply voltage dependent at least in part on a voltage provided by the tunable power supply and an input signal at the mixer input. The tunable mixer is further configured generate an output signal based at least in part on the input signal and the supply voltage. The tunable amplifier is configured to receive a supply voltage dependent at least in part on the voltage provided by the tunable power supply and the output signal from the tunable mixer at the amplifier input. The tunable amplifier is further configured to amplify the output signal based at least in part on the supply voltage.



MULTIFREQUENCY RECONFIGURABLE TRANSCEIVER SYSTEMS AND METHODS

CROSS REFERENCE TO RELATED APPLICATIONS

This application claims priority to U.S. Patent Application No. 61/370,500,
5 filed on August 4, 2010, the contents of which are incorporated herein by reference in
their entirety. This application also claims priority to U.S. Patent Application
No. 61/419,568, filed on December 3, 2010, the contents of which are incorporated
herein by reference in their entirety.

FIELD

10 The present invention relates generally to wireless communication
systems, and more particularly to multifrequency reconfigurable RF communication
systems.

BACKGROUND

15 Wireless transmitters and receivers are essential building blocks in the
implementation of wireless communication systems. Wireless communication may occur
over a wide range of frequencies. It is important that wireless communications systems
be able to take advantage of this wide range of frequencies in order to optimize wireless
data communication. Improved wireless transmitters and receivers that utilize a wide
range of frequencies are therefore desirable.

SUMMARY

20 Aspects of the present invention are related to multifrequency
reconfigurable communication systems and methods.

In accordance with one aspect of the present invention, a multifrequency
reconfigurable communication system is disclosed. The system includes a tunable power
25 supply, a tunable mixer, and a tunable amplifier. The tunable power supply is operable
to provide a voltage. The tunable mixer has a mixer input and a mixer output. The
tunable mixer is configured to receive a supply voltage dependent at least in part on the
voltage provided by the tunable power supply and an input signal at the mixer input.
The tunable mixer is further configured generate an output signal based at least in part
30 on the input signal and the supply voltage. The tunable amplifier has an amplifier input
and an amplifier output. The tunable amplifier is configured to receive a supply voltage
dependent at least in part on the voltage provided by the tunable power supply and the
output signal from the tunable mixer at the amplifier input. The tunable amplifier is
35 further configured to amplify the output signal based at least in part on the supply
voltage.

In accordance with another aspect of the present invention, a method of
operating a multifrequency reconfigurable communication system is disclosed. The

method comprises the steps of providing a voltage with a tunable power supply, generating an output signal with a tunable mixer, the tunable mixer configured to receive a supply voltage dependent at least in part on the voltage provided by the tunable power supply and an input signal, the tunable mixer further configured to generate the output signal based at least in part on the input signal and the supply voltage, and amplifying the output signal with a tunable amplifier, the tunable amplifier configured to receive a supply voltage dependent at least in part on the voltage provided by the tunable power supply and the output signal from the tunable mixer, the tunable amplifier further configured to amplify the output signal based at least in part on the supply voltage.

BRIEF DESCRIPTION OF THE DRAWINGS

The invention is best understood from the following detailed description when read in connection with the accompanying drawings. It is emphasized that, according to common practice, the various features of the drawings are not to scale. On the contrary, the dimensions of the various features may be arbitrarily expanded or reduced for clarity. Included in the drawings are the following figures:

FIG. 1 is a schematic drawing of an exemplary receiver system in accordance with aspects of the present invention;

FIG. 2 is a schematic drawing with photomicrographs of an exemplary filter of the receiver system of FIG. 1;

FIG. 3 is a cut-away side plan view of an exemplary switch of the receiver system of FIG. 1;

FIG. 4 is a schematic diagram with photomicrographs of an exemplary local oscillator of the receiver system of FIG. 1;

FIG. 5 is a schematic diagram of an exemplary tunable mixer of the receiver system of FIG. 1;

FIG. 6 is a graph of conversion gain versus voltage which is useful for describing the tunable mixer of FIG. 5;

FIG. 7 is a schematic diagram of an exemplary tunable amplifier of the receiver system of FIG. 1;

FIG. 8 is a schematic diagram of an alternative exemplary tunable amplifier of the receiver system of FIG. 1;

FIG. 9A is a graph of transconductance versus supply voltage which is useful for describing the tunable amplifier of FIG. 7;

FIG. 9B is a graph of voltage gain versus frequency which is useful for describing the tunable amplifier of FIG. 7;

FIG. 10 is a schematic diagram of an exemplary transmitter system in accordance with aspects of the present invention; and

FIG. 11 is a flow chart of an exemplary method of operating a receiver system in accordance with aspects of the present invention.

DETAILED DESCRIPTION

The exemplary systems and methods disclosed herein provide a tunable and scalable architecture for multifrequency reconfigurable wireless transmitters, receivers, or transceivers. This architecture may enable efficient spectral utilization. For example, the disclosed communication systems and methods may be operable to selectively process wireless signals (e.g., RF signals) over a wide frequency range. The disclosed communication systems and methods may further be operable to rapidly switch between frequency bands and communications standards. Exemplary wireless communications standards that may be employed by the disclosed systems and methods include, for example, Global System for Mobile communications (GSM), Personal Communications Service (PCS), Code Division Multiple Access 2000 (CDMA2000), and Wideband Code Division Multiple Access (WCDMA).

The exemplary systems and methods disclosed herein may be particularly suitable to provide a RF architecture that can perform both channel selection and frequency synthesis over a wide range of frequencies with a single transceiver. The disclosed communication systems and methods may achieve high level chip-scale integration and low power consumption. For example, the disclosed systems and methods may employ components having both high quality factors (Q) and CMOS compatibility. Suitable components include RF MicroElectroMechanical Systems (MEMS) components, including MEMS resonators.

One exemplary MEMS resonator usable with the disclosed systems and methods is a contour-mode piezoelectric resonator. The resonator includes a piezoelectric layer sandwiched between top and bottom electrodes. The piezoelectric layer may desirably comprise aluminum nitride (AlN). The piezoelectric layer has a planar surface with a cantilevered periphery. The surface of the piezoelectric layer may be rectangular or disc-shaped. The dimensions of the piezoelectric layer are chosen such that the resonator undergoes in-plane lateral displacement at its periphery. When a suitable alternating electric field is applied across the top and bottom electrodes of the resonator, the resonator experiences a contour mode in-plane lateral displacement that is substantially in the plane of the planar surface of the resonator. The frequency of the applied alternating electric field may be selected to be in the radio frequency (RF) range.

A suitable aluminum nitride contour-mode RF MEMS piezoelectric resonator is disclosed in U.S. Patent Application Publication No. 2006/0290449 A1 to Piazza et al., which is incorporated herein by reference in its entirety for its teachings on MEMS resonators. Aluminum nitride contour-mode resonators may reliably cover a wide range of frequencies, from 10 MHz up to several GHz (operating in the fundamental

mode of mechanical vibration) on the same silicon chip. Such resonators may also offer high Q (1,000-4,000) and low motional resistance (25-500 Ω) in air, thereby allowing the resonators to be easily interfaced to conventional electronics without the need for special circuit design or complicated matching networks. Aluminum nitride contour mode MEMS technology may be used to fabricate channel-select filters having passbands in a wide frequency range, including but not limited to 100 MHz to 2 GHz, or oscillators having resonant frequencies in a wide range of frequencies including but not limited to from 100 MHz to 1 GHz. When implemented as filters, the disclosed resonators may achieve a narrow fractional bandwidth (approximately 0.2%), low insertion loss (less than approximately 2 dB), high off-band rejection (approximately 60 dB), high linearity (IIP3 approximately 100 dBmV), and high order (up to 4th order for better shape factor). The disclosed resonators may also enable co-fabrication of switches, resonators, and filters all on the same substrate.

The exemplary systems described herein are based on three basic building blocks: a tunable power supply, a tunable mixer, and a tunable amplifier. The three building blocks are very flexible in terms of being used to synthesize different functions in a wireless communication system. For example, the tunable amplifier can be configured to function as a local oscillator (LO) or as an intermediate frequency (IF) amplifier, etc. Therefore, the three basic building blocks can be configured for operation at different frequencies.

Referring now to the drawings, FIGS. 1-10 illustrate an exemplary multifrequency reconfigurable communication system in accordance with an aspect of the present invention. The communication system may be used to enable wireless communication over a wide range of frequencies. As a general overview, the communication system includes a receiver system 100 and a transmitter system 200. It will be understood that receiver system 100 and transmitter system 200 may be integrated in a single transceiver system, or may be separate systems.

As illustrated in FIG. 1, receiver system 100 includes an antenna 102, a filter 104, a local oscillator 106, a tunable mixer 108, tunable amplifiers 110, 130, and 132, a tunable power supply 112, and an envelope detector 154. Additional details of receiver system 100 are described below.

Antenna 102 receives a wireless signal. In an exemplary embodiment, antenna 102 is a radio frequency (RF) antenna. Suitable RF antennas for use with the present invention include, for example, mobile phone antennas or wireless network antennas. Other suitable RF antennas will be understood by one of ordinary skill in the art from the description herein. Although the example circuit is shown as receiving RF signals from antenna 102, it is contemplated that it may receive signals from other

sources, for example, a coaxial cable or a fiber optic network having an optoelectrical transducer.

Filter 104 filters the signal received by receiver 102. Filter 104 may include an array of channel-select or band-select filters 114 connected in parallel, as illustrated in FIGS. 1 and 2. In one example system, the array may include one or more channel-select filters 114 having a passband corresponding to one or more desired frequencies. Optionally, each channel-select filter 114 of the array may correspond to a different signal frequency. Alternatively, the array may include multiple channel-select filters 114 corresponding to certain desired frequencies. The channel-select filters 114 may desirably have a very low fractional channel bandwidth, e.g., less than 0.3%. Low fractional bandwidth may enable filter 104 to more efficiently utilize the electromagnetic spectrum and obtain a higher signal-to-noise ratio. The channel-select filters 114 may further desirably have very low insertion loss, e.g., less than 1 dB. Low insertion loss may reduce power consumption and reduce chip area consumption in other areas of the receiver system 100.

In an exemplary embodiment, the array of channel-select filters 114 comprises an array of MicroElectroMechanical Systems (MEMS) resonators. Each channel-select filter 114 may comprise one or more MEMS resonators in series, each resonator having the same resonant frequency. The MEMS resonators used as the array of channel-select filters 114 may all be integrated on the same substrate. Suitable resonators include aluminum nitride (AlN) contour-mode RF MEMS piezoelectric resonators detailed above and described in the above-referenced published application. However, other piezoelectric resonators such as PZT or ZnO resonators may be suitable for use as filter 114, as would be understood by one of ordinary skill in the art. Additionally, other MEMS resonators, such as electrostatically transduced MEMS resonators and piezoelectric-on-substrate MEMS resonators, may be suitable for use as filter 114. Nonetheless, it will be understood that the resonators in the array of channel-select filters 114 are desirably usable at more than one frequency on a single substrate. This may preclude the use of certain resonators for multifrequency reconfigurable communications systems such as, for example, quartz crystal resonators or film bulk acoustic resonators, for which only a single frequency per substrate is possible. However, for single-band wireless communications, such the above resonators can be used, as would be understood by one of ordinary skill in the art from the description herein.

Desirably, the structure of the above piezoelectric resonators may be chosen to intrinsically transform impedance in the channel-select filter 114, to obtain any desired output impedance. This may promote impedance matching with any downstream components of receiver system 100 (e.g., tunable mixer 108).

Filter 104 may further include an array of switches 116 connected in series with the array of channel-select filters 114, as illustrated in FIGS. 1 and 2. Optionally, switches 116 may be connected on both sides of each filter 114 in series to reduce parasitic capacitance from filters 114. The array of switches 116 may be used to turn on and off channel-select filters 114 in order to reconfigure filter 104 to pass a signal having a desired signal frequency, for example, by switching on only the channel-select filter(s) 114 having a passband corresponding to the desired signal frequency. In an exemplary embodiment, switches 116 comprise aluminum nitride RF MEMS piezoelectric switches. The switches may be integrated with filters 114 on a single silicon substrate using a post-CMOS compatible micro-fabrication process. The switches may be operable to effectively turn on and off the RF MEMS piezoelectric resonators used in channel-select filters 114 when both elements are co-fabricated next to each other on the same substrate. Thus, aluminum nitride RF MEMS switches may be optimal for use as switches 116.

One suitable aluminum nitride RF MEMS piezoelectric switch is illustrated in FIG. 3. Each switch includes a first cantilevered piezoelectric actuator 118 having a first contact region 120, a second cantilevered piezoelectric actuator 122 having a second contact region 124, and a bias voltage (not shown). The first and second piezoelectric actuators 118 and 122 are mounted at their respective ends to a substrate (not shown). The piezoelectric actuators 118 and 122 may comprise layers of piezoelectric material sandwiched between top and bottom electrodes. The layers of piezoelectric material desirably comprise aluminum nitride (AlN). The dimensions of the piezoelectric material layers are selected such that when a bias voltage is applied to the top and bottom electrodes of the first and second actuators 118 and 122, the actuators deform in the directions indicated by the arrows in FIG. 3, thereby closing the switch 116. The bias voltage may be a DC voltage. The bias voltage may further having an time-varying component for controlling the switching process.

However, other switches such as traditional solid-state devices (e.g., field effect transistors or p-i-n diodes) may be suitable for use as switch 116, as would be under by one of ordinary skill in the art. The AlN RF MEMS switches used as switches 116 may all be integrated on the same substrate, and may further be integrated on the same substrate with AlN RF MEMS resonators used as channel-select filters 114. Accordingly, the resonators comprising switches 116 may desirably be usable at more than one frequency on a single substrate, as described above.

Filter 104 transmits the filtered signal to tunable mixer 108. Receiver system 100 may further include a low noise amplifier (not shown) connected between the filter 104 and the tunable mixer 108. The low noise amplifier may receive the filtered signal from filter 104 and amplify the filtered signal before sending it to tunable

mixer 108. Alternatively, a low noise amplifier may be connected between antenna 102 and filter 104 to amplify the received signal before filtering. In an exemplary embodiment, the low noise amplifier(s) may be tunable supply inverter amplifier(s), the structure of which will be described in further detail below with reference to tunable
5 amplifier 110. However, the function of the low noise amplifier may be performed by the tunable mixer 108 and/or tunable amplifier 110. Accordingly, the low noise amplifier may be omitted, as illustrated in FIG. 1.

Local oscillator 106 generates a switching signal. The switching signal may be, for example, a square wave signal or a sinusoidal signal. Local oscillator 106
10 may include an array of resonators 126 connected in parallel, as illustrated in FIGS. 1 and 4. The array may include one or more resonators 126 having a resonant frequency corresponding to one or more desired frequencies. Optionally, each resonator 126 of the array may correspond to a different signal frequency. Alternatively, the array may include multiple resonators 126 corresponding to certain desired frequencies. The
15 resonators 126 may desirably have a high quality factor, e.g., greater than 1000. A high quality factor may enable local oscillator 106 to produce a switching signal having a precisely determinable frequency with low phase noise. The resonators 126 may further desirably have low motional resistance, e.g., less than 50 Ω . Low motional resistance may minimize the necessary power consumption for generating the switching signal.

20 In an exemplary embodiment, the array of resonators 126 comprises an array of MicroElectroMechanical Systems (MEMS) resonators. The array of MEMS resonators 126 may all be integrated on the same substrate. Suitable resonators include aluminum nitride (AlN) contour-mode RF MEMS resonators described in the above-referenced published patent application.

25 Local oscillator 106 may further include an array of switches 128 connected in series with the array of resonators 126, as illustrated in FIGS. 1 and 4. The array of switches 128 may be used to reconfigure local oscillator 106 to produce a switching signal having a desired signal frequency, for example, by switching on only the resonator(s) 126 having a resonant frequency corresponding to the desired signal
30 frequency. In an exemplary embodiment, switches 128 comprises piezoelectric MEMS switches, substantially as described above with respect to switches 116. Suitable piezoelectric MEMS switches for use as switches 128 include aluminum nitride (AlN) RF MEMS switches described above. The AlN RF MEMS switches used as switches 128 may all be integrated on the same substrate, and may further be integrated on the same
35 substrate with other AlN contour-mode RF MEMS resonators, which may be used as resonators 126 or filters 114.

Local oscillator 106 may further include a tunable sustaining amplifier 130 connected in parallel with the array of resonators 126, as illustrated in FIGS. 1 and 4.

Tunable sustaining amplifier 130 is connected to receive feedback signals provided by the resonators 126. The combination of amplifier 130 with resonators 126 forms an oscillator. Tunable sustaining amplifier 130 may further be tuned to conform to the feedback signal provided by resonators 126, as described in further detail below. In an exemplary embodiment, tunable sustaining amplifier 130 is a tunable supply inverter amplifier, the structure of which will be described in further detail below with reference to tunable amplifier 110.

Local oscillator 106 transmits the switching signal V_s to tunable mixer 108. Receiver system 100 may further include one or more local oscillator buffers 132 connected between the local oscillator 106 and the tunable mixer 108. The local oscillator buffer 132 may receive the signal from local oscillator 106 and buffer the signal before sending it to tunable mixer 108. In an exemplary embodiment, local oscillator buffer 132 comprises one or more tunable supply inverter amplifiers. Other suitable local oscillator buffers such as conventional wideband amplifiers will be known to one of ordinary skill in the art from the description herein.

Although the example circuits described below use pMOS and nMOS transistors, it is contemplated that the pMOS transistors may be replaced by nMOS transistors and vice versa if the polarity of the supply voltage V_{DD} is switched from positive to negative.

Tunable mixer 108 mixes the filtered signal from filter 104 and the switching signal from local oscillator 106 to generate an output signal. Tunable mixer receives the filtered signal at a mixer input 133, and provides the output signal at a mixer output 143. In an exemplary embodiment, tunable mixer 108 is a tunable supply inverter mixer, as illustrated in FIG. 5. The tunable supply inverter mixer receives a supply voltage, V_{DD} . The supply voltage V_{DD} is dependent on a voltage provided by the tunable power supply 112. The tunable supply inverter mixer includes two transistors 134 and 140 which are self-biased through another transistor 142. The tunable supply inverter mixer further includes two transistors 136 and 138 that serve as switches based on the signal, V_s , from local oscillator 106. Transistors 134, 136, 138 and 140 are connected in series as shown in FIG. 5. The tunable supply inverter mixer also includes a transistor 142 connected between the mixer input 133 and the mixer output 143. Transistor 142 is biased by the supply voltage V_{DD} of the tunable supply inverter mixer. Transistor 142 is therefore biased to be always on, and serves as a sufficiently large resistor to bias the gate and drain voltages of transistors 136 and 138 at one half of supply voltage V_{DD} . In an exemplary embodiment, transistor 134 is a pMOS transistor and transistors 136, 138, and 140 are nMOS transistors. In an exemplary embodiment, transistor 142 is an nMOS transistor but may be either a pMOS or an nMOS transistor.

Tunable mixer 108 generates an output signal by mixing the two input signals V_{in} and V_s . The output signal is dependent in part on the supply voltage. In an exemplary embodiment, the output signal is the frequency difference of the two inputs. Accordingly, the output signal generated by mixer 108 may be controlled or tuned by
 5 adjusting the supply voltage V_{DD} applied to tunable mixer 108. For example, the conversion gain achieved by tunable mixer 108 (which is the amplitude ratio of signal output to the signal input) is dependent on the supply voltage applied to tunable mixer 108. An exemplary graph of conversion gain as a function of supply voltage is illustrated in FIG. 6.

Referring to FIG. 1, tunable mixer 108 transmits the output signal to
 10 tunable amplifier 110. Tunable amplifier 110 amplifies the output signal from tunable mixer 108. Tunable amplifier 110 receives the output signal from mixer 108 at an amplifier input 144, and provides an amplified output signal at an amplifier output 149. In receiver system 100, tunable amplifier 110 functions as an intermediate frequency
 15 (IF) amplifier. In an exemplary embodiment, tunable amplifier 110 is a tunable supply inverter amplifier, as illustrated in FIG. 7. The tunable supply inverter amplifier receives a supply voltage, V_{DD} . The supply voltage V_{DD} is dependent on a voltage provided by the tunable power supply 112. While the supply voltage for tunable amplifier 110 is illustrated as being the same as the supply voltage for the tunable mixer, it will be
 20 understood that the supply voltages may be different if desired. The tunable supply inverter amplifier includes two transistors, pMOS transistor 145 and nMOS transistor 146, which are self-biased through another transistor 148. Transistors 145 and 146 are connected in series as shown in FIG. 7. The tunable supply inverter amplifier also includes an nMOS transistor 148 connected between the amplifier input 144 and the
 25 amplifier output 149. Transistor 148 is biased by the supply voltage V_{DD} of the tunable supply inverter amplifier. Transistor 148 is therefore biased to be always on, and serves as a sufficiently large resistor to bias the gate and drain voltages of transistors 145 and 146 at one half of supply voltage, $V_{DD}/2$. The transistors comprising tunable amplifier 110 may be formed on the same substrate at the transistors comprising tunable mixer
 30 108.

It may be desirable that transistor 148 bias amplifier input 144 and amplifier output 149 to be at one half of the supply voltage, $V_{DD}/2$, such that no DC power is consumed in transistor 148. Accordingly, the tunable supply inverter amplifier may be designed according to the equation:

$$K_n \cdot W_n / L_n = K_p \cdot W_p / L_p$$

where K_n and K_p are transconductance parameters of nMOS and pMOS transistors, respectively; and W_p/L_p and W_n/L_n are the width-to-length ratios of transistors 145 and 146.

The small-signal AC transconductance (g_m) of the tunable supply inverter amplifier may be tuned by changing the supply voltage V_{DD} applied to the amplifier. An exemplary graph of transconductance as a function of supply voltage is illustrated in FIG. 9A. As illustrated in FIG. 9A, the small-signal AC transconductance is dependent on the width-to-length ratios of transistors 145 and 146 in tunable amplifier 110. Accordingly, transistors 145 and 146 may be structured to minimize or maximize the transconductance of tunable amplifier 110 as desired.

In an alternative exemplary embodiment, tunable amplifier is a tunable supply composite inverter amplifier, as illustrated in FIG. 8. The tunable supply composite inverter amplifier substantially corresponds to the tunable supply inverter amplifier. However, the tunable supply composite inverter amplifier includes two transistors, pMOS transistor 150 and nMOS transistor 152, in place of transistors 145 and 146. Transistors 150 and 152 are composite transistors. Composite transistors may have a higher output resistance than conventional pMOS and nMOS transistors.

Tunable amplifier 110 amplifies the output signal from tunable mixer 108 based on the supply voltage of the tunable amplifier 110. As illustrated in FIG. 1, receiver system 100 may include one or more tunable amplifiers 110. In an exemplary embodiment, the voltage gain achieved by tunable amplifier 110 is dependent on the supply voltage applied to tunable amplifier 110 and the frequency of the output signal from mixer 108. An exemplary graph of voltage gain versus frequency for several different supply voltages is illustrated in FIG. 9B. As illustrated in FIG. 9B, the voltage gain can be tuned within a certain frequency range (from 10^7 to 10^9 Hz in this example) by changing the supply voltage V_{DD} applied to tunable amplifier 110 (from 1.4 to 2 V in this example). Thus, communication system can be effectively tuned while the transistors of tunable amplifier 110 are operated within the weak, moderate, and strong inversion regions. Increasing supply voltage above strong inversion may decrease the voltage gain achieved by tunable amplifier 110. Nonetheless, operating tunable amplifier 110 at a supply voltage of 5 V may be useful for ultra-wideband applications due to the relatively constant gain over a large frequency range. Accordingly, the voltage gain applied to the signal received by tunable amplifier 110 may be controlled or tuned by adjusting the supply voltage V_{DD} applied to tunable amplifier 110.

Tunable power supply 112 provides a DC voltage to the components of receiver system 100. The supply voltages V_{DD} received by tunable mixer 108 and tunable amplifier 110 are dependant at least in part on the voltage provided by tunable power supply 112. The voltage provided by tunable power supply 112 may be controlled

or tuned based on the frequency of the signal to be received in order to conserve power, as described herein.

Receiver system 100 is not limited to the above components, but may include additional or alternative components, as would be understood by one of ordinary skill in the art from the description herein. For example, receiver system 100 may include an envelope detector 154. Envelope detector 154 may be configured to convert the output of tunable amplifier(s) 110 into a baseband signal. In an exemplary embodiment, envelope detector 154 is a squaring circuit. Other types of amplitude, frequency, or phase demodulators may be used in place of envelope detector 154 as would be understood by one of ordinary skill in the art from the description herein.

As illustrated in FIG. 10, transmitter system 200 includes a signal source 202, a local oscillator 204, a tunable mixer 206, a tunable amplifier 208, a filter 210, an antenna 212, and a tunable power supply 214. The components of transmitter system 200 may be integrated with receiver system 100. In one embodiment, the components used by receiver system 100 may also be reconfigured for use by transmitter system 200, for example, by adding one or more switches. Additional details of transmitter system 200 are described below.

Signal source 202 generates a signal and transmits the signal to the mixer 206. In an exemplary embodiment, signal source 202 is a transducer. For example, signal source 202 may be an electroacoustic transducer for a mobile telephone. Suitable signal sources 202 will be understood by one of ordinary skill in the art from the description herein.

Local oscillator 204 generates a carrier signal. The carrier signal may be a sinusoidal signal. Local oscillator 204 may include an array of resonators 216 connected in parallel and an array of switches 218 connected in series with the array of resonators 216, as illustrated in FIG. 10. In an exemplary embodiment, local oscillator 204 is a local oscillator substantially as described above with respect to local oscillator 106. In local oscillator 204, the tunable sustain amplifier 130 may desirably be replaced with a tunable supply inverter mixer. This may allow a more compact device for use when on-off keying (OOK) modulation is desired for transmitting.

Local oscillator 204 transmits the carrier signal to tunable mixer 206. The carrier signal generated by local oscillator 204 is modulated by the signal from the signal source 202 through the tunable mixer 206 to generate an output signal. In an exemplary embodiment, tunable mixer 206 is a tunable supply inverter mixer, substantially as described above with respect to tunable mixer 108. Tunable mixer 206 generates an output signal based on the supply voltage. In an exemplary embodiment, the output signal generated by tunable mixer 206 is dependent on the supply voltage applied to tunable mixer 206 and the signal from signal source 202.

Tunable mixer 206 provides its output signal to tunable amplifier 208. Tunable amplifier 208 amplifies the output signal from tunable mixer 206. In transmitter system 200, tunable amplifier 208 functions as power amplifier. As a power amplifier, tunable amplifier 208 is operable to amplify the low-power RF signal modulated by tunable mixer 206. In an exemplary embodiment, tunable amplifier 208 is a tunable supply inverter amplifier, substantially as described above with respect to tunable amplifier 110. Tunable amplifier 208 amplifies the output signal from tunable mixer 206 based on the supply voltage of the tunable amplifier 208. As illustrated in FIG. 10, transmitter system 200 may include one or more tunable amplifiers 208. Multiple tunable supply inverter amplifiers may be used to amplify the modulated signal from tunable mixer 206 to the required power level (e.g., 1 V at 1 k Ω for 1 mW). In an exemplary embodiment, the gain achieved by tunable amplifier 208 is dependent on the supply voltage applied to tunable amplifier 208 and the frequency of the output signal from tunable mixer 206.

Filter 210 filters the signal amplified by tunable amplifier 208. Filter 210 may include an array of channel-select filters 220 connected in parallel, and an array of switches 222 connected in series with the array of filters 220, as illustrated in FIG. 10. In an exemplary embodiment, filter 210 is a filter substantially as described above with respect to filter 104. Filter 210 is operable to transform the amplified signal from tunable amplifier 208 to a current signal (e.g., 4.5 mA at 50 Ω). Filters 210 may be particularly suitable for transforming the signal from tunable amplifier 208 due to the impedance transformation achievable by the disclosed filters, as described above. Filters 210 may thereby be suitable for accepting a low voltage signal at high impedance from the output of tunable amplifier 208. Further, the aluminum nitride contour-mode MEMS filters described above may have a large power handling capability (e.g. > 10 dBm) specially suited for use as power filters in short-range low-power low-voltage transceivers.

Filter 210 then passes the filtered signal to antenna 212. Antenna 212 transmits a wireless signal. In an exemplary embodiment, transmitter 212 is a radio frequency (RF) antenna, substantially as described above with respect to antenna 102. Although the example circuit is shown as transmitting RF signals via antenna 212, it is contemplated that it may transmit signals using other channels, for example, a coaxial cable or a fiber optic network having an optoelectrical transducer.

Tunable power supply 214 provides a voltage to the components of receiver system 200. The supply voltages received by tunable mixer 206 and tunable amplifier 208 are dependant at least in part on the voltage provided by tunable power supply 214. The voltage provided by tunable power supply 214 may be controlled or tuned based on the frequency of the signal to be received or transmitted, as will be

described herein. Tunable power supply 214 may be the same power supply or a different power supply from tunable power supply 112.

The operation of the exemplary transceiver systems described above will now be described. FIG. 11 illustrates an exemplary method 300 of operating a multifrequency reconfigurable transceiver system in accordance with aspects of the present invention. The transceiver system may be used to enable wireless communication over a wide range of frequencies. Method 300 will be described with reference to the components of receiver system 100. However, it will be understood that any or all of the steps of method 300 may be performed by transmitter system 200. Additional details of method 300 are described below.

In step 302, a voltage is provided with a tunable power supply. In an exemplary embodiment, tunable power supply 112 provides a voltage. The voltage provided by tunable power supply 112 may be controlled or tuned based on the frequency of the signal received by receiver 102, as will be explained below.

In step 304, an output signal is generated with a tunable mixer. In an exemplary embodiment, tunable mixer 108 generates an output signal. The output signal is based at least in part on the supply voltage V_{DD} supplied to tunable mixer 108.

In step 306, the output signal is amplified with a tunable amplifier. In an exemplary embodiment, tunable amplifier 110 amplifies the output signal from tunable mixer 108. The gain achieved by tunable amplifier 110 is based at least in part on the supply voltage V_{DD} supplied to tunable amplifier 110.

Method 300 may further comprise the step of receiving a signal with a wireless receiver. In an exemplary embodiment, a signal is received with receiver 102.

Method 300 may further comprise the step of filtering the signal with a filter. In an exemplary embodiment, the signal received by receiver 102 is filtered with filter 104. One or more channel select filter(s) 114 have a passband corresponding to the frequency of the received signal. The switch or switches 116 corresponding the above filter(s) may be actuated in order to filter the signal. When a different signal having a new frequency is desired to be received, switches 116 of filter 104 may be changed in order to utilize different channel-select filters, as would be understood to one of ordinary skill in the art. Thereby, receiver system 100 and transmitter system 200 may be reconfigured based on the frequency of the desired signal.

Method 300 may further comprise the step of generating a switching signal with a local oscillator. In an exemplary embodiment, local oscillator 106 generates the switching signal. The switches 128 of local oscillator 106 may be selectively actuated in order to provide a switching signal having the desired frequency, as described above for filter 104.

Method 300 may further comprise the step of tuning or controlling the voltage provided by the tunable power supply. In an exemplary embodiment, the voltage provided by tunable power supply 112 is predetermined based on the frequency of the signal received by receiver 102. For example, the supply voltage for tunable mixer 108 may be selected to provide adequate gain for the output signal while keeping the supply voltage low and thus conserving power. Likewise, the supply voltage for the tunable amplifier 110 may be selected to ensure that adequate gain is provided for the output signal by tunable amplifier 110. It will be understood that both the gain and the power consumption of the transceiver system are dependent on the frequency of the received signal. Thus, the frequency of the received signal may be considered in determining a suitable supply voltage. Determination of suitable supply voltages to optimize the above characteristics will be understood by one of ordinary skill in the art from the description herein.

Method 300 may further comprise the step of retuning the tunable power supply to provide a different voltage. In an exemplary embodiment, the voltage provided by tunable power supply 112 may further be changed or retuned when it is desired to change the frequency of signal received by or transmitted by the transceiver system. For example, the voltage may be retuned in order to conform the gain provided at the new desired frequency, as described above. Alternatively, the voltage may be retuned in order to minimize the power consumption provided at the new desired frequency, as described above. Thereby, receiver system 100 and transmitter system 200 may be reconfigured based on the frequency of the desired signal.

An exemplary application for the disclosed communication systems and methods is described below. Receiver system 100 may be tuned to operate at a low frequency (e.g., 433 MHz) when no data is in the process of being transmitted or received. When the receiver system is configured to operate at the low frequency, the tunable power supply 112 of receiver system 100 may be tuned to limit power consumption by the receiver system. Thereby, the communication system can be used as a wake-up radio at the low frequency. This may allow the transceiver system to minimize power consumption until a signal is received. Then, when a transmission is to be made, the transmitter system 200 may be retuned to broadcast at a higher frequency (e.g., 910 MHz). This may enable the communication system to transmit information at a higher data rate (e.g., > 1 Mbps) and with greater energy efficiency (e.g., < 0.1 nJ/bit).

By using the disclosed communication systems as described above, in conjunction with narrowband channel-select filters employing piezoelectric RF MEMS resonators, power consumption in the communication system may be reduced to values in nanowatt range. Operating the communication system as a wake-up radio at low frequencies may further increase the working range of the communication system.

Operating the disclosed communication systems at multiple frequencies as described above may provide increased reconfigurability not only at point communication nodes (e.g., individual sensor nodes in a wireless sensor network), but may also allow network-scale optimization for performance and efficiency.

5 The above-described wireless transceiver systems and methods may be usable, for example, in wireless communications systems and wireless sensor networks. The above systems and methods advantageously allow tunability and reconfigurability over a wide frequency range while conserving power. Accordingly, the disclosed systems may achieve highly efficient spectral utilization with a single device.

10 The above-described wireless transceiver systems and methods may employ AIN piezoelectric resonators in one or more different components. The use of these resonators advantageously allows the components of the above systems to be integrated together on one or more substrates, if desired, thereby allowing a compact structure for the transceiver. The disclosed resonators may achieve a high quality factor,
15 low motional resistance, narrow fractional bandwidth, low insertion loss, high off-band rejection, high linearity, low impedance, and impedance transformation. Accordingly, the disclosed resonators may be particularly suitable for use in the applications described above.

20 Although the invention is illustrated and described herein with reference to specific embodiments, the invention is not intended to be limited to the details shown. Rather, various modifications may be made in the details within the scope and range of equivalents of the claims and without departing from the invention.

What is Claimed:

1. A multifrequency reconfigurable communication system comprising:
a tunable power supply operable to provide a voltage;
a tunable mixer having a mixer input and a mixer output, the tunable
5 mixer configured to receive a supply voltage dependent at least in part on the voltage
provided by the tunable power supply and an input signal at the mixer input, the tunable
mixer further configured generate an output signal based at least in part on the input
signal and the supply voltage; and
a tunable amplifier having an amplifier input and an amplifier output, the
10 tunable amplifier configured to receive a supply voltage dependent at least in part on the
voltage provided by the tunable power supply and the output signal from the tunable
mixer at the amplifier input, the tunable amplifier further configured to amplify the
output signal based at least in part on the supply voltage.
2. The system of claim 1, wherein
15 the tunable mixer includes a transistor connected between the mixer input
and the mixer output, the transistor biased by the mixer supply voltage; and
the tunable amplifier includes a transistor connected between the amplifier
input and the amplifier output, the transistor biased by the amplifier supply voltage.
3. The system of claim 2, wherein:
20 the mixer is a tunable supply inverter mixer; and
the amplifier is a tunable supply inverter amplifier.
4. The transceiver system of claim 1, wherein:
the voltage provided by the tunable power supply is selected based on a
frequency of the input signal.
- 25 5. The transceiver system of claim 4, wherein:
the voltage provided by the tunable power supply is selected to provide an
adequate gain to the input signal while conserving power used by the communication
system.
6. The system of claim 1, further comprising:
30 an antenna for wirelessly receiving the input signal;
a filter configured to filter the input signal and pass the input signal to the
tunable mixer; and
a local oscillator operable to provide a switching signal to the tunable
mixer,
35 wherein the tunable mixer mixes the input signal and the switching signal
to generate the output signal.
7. The system of claim 6, wherein the filter comprises:

an array of filters connected in parallel, each filter composed of an array of resonators coupled together at least electrically or mechanically; and

an array of switches, each switch connected in series with a respective filter of the array of filters.

5 8. The system of claim 6, wherein the local oscillator comprises:
an array of resonators connected in parallel;
an array of switches, each switch connected in series with a respective
resonator of the array of resonators; and
a tunable sustaining amplifier connected in parallel with the array of
10 resonators.

9. The system of claim 1, further comprising:
a signal source configured to provide a switching signal to the tunable
mixer;
a local oscillator operable to provide the input signal to the tunable mixer;
15 a filter configured to filter an amplified output signal provided by the
tunable amplifier and pass the amplified output signal; and
an antenna for wirelessly transmitting the filtered signal,
wherein the tunable mixer modulates the input signal from the local
oscillator using the switching signal from the signal source to generate the output signal.

20 10. The system of claim 9, wherein:
the voltage provided by the tunable power supply is selected based on a
frequency of the signal transmitted by the local oscillator.

11. The system of claim 9, wherein the filter comprises:
an array of filters connected in parallel, each filter composed of an array of
25 resonators coupled together at least electrically or mechanically; and
an array of switches, each switch connected in series with a respective
filter of the array of filters.

12. The system of claim 9, wherein the local oscillator comprises:
an array of resonators connected in parallel;
30 an array of switches, each switch connected in series with a respective
resonator of the array of resonators; and
a tunable sustain amplifier connected in parallel with the array of
resonators.

13. A method of operating a multifrequency reconfigurable
35 communication system, the method comprising the steps of:
providing a voltage with a tunable power supply;
generating an output signal with a tunable mixer, the tunable mixer
configured to receive a supply voltage dependent at least in part on the voltage provided

by the tunable power supply and an input signal, the tunable mixer further configured to generate the output signal based at least in part on the input signal and the supply voltage; and

amplifying the output signal with a tunable amplifier, the tunable amplifier
5 configured to receive a supply voltage dependent at least in part on the voltage provided by the tunable power supply and the output signal from the tunable mixer, the tunable amplifier further configured to amplify the output signal based at least in part on the supply voltage.

14. The method of claim 13, further comprising the steps of:
10 determining a frequency of the input signal; and
selecting the voltage provided by the tunable power supply to the tunable mixer and the tunable amplifier based on the frequency of the input signal.

15 15. The method of claim 14, wherein the selecting step comprises:
selecting the voltage provided by the tunable power supply in order to
provide an adequate gain to the input signal while conserving power used by the
communication system.

16. The method of claim 13, further comprising the steps of:
receiving the input signal with an antenna;
filtering the input signal with a filter; and
20 generating a switching signal with a local oscillator,
wherein the step of generating the output signal comprises mixing the
input signal and the switching signal with the tunable mixer to generate the output
signal.

25 17. The method of claim 13, further comprising the steps of:
providing a switching signal with a signal source;
generating the input signal with a local oscillator;
filtering the amplified output signal from the amplifier with a filter; and
transmitting the amplified output signal with a wireless transmitter,
wherein the step of generating the output signal comprises mixing the
30 input signal from the local oscillator and the switching signal from the signal source with
the tunable mixer to generate the output signal.

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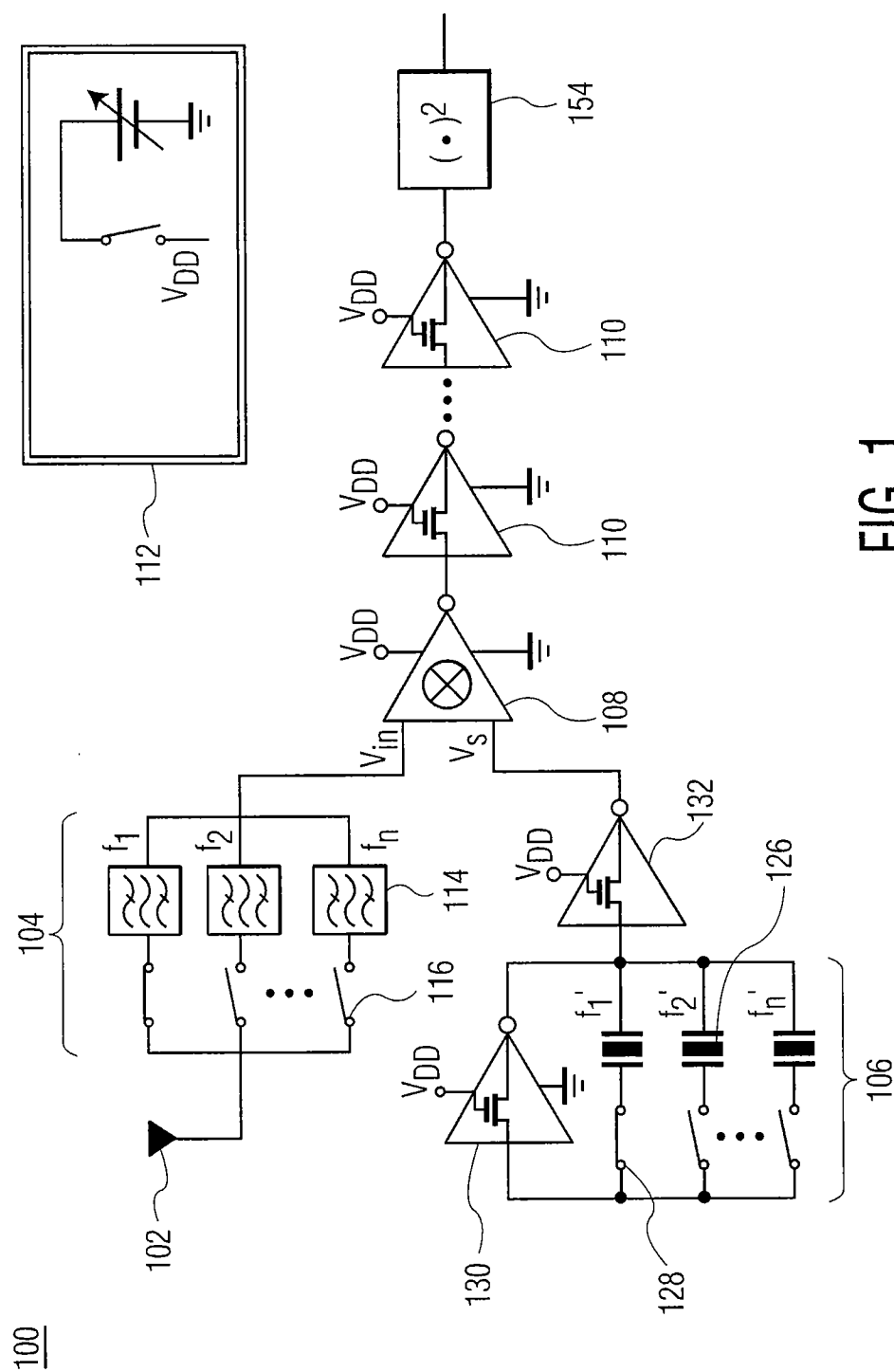


FIG. 1

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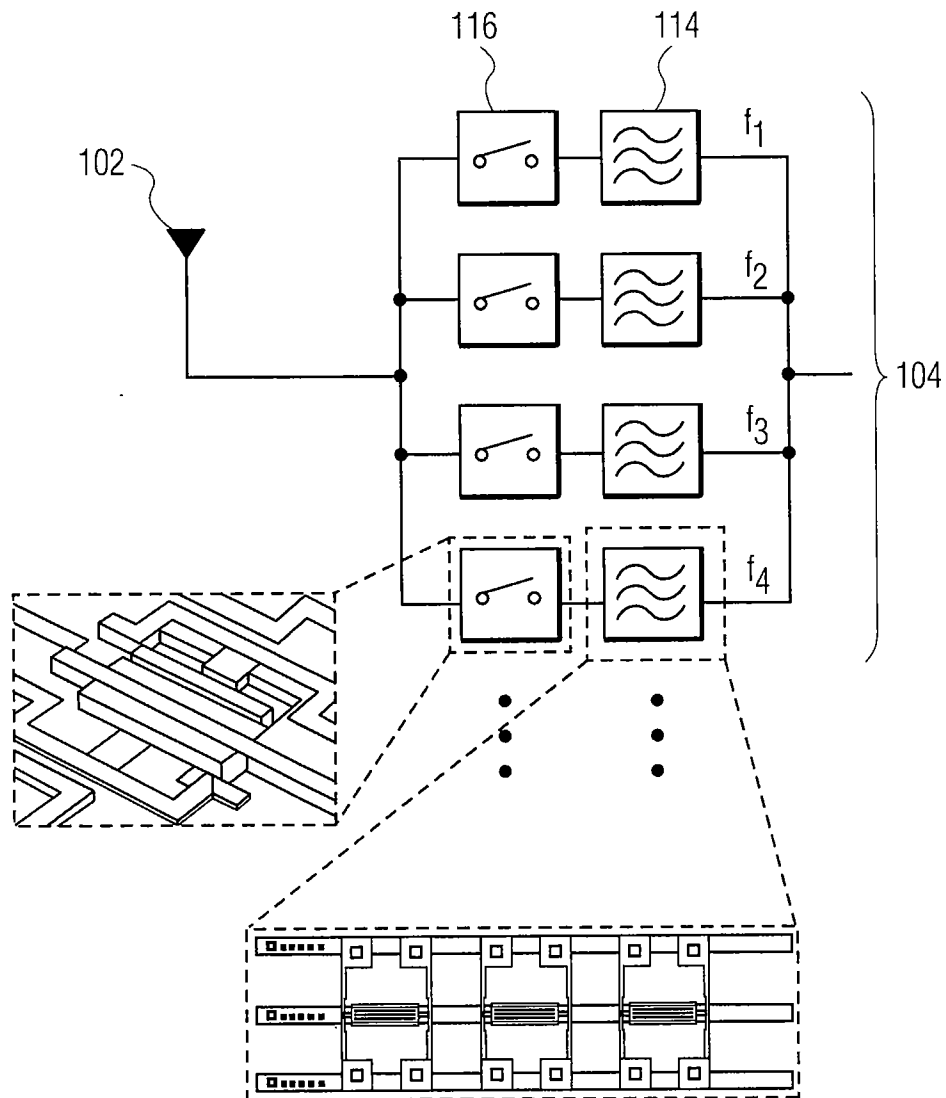


FIG. 2

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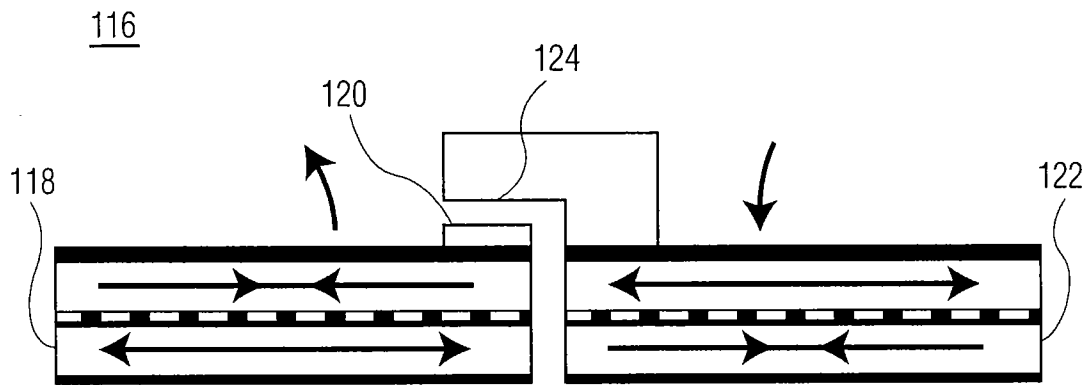


FIG. 3

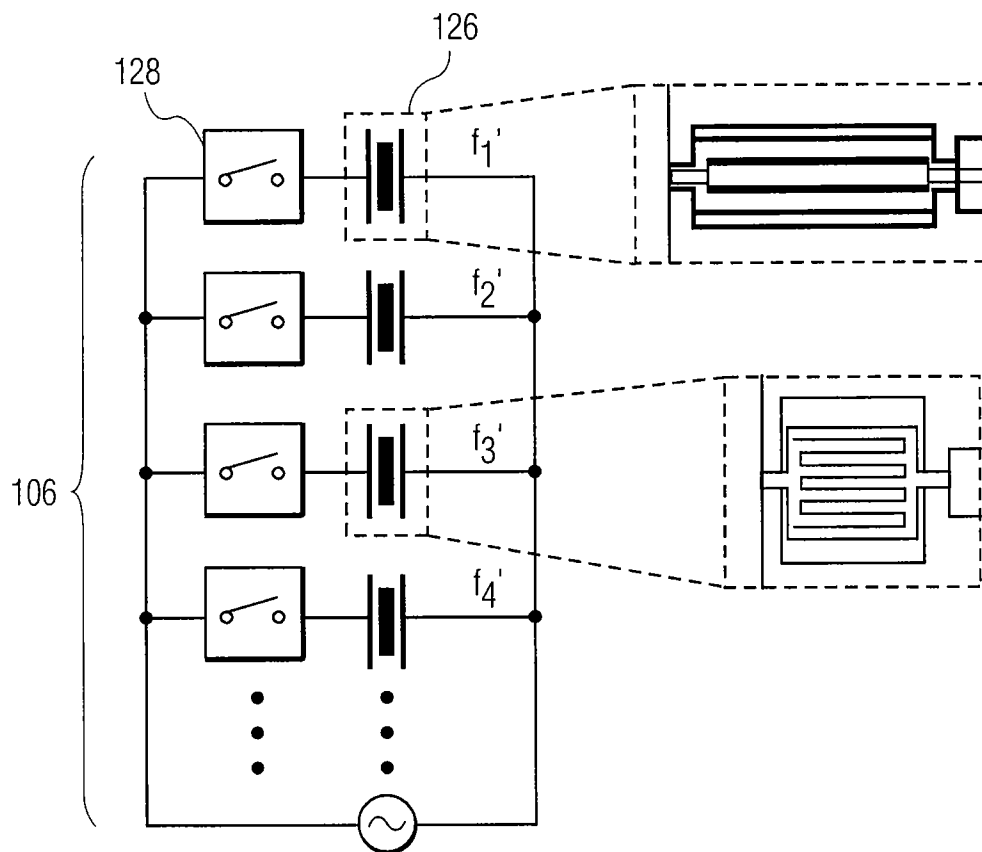


FIG. 4

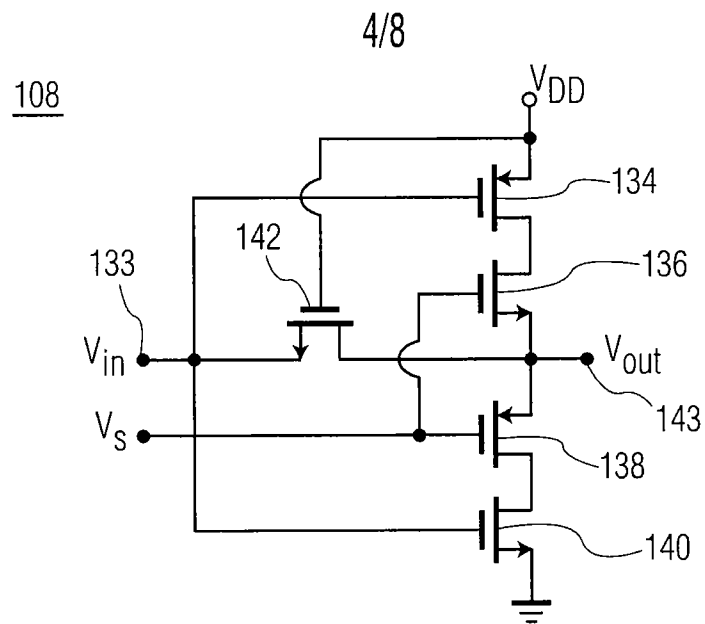


FIG. 5

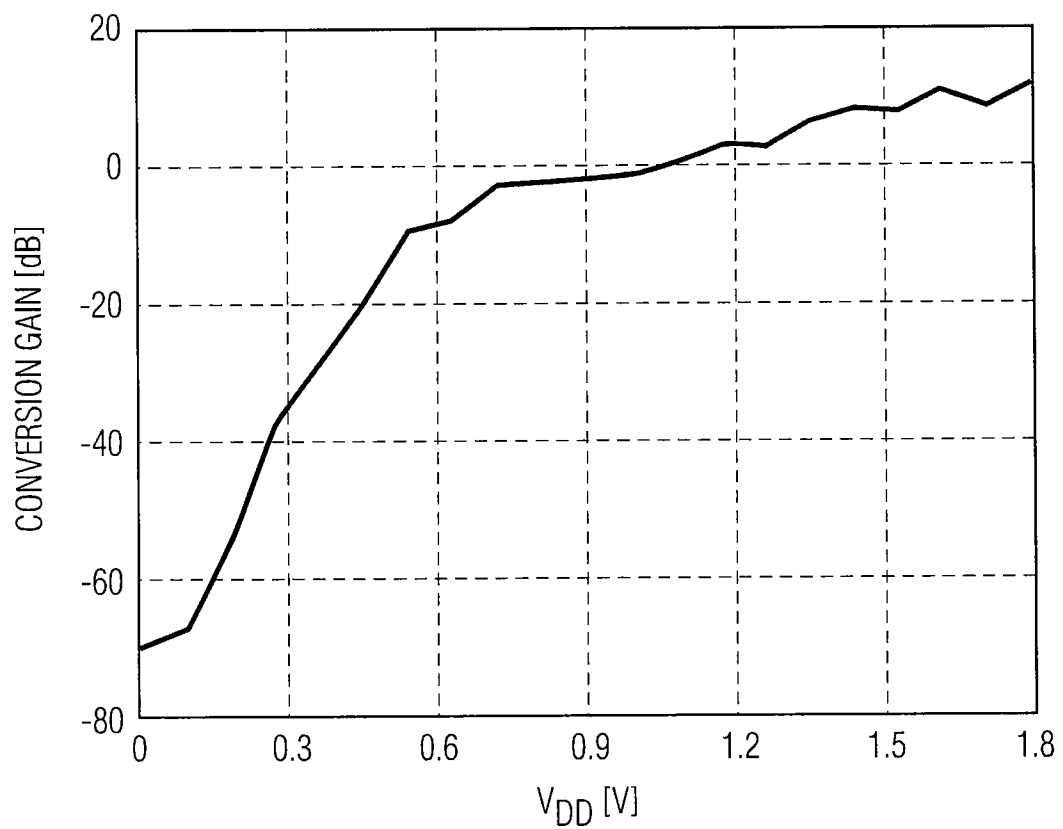


FIG. 6

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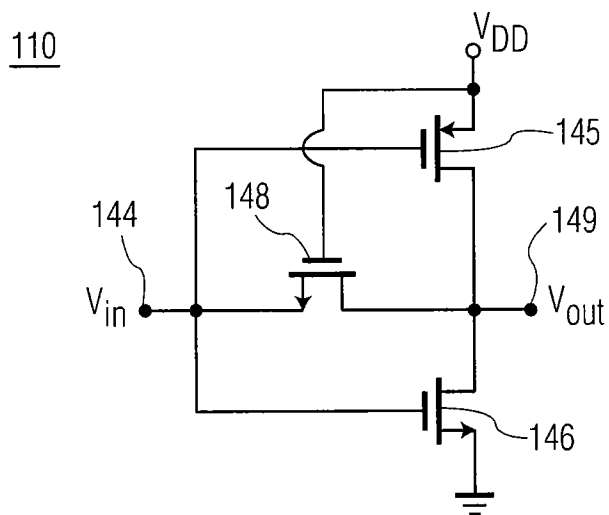


FIG. 7

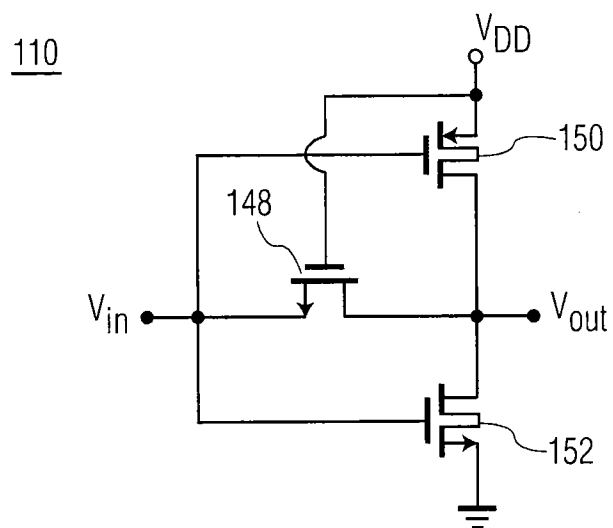


FIG. 8

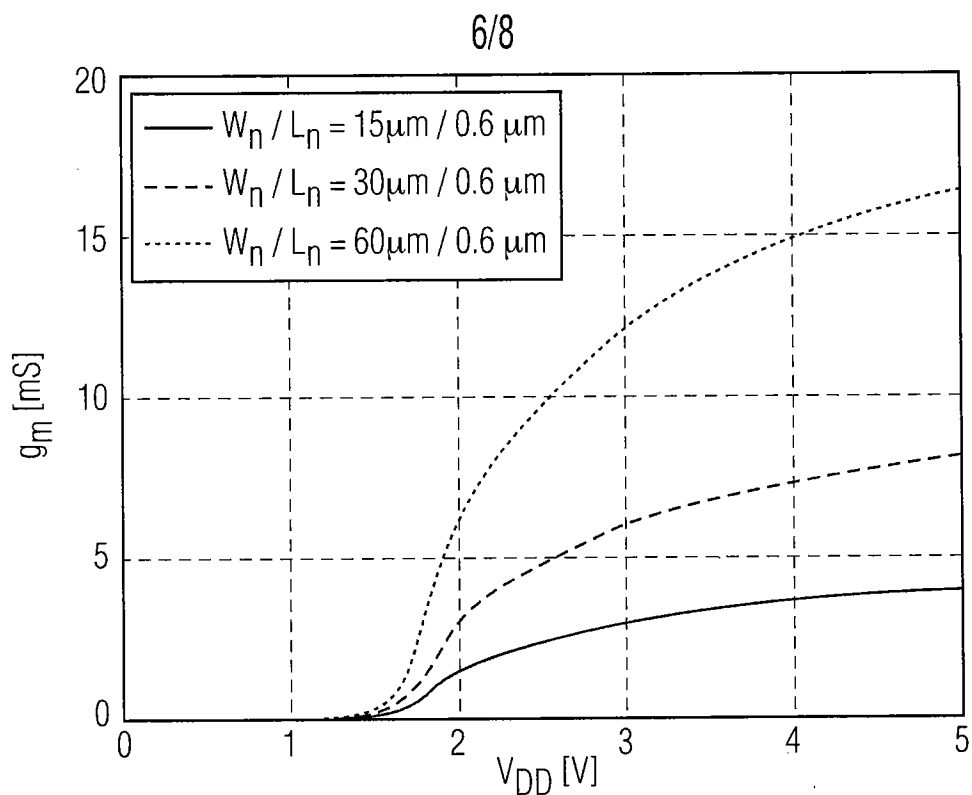


FIG. 9A

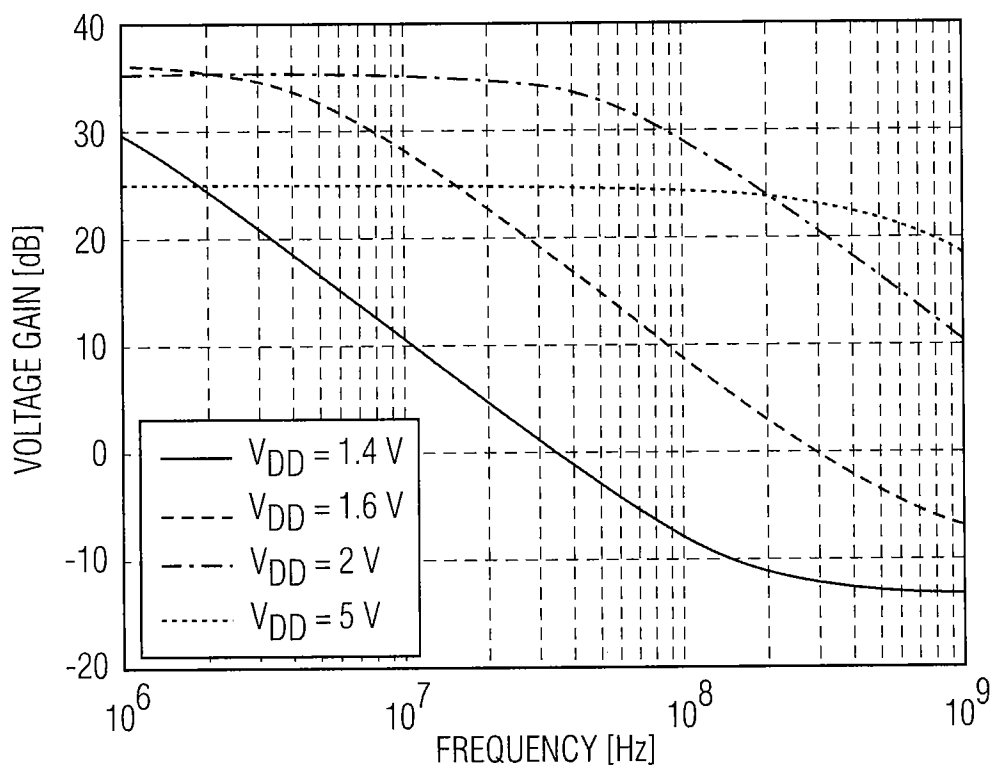


FIG. 9B

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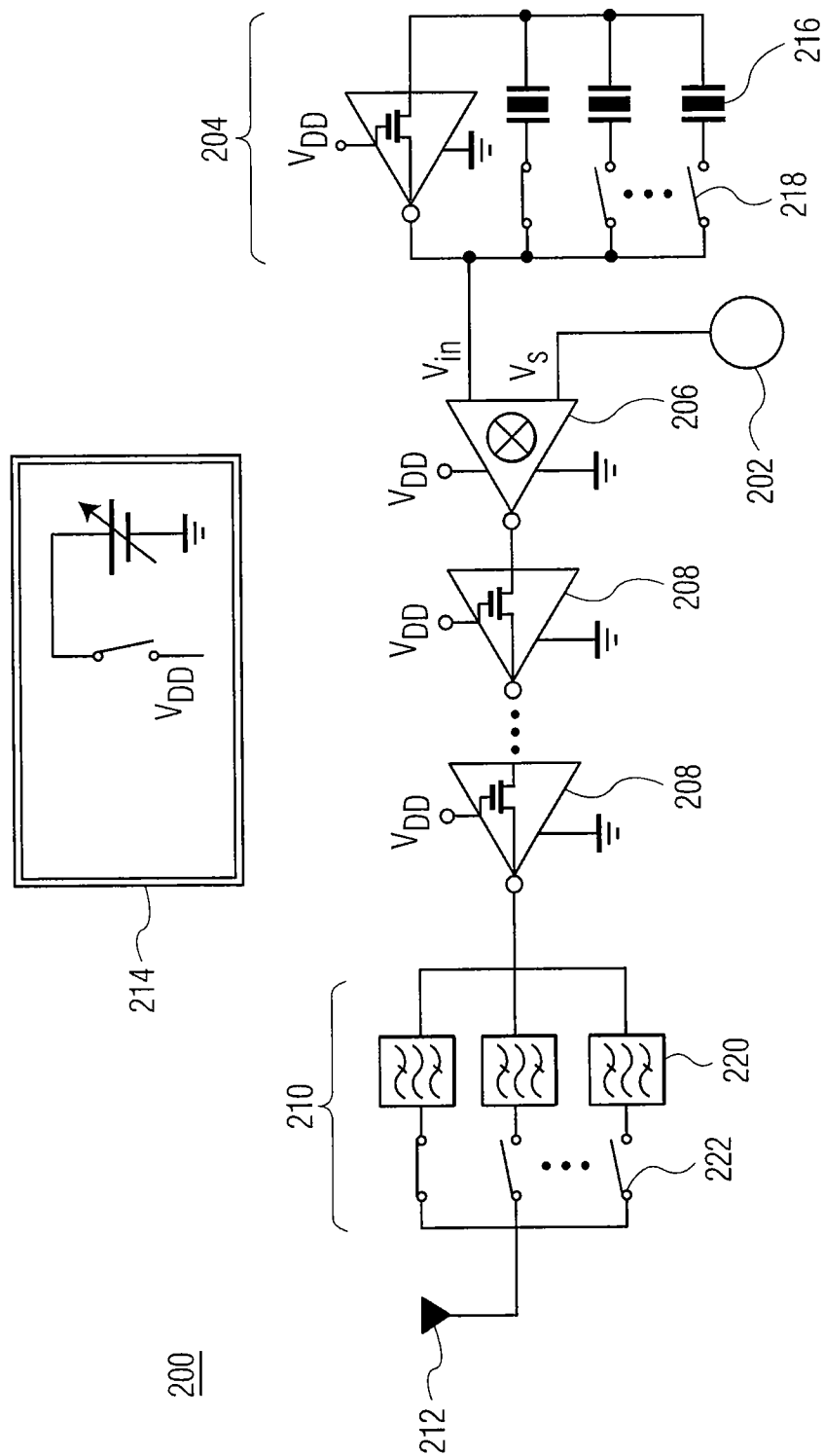


FIG. 10

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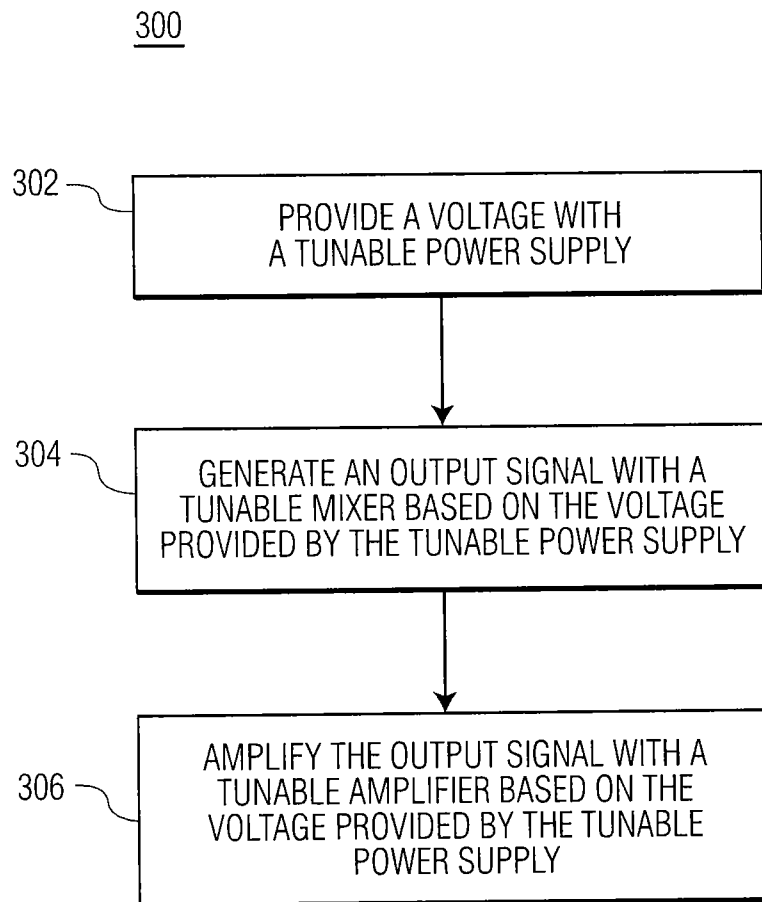


FIG. 11

INTERNATIONAL SEARCH REPORT

International application No.

PCT/US2011/046404

A. CLASSIFICATION OF SUBJECT MATTER

IPC(8) - G06G7/00 (2011.01)

USPC - 327/355

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

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC(8) - G06G7/00;H04B1/38 (2011.01)

USPC - 327/355;455/125; 455/189.1; 326/33

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

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

Minesoft PatBase

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	US 2010/0171542 A1 (DAWE et al) 8 July 2010 (08.07.2010) entire document	1 - 17
Y	US 2009/0096517 A1 (HUANG et al) 16 April 2009 (16.04.2009) entire document	1 - 17
A	US 5,220,686 B1 (KASPERKOVITZ et al) 15 June 1993 (15.06.1993) entire document	1, 13
A	US 6,275,687 B1 (LLOYD) 14 August 2001 (14.08.2001) col. 2, lns 31-63	1, 13
A	US 2003/0199259 A1 (MACEDO et al) 23 October 2003 (23.10.2003) see [0007]; Figure 7	1-2, 6, 13, 16

☐ Further documents are listed in the continuation of Box C.


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"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search

21 November 2011

Date of mailing of the international search report

12 DEC 2011

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