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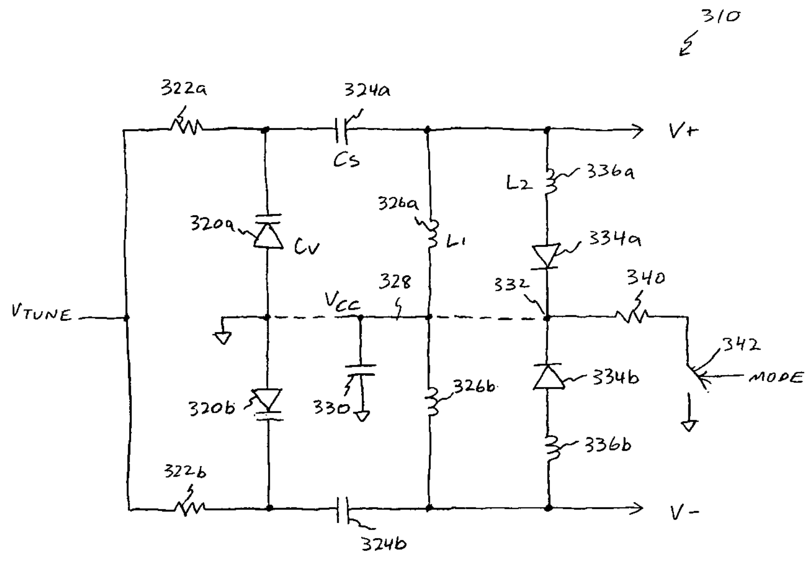
(54) Title: DUAL BAND TANK CIRCUIT



(57) Abstract: Tank circuits that can support multiple frequency bands and have good RF performance. The tank circuit can be used for oscillators, filters, and other applications. The tank circuit includes the elements normally associated with the particular application. For example, the tank circuit for an oscillator typically includes one or more of varactor (320a, 320b), capacitor (324a, 324b), inductor (326a, 326b), and biasing and filtering elements. The tank circuit further includes an additional reactive element (336a, 336b) coupled via switching means to either the capacitor or inductor. The additional reactive element (336a, 336b) and switching means (342, 334a, 334b) are selected to provide the desired circuit characteristics and good RF performance. In a specific implementation, an additional inductor (336a) is coupled, via a pin diode (334a), in parallel with the other inductor (326a).

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DUAL BAND TANK CIRCUIT

BACKGROUND OF THE INVENTION

I. Field of the Invention

The present invention relates to electronics circuits. More particularly, the present invention relates to novel and improved dual band tank circuits.

II. Description of the Related Art

Tank circuits are commonly used in a variety of circuits such as oscillators, filters, and others. Generally, a tank circuit is used to provide a phase shift and/or an amplitude response that is dependent on frequency. The amount of phase shift and the amplitude response can be controlled, to an extent, by properly designing the tank circuit.

In an oscillator, the tank circuit provides a particular amount of phase shift or a particular amount of signal attenuation that is dependent on frequency. The phase shift or signal attenuation from the tank circuit is used to satisfy one of the oscillation conditions. For example, for a feedback-type oscillator, the tank circuit can be used to provide a portion of the 360° of phase shift required around the closed loop.

In a filter, the tank circuit provides a particular frequency response. For example, the tank circuit can be used to provide a bandpass frequency response having a particular center frequency and bandwidth. The bandpass response is often used for filtering modulated signals centered at an intermediate frequency (IF) or a radio frequency (RF).

In some applications, it is desirable or necessary to adjust the characteristics of the tank circuit. For example, an oscillator may be required to lock in frequency or phase to a reference signal. A phase-lock-loop (PLL) is then provided to generate a control signal that adjusts the frequency or phase of the oscillator to match that of the reference signal. Specifically, the control signal adjusts the characteristics (e.g., the phase and/or amplitude response) of the tank circuit, which in turn changes the frequency of oscillation for the oscillator.

The characteristics of the tank circuit are typically adjusted, if at all, within a somewhat narrow range. When this is the case, a variable capacitor (or varactor) can be used to provide the necessary phase/amplitude adjustment. The capacitance of the varactor varies in accordance with the applied voltage, and the phase/ amplitude response of the tank circuit varies with the capacitance of the varactor. The varactor has a finite range of capacitance that typically spans, for example, two or three octaves (e.g., from 10 pF to 40 pF, or 2 pF to 16 pF).

For some applications, a wider change in characteristics of the tank circuit is desired or necessary. One such application is in cellular communications systems that support two or more operating modes. Each operating mode can correspond to, for example, a particular frequency band, modulation scheme, data format, and so on, or any combination thereof. For example, a system may support two operating modes, with the modes corresponding to a cellular band and a personal communications system (PCS) band, and with each band associated with a different center frequency. The center frequencies of these bands may be sufficiently separated such that a varactor cannot be used to tune the tank circuit to the proper center frequency.

Accordingly, tank circuits that can support multiple frequency bands are highly desirable. It is also desirable that the tank circuits provide good (e.g., RF) performance at the supported bands.

SUMMARY OF THE INVENTION

The present invention provides tank circuits that can support multiple frequency bands and have good RF performance. The tank circuit can be used for oscillators, filters, and other applications. The tank circuit includes the elements normally associated with the particular application. For example, the tank circuit for an oscillator typically includes one or more of varactor, capacitor, inductor, and biasing and filtering elements. The tank circuit further includes an additional reactive element coupled via switching means to either the capacitor or inductor. The additional reactive element and switching means are selected to provide the desired circuit characteristics and good RF performance.

An embodiment of the invention provides a tank circuit that includes a variable capacitor, first and second inductors, and switching means. The first inductor operatively couples in parallel with the variable capacitor, and the second inductor selectively and operatively couples in parallel with the first inductor. The switching means couples in series with the second inductor. The switching means can comprise a pin diode that is selectively biased on or off, and can further comprise a transistor coupled to the pin diode. The tank circuit can be implemented as a differential circuit.

Another embodiment of the invention provides a tank circuit that includes three or more reactive elements and switching means. The first and second reactive elements operatively couple between a first node and a second node, and have first and second reactance values, respectively. The second reactance value is opposite in polarity from the first reactance value. The third reactive element selectively and operatively couples to the second reactive element. The switching means operatively couples to the third reactive element and selectively couple the third reactive element to the second reactive element. The third reactive element can be an inductor or a capacitor, and can be coupled in parallel or in series with the second reactive element.

Yet another embodiment of the invention provides a voltage control oscillator (VCO) that includes a tank circuit, an active circuit coupled to the tank circuit, and a buffer coupled to the active circuit. The tank circuit includes a variable capacitor, a first inductor operatively coupled to the variable capacitor, a reactive element selectively and operatively coupled to the variable capacitor or the inductor, and switching means coupled to the reactive element. The switching means selectively couples the reactive element to the tank circuit. The active circuit can include a first pair of transistors configured as a differential amplifier and coupled to the tank circuit. The active circuit can also include a second pair of transistors cross-coupled with the first pair of transistors.

Yet another embodiment of the invention provides a filter for filtering a modulated signal. The filter includes a capacitor, an inductor, a reactive element, and switching means. The inductor operatively couples in parallel with the capacitor, and the reactive element selectively and operatively couples to the inductor or capacitor. The switching means couples to the reactive element and selectively couples the reactive element to the inductor or capacitor.

Yet another embodiment of the invention provides a transmitter for use in a cellular telephone. The transmitter includes a modulator, a filter, and a mixer. The modulator receives and modulates an information-bearing signal with a first carrier signal to generate a modulated signal. The filter operatively couples to the modulator, and receives and filters the modulated signal to generate a filtered signal. The mixer operatively couples to filter, and receives and upconverts the filtered signal with a second carrier signal to generate an output signal. The filter includes a capacitor, an inductor, a reactive element, and switching means configured as described above.

Yet another embodiment of the invention provides a receiver for use in a cellular telephone. The receiver includes a mixer, a filter, and a demodulator. The mixer receives and downconverts a modulated signal with a first carrier signal to generate a downconverted signal. The filter operatively couples to the mixer, and receives and filters the demodulated signal to generate a filtered signal. The demodulator couples to the filter, and receives and demodulates the filtered signal with a second carrier signal to generate a demodulated signal. The filter includes a capacitor, an inductor, a reactive element, and switching means configured as described above.

BRIEF DESCRIPTION OF THE DRAWINGS

The features, nature, and advantages of the present invention will become more apparent from the detailed description set forth below when taken in conjunction with the drawings in which like reference characters identify correspondingly throughout and wherein:

FIGS. 1A and 1B show simplified block diagrams of an embodiment of a quadrature transmitter and receiver, respectively;

FIG. 2 shows a block diagram of an embodiment of a VCO;

FIG. 3 shows a schematic diagram of an embodiment of a tank circuit;

FIG. 4 shows a schematic diagram of an embodiment of an active circuit suitable for used in the VCO;

FIG. 5 shows a schematic diagram of an embodiment of a tank circuit;

FIG. 6 shows two frequency responses and for the tank circuit in FIG. 5 with the switch opened and closed, respectively;

FIG. 7 shows a schematic diagram of another embodiment of a tank circuit; and

FIG. 8 shows a schematic diagram of an embodiment of a switch.

DETAILED DESCRIPTION OF THE SPECIFIC EMBODIMENTS

The invention can be implemented in various electronics circuits and systems. For clarity, the invention is described for a specific implementation in a transmitter of a cellular communications system.

FIG. 1A shows a simplified block diagram of an embodiment of a quadrature transmitter 100. A digital processor 110 generates data, encodes the data, and converts the digitally processed data into inphase (I) and quadrature (Q) baseband signals. The baseband signals are provided to baseband (BB) buffers 122a and 122b that buffer the signals and provide the buffered signals to a modulator 124. Modulator 124 also receives a signal (e.g., a carrier sinusoid) at an intermediate frequency (TX_IF_LO), and modulates the buffered baseband signals with the TX_IF_LO to generate an IF modulated signal. The IF signal is provided to an IF variable gain amplifier (IF VGA) 126 that amplifies the signal with a gain determined by a gain control signal from a gain control circuit (not shown in FIG. 1A). The amplified IF signal is provided to a filter 132 that filters the IF signal to remove out-of-band noise and undesired signals. In an embodiment, filter 132 is a bandpass filter, as described below.

The filtered IF signal is provided to an IF buffer 142 that buffers the signal and provides the buffered IF signal to a mixer 144. Mixer 144 also receives a signal (e.g., a carrier sinusoid) at a radio frequency (TX_RF_LO) from a voltage controlled oscillator (VCO) 150. Mixer 144 upconverts the buffered IF signal with the TX_RF_LO to generate a RF signal. Mixer 144 can be a single sideband or double sideband mixer. The RF signal is provided to a RF amplifier (RF AMP) 146 that amplifies the signal with a particular gain. The amplified RF signal comprises the RF output from transmitter 100.

FIG. 1B shows a simplified block diagram of an embodiment of a quadrature receiver 102. A modulated signal is received by an antenna 160 and filtered by a bandpass filter (BPF) 162. The filtered signal is then provided to, and amplified by, a low noise amplifier (LNA) 164. The amplified signal may be further filtered by another BPF 166 and provided to a mixer 168. Mixer 168 also receives a signal (e.g., a carrier sinusoid) at a radio frequency (RX_RF_LO) from a VCO 170, and downconverts the signal with the RX_RF_LO to generate an IF signal. The IF signal is provided, via a switch 172a, to either BPF 174a or 174b, depending on whether the receiver is operating in the cellular or PCS band. The filtered signal from BPF 174 is provided, via a switch 172b, to a demodulator (DEMOD) 176 that performs quadrature demodulation to provide the baseband I and Q signals. Quadrature demodulation is performed using a signal (e.g., a carrier sinusoid) at an intermediate frequency (RX_IF_LO).

Various modifications can be made to the transmitter and receiver embodiments shown in FIGS. 1A and 1B. For example, fewer or additional filter, buffer, and amplifier stages can be provided in the transmit and receive signal paths. Moreover, the elements within the signal paths can be arranged in different order. In addition, the variable gain in the transmit signal path can be provided by one or more VGAs (as shown in FIG. 1A), variable attenuators, multipliers, other variable gain elements, or a combination of the above.

Transmitter 100 an receiver 102 can be used in many applications, such as cellular communications systems. Examples of cellular communications systems include Code Division Multiple Access (CDMA) communications systems, Time Division Multiple Access (TDMA) communications systems, and analog FM communications systems. The use of CDMA techniques in a multiple access communications system is disclosed in U.S. Patent No. 4,901,307, entitled "Spread Spectrum Multiple Access Communication System Using Satellite or Terrestrial Repeaters," and U.S. Patent No. 5,103,459, entitled "System and Method for Generating Waveforms in a CDMA Cellular

Telephone System," both patents assigned to the assignee of the present invention and incorporated herein by reference. CDMA systems are typically designed to conform to the "TIA/EIA/IS-95-A Mobile Station-Base Station Compatibility Standard for Dual-Mode Wideband Spread Spectrum Cellular System" and the "TIA/EIA/IS-95-B Mobile Station-Base Station Compatibility Standard for Dual-Mode Wideband Spread Spectrum Cellular System," hereinafter collectively referred to as the IS-95 standard, which is also incorporated herein by reference.

In an embodiment, the transmit signal path from BB buffers 122 to RF AMP 146 (possibly excluding filter 132) is implemented within one or more (e.g., analog) integrated circuits. In an embodiment, digital processor 110 is implemented on another (e.g., digital) integrated circuit. A portion or all of filter 132 and VCO 150 can be implemented on the same integrated circuit(s) used to implement the transmit signal path, or on a separate integrated circuit. Similarly, receiver 102 can be implemented within one or more integrated circuits, or can be implemented on the same integrated circuit with the transmitter.

Transmitter 100 and receiver 102 may each be required to support several operating modes such as, for example, cellular and PCS modes. The cellular mode is characterized, in part, by a RF output having a center frequency of between 824 MHz and 849 MHz, and the PCS mode is characterized, in part, by a RF output having a center frequency of between 1850 MHz and 1910 MHz. These different RF output frequencies can be obtained with various designs.

In one transmitter and receiver design, the frequency of the IF_LO (i.e., TX_IF_LO or RX_IF_LO) is varied depending on the operating mode to obtain the desired output RF frequency. In a specific embodiment, the IF_LO has center frequencies of 228 MHz and 263 MHz for the cellular and PCS bands, respectively. In this embodiment, the RF_LO has a frequency range of 1052 MHz to 1077 MHz for the cellular band and a range of 2113 MHz to 2173 MHz for the PCS band (i.e., using low side conversion in both bands). In an embodiment, the IF VCO is operated at twice the frequency of the IF_LO, and the frequency of the VCO output is divided by two during the quadrature signal generation (i.e., to generate the inphase and quadrature signals used for modulation).

In another transmitter design, a single modulation stage is provided to directly modulate the baseband signals to the RF frequency. In this embodiment, the direct upconversion LO has a frequency range of 824 MHz to 849 MHz for the cellular band and 1850 MHz to 1910 MHz for the PCS band.

As can be seen, the cellular and PCS bands cover two frequency ranges that are spaced relatively far apart (i.e., over an octave apart). Because of the wide frequency separation, it is typically not feasible to design a VCO that can continuously adjust it frequency (i.e., using a varactor) to cover the ranges of the cellular and PCS bands.

For good RF performance, it is often not desirable to generate a RF_LO with a VCO running at the same frequency as that of the RF output signal. When the VCO and RF output are at the same frequency, the VCO output can leak onto the RF signal, which can cause performance degradation at the receiver. Also, the RF signal can cause "pulling" on the VCO and degrade the phase noise of the VCO output signal. To avoid these potential degradations, the RF_LO can be obtained by mixing two intermediate LOs.

FIG. 2 shows a block diagram of an embodiment of VCO 150. VCO 150 can be used for any of the VCOs shown in FIGS. 1A and 1B, particularly IF VCOs 150 and 178. VCO 150 includes a tank circuit 210 coupled to an active circuit 220. Active circuit 220 provides the required signal gain necessary for achieving and maintaining oscillation. Tank circuit 210 behaves as a bandpass filter that provides the greater amounts of feedback at the filter center frequency. In an embodiment, the tank circuit is designed to allow the VCO to cover the supported bands (e.g., the cellular and PCS bands). A buffer 230 couples to active circuit 220, receives and buffers the signal from the active circuit, and provides the buffered signal as the RF_LO. The RF_LO is typically a differential signal, although it can also be designed as a single-ended signal.

FIG. 3 shows a schematic diagram of an embodiment of a tank circuit 310. Tank circuit 310 can be used as tank circuit 210 in FIG. 2. As shown in FIG. 3, tank circuit 310 includes a pair of varactors 320a and 320b having anodes coupled to circuit ground. The cathode of varactor 320a couples to one end of a resistor 322a and one end of a capacitor 324a. Similarly, the cathode of varactor 320b couples to one end of a resistor 322b and one end of a capacitor 324b. The other ends of resistors 322a and 322b couple together and receives a control signal V_{TUNE}. The other ends of capacitors 324a and 324b comprises the tank circuit output nodes V+ and V-, respectively. A pair of inductors 326a and 326b couple in series, and the series combination couples between nodes V+ and V-. A node 328 is formed at the common connection point of inductors 326a and 326b, and this node is coupled to a power supply V_{CC}. A capacitor 330 couples between node 328 and circuit ground. Capacitor 330 provide filtering for the power supply and is not needed for RF operation.

A pair of diodes 334a and 334b couple in series, with their cathodes coupled together at a node 332. A pair of inductors 336a and 336b couple in series with the pair of diodes 334a and 334b, and the series combination of diodes 334 and inductors 336 couple between nodes V+ and V-. A resistor 340 couples in series with a switch 342, and the series combination couples between node 332 and circuit ground. Switch 342 receives a control signal MODE that selectively turns switch 342 on or off. Switch 342 can be implemented in various manners, as described below. A capacitor can be provided between node 332 and AC ground, but is not needed for RF operation.

Tank circuit 310 is a differential circuit that can be divided into two halves, as shown by the dotted line. The nodes along the dotted line are at AC ground or virtual ground and, ideally, the voltages at these nodes do not vary even when the tank circuit is operational. Thus, analysis of the tank circuit can be performed on either the top half or the bottom half.

Tank circuit 310 operates in the following manner. Varactor 320, capacitor 324, and inductor 326 form a resonant circuit that provides a particular amplitude response at a specified frequency. When switch 342 is opened, diode 334 is not biased and turns off, thereby creating an open circuit for the signal path with inductor 336. Thus, when switch 342 is opened, the amplitude response is determined predominantly by varactor 320, capacitor 324, and inductor 326. With the switch opened, the resonant frequency f_O can be expressed as:

$$f_O = \frac{1}{2\pi\sqrt{L_1(C_V \,||\, C_S)}}, \quad \text{Eq. (1)}$$

where

$$C_V \,||\, C_S = \frac{C_V C_S}{C_V + C_S}. \quad \text{Eq. (2)}$$

Alternatively, when switch 342 is closed, diode 334 is biased and turns on, thereby providing a signal path for inductor 336. Inductor 336 is then coupled in parallel with inductor 326, and the parallel combination provides a lower inductance. Thus, when switch 342 is closed, the amplitude response is determined predominantly by varactor 320, capacitor 324, and inductors 326 and 336. With the switch closed, the resonant frequency f_C can be expressed as:

$$f_C = \frac{1}{2\pi\sqrt{(L_1 \,||\, L_2)(C_V \,||\, C_S)}}, \quad \text{Eq. (3)}$$

where

$$L_1 \,||\, L_2 = \frac{L_1 L_2}{L_1 + L_2}. \quad \text{Eq. (4)}$$

Resistor 322 couples the control signal V_{TUNE} to varactor 320 and provides several additional functions. Resistor 322 and varactor 320 form a lowpass filter for the control signal V_{TUNE}. Resistor 322 also isolates the control signal node from loading the tank circuit. The capacitance of varactor 320 varies in accordance with the voltage supplied by the control signal V_{TUNE}.

Capacitor 330 provides an AC short for node 328 and also filters the power supply V_{CC}. The supply voltage V_{CC} is provided through inductors 326 and 336 to the anode of diode 334. Switch 342 can be selectively opened or closed. When switch 342 is closed, a current path is provided for diode 334 from node 328 through diode 334 and further through switch 342 to ground. Resistor 340 sets the amount of current flowing through diode 334 when switch 342 is closed. Capacitor 324 isolates the power supply V_{CC} from the control signal V_{TUNE} and, depending on its selected value, can help set the tuning sensitivity.

In an embodiment, diodes 334 are pin diodes that have low ON resistance when turned on. The ON resistance affects the quality (or Q) of the tank circuit. A lower ON resistance corresponds to a higher circuit Q, which is often desirable for a VCO. In an embodiment and as shown in FIG. 3, diodes 334 are coupled to virtual ground at node 332, as opposed to nodes V+ and V-, which tends to reduce the effect of these diodes on the tank circuit.

In a specific implementation, varactor 320 is a 1SV273 and diode 334 is a 1SF381 pin diode. These parts are standard in the industry and are commercially available, for example, from Toshiba Corporation. In a specific implementation, capacitor 324 has a value of 68 pF, inductor 326 has a value of 62 nH, inductor 336 has a value of 15 nH, resistor 322 has a value of 10 KΩ, resistor 340 has a value of 1 KΩ, and capacitor 330 has a value of 1 μF. These values are used to provide a resonance at approximately 170 MHz for the cellular band when switch 342 is opened and a resonance at approximately 420 MHz for the PCS band when switch 342 is closed (e.g., for the receiver block diagram shown in Fig. 1B). It should be noted that these specific values are selected for a specific application. Other values can be selected for these elements for other applications, with the values being dependent on, for example, the required VCO frequencies.

FIG. 4 shows a schematic diagram of an embodiment of an active circuit 420 suitable for used in a VCO. Active circuit 420 can be used to implement active circuit 220 in FIG. 2. Active circuit 420 includes a differential amplifier 432 comprised of transistors 432a and 432b having their emitters coupled together and to a current source 434. The base of transistor 432a couples to the emitter of a transistor 438a, a current source 440a, and one input of a buffer 430.

Similarly, the base of transistor 432b couples to the emitter of a transistor 438b, a current source 440b, and the other input of buffer 430. The collector of transistor 432a couples to the base of transistor 438b and to one terminal of a tank circuit 410. The collector of transistor 432b couples to the base of transistor 438a and to the other terminal of tank circuit 410. Transistors 438a and 438b are thus cross-coupled between the outputs and inputs of differential amplifier 432. Tank circuit 410 can be implemented with tank circuit 310 in FIG. 3. The collectors of transistors 438a and 438b couple to the power supply V_{CC}. Current sources 434, 440a, and 440b also couple to circuit ground.

Differential amplifier 432 provides the signal gain required for oscillation. Transistor 438 buffers the output signal from the differential amplifier and also provides a positive feedback path from the output to the input of the differential amplifier. Current sources 434 and 440 set the bias currents for the transistors. The power supply V_{CC} for the differential amplifier comes from tank circuit 410 (i.e., from node 328 and through inductors 326 in FIG. 3).

Buffer 430 provides buffering of the signal from active circuit 420. Buffer 430 can provide a single-ended output signal (i.e., as shown in FIG. 4) or a differential output signal.

FIG. 4 shows one example of an active circuit suitable for use in a VCO. Other active circuits can also be designed and used for the VCO, and this is within the scope of the invention.

FIG. 5 shows a schematic diagram of an embodiment of a tank circuit 500. Tank circuit 500 can be used as filter 132 in FIG. 1A. As shown in FIG. 5, tank circuit 500 includes a capacitor 512 coupled between nodes 510a and 510b. A pair of inductors 516a and 516b couple in series, and the series combination couples between nodes 510a and 510b. A node 518 is formed at the common connection point of inductors 516a and 516b, and this node is coupled to the power supply V_{CC}. A capacitor 520 couples between node 518 and circuit ground.

A pair of diodes 524a and 524b couple in series, with their cathodes coupled together at a node 522. A pair of inductors 526a and 526b couple in series with the pair of diodes 524a and 524b, and the series combination of diodes 524 and inductors 526 couple between nodes 510a and 510b. A resistor 530 couples in series with a switch 532, with the series combination coupled between node 522 and circuit ground. Switch 532 receives a control signal MODE that selectively turns switch 532 on or off. Switch 532 can implement, for example, switches 172a and 172b in FIG. 1B

Tank circuit 500 is a differential circuit that can be divided into two halves (i.e., obtained by an imaginary horizontal line that bisects the middle of the tank circuit). For a differential input signal V_{IN}, the nodes along the dotted line are at AC ground or virtual ground and, ideally, the voltages at these nodes do not vary even when the tank circuit is operational. Thus, analysis of the tank circuit can be performed on either the top half or the bottom half.

Tank circuit 500 operates in the following manner. When switch 532 is opened, diode 524 is not biased and turns off, thereby creating an open circuit for the signal path with inductor 526. Tank circuit 500 then resonant with only capacitor 512 and inductor 516. With the switch opened, the resonant frequency f_O can be expressed as:

$$f_O = \frac{1}{2\pi\sqrt{L_1 C_1}}, \qquad \text{Eq. (5)}$$

Alternatively, when switch 532 is closed, diode 524 is biased and turns on, thereby providing a signal path for inductor 526. Inductor 526 is then coupled in parallel with inductor 516, and the parallel combination provides a lower inductance. Tank circuit 500 then resonant with capacitor 512 and inductors 516 and 526. With the switch closed, the resonant frequency f_C can be expressed as:

$$f_C = \frac{1}{2\pi\sqrt{(L_1 \| L_2)C_1}}, \qquad \text{Eq. (6)}$$

where

$$L_1 \| L_2 = \frac{L_1 L_2}{L_1 + L_2}. \qquad \text{Eq. (7)}$$

FIG. 6 shows frequency responses 610 and 612 for tank circuit 500 in FIG. 5 with the switch open and closed, respectively. As indicated in FIG. 6, tank circuit 500 provides bandpass frequency responses having particular center frequencies and bandwidths. The Q of a bandpass response is related to the center frequency and bandwidth, and can be expressed as:

$$Q = \frac{f}{BW}, \qquad \text{Eq. (8)}$$

where f is the center frequency of the bandpass response, BW is the (-3 dB) bandwidth, and Q is the quality factor of the bandpass response.

When the switch is opened, the center frequency of the response (or the resonant frequency of the tank circuit) is determined by capacitor 512 and inductors 516, as shown in equation (5). Since inductors are inherently lossy (i.e., having a finite amount of resistance) the frequency response has a particular bandwidth. As the inductor Q decreases, corresponding to a more lossy inductor, the Q of the tank circuit also decreases and the bandwidth widens correspondingly.

Alternatively, when the switch is closed, the center frequency of the response is determined by capacitor 512 and inductors 516 and 526, as shown in equation (6). The parallel combination of inductors 516 and 526 provides a lower inductance value, which results in a higher center frequency. The Q of the tank circuit is determined, to a large extent, by the Q of inductor 526 and the ON resistance of diode 524.

FIG. 7 shows a schematic diagram of another embodiment of a tank circuit 700. Tank circuit 700 can also be used as filter 132 in FIG. 1A. As shown in FIG. 7, tank circuit 700 includes a capacitor 712 coupled in parallel with an inductor 716, with the parallel combination coupled between nodes 710a and 710b. A pair of diodes 724a and 724b couple in series, with their cathodes coupled together at a node 722. A pair of capacitors 726a and 726b couple in series with the pair of diodes 724a and 724b, and the series combination of diodes 724 and capacitors 726 couple between nodes 710a and 710b. A pair of RF chokes 720a and 720b couple between the power supply V_{CC} and the anodes of diodes 724a and 724b, respectively. A capacitor 718 couples between the power supply V_{CC} and circuit ground, and provides filtering of the power supply. A resistor 730 couples in series with a switch 732, with the series combination coupled between node 722 and circuit ground. Switch 732 receives a control signal MODE that selectively turns switch 732 on or off.

RF chokes 720a and 720b provides biasing for diodes 724a and 724b, respectively. RF chokes 720 are selected to provide high impedance at the resonant frequency.

Tank circuit 700 operates in the following manner. When switch 732 is opened, diode 724 is not biased and turns off, thereby creating an open circuit for the signal path with capacitor 726. Tank circuit 700 then resonates with only capacitor 712 and inductor 716. With the switch opened, the resonant frequency f_O can be expressed as:

$$f_O = \frac{1}{2\pi\sqrt{L_1C_1}}, \qquad \text{Eq. (9)}$$

Alternatively, when switch 732 is closed, diode 724 is biased and turns on, thereby providing a signal path for capacitor 726. Capacitor 726 is then coupled in parallel with capacitor 716, and the combination provides a higher capacitance. Tank circuit 700 then resonant with capacitors 712 and 726 and inductor 716. With the switch closed, the resonant frequency f_C can be expressed as:

$$f_C = \frac{1}{2\pi\sqrt{L_1(C_1 + C_2)}}\ , \qquad \text{Eq. (10)}$$

In FIG. 7, a capacitor is selectively coupled to the tank circuit to provide the desired circuit characteristics. Selectively coupling an additional capacitor may be more desirable in some applications. Capacitor typically has higher Q than inductor, costs less, tighter tolerance (e.g., 1%), and some other advantages. However, for some other applications, selectively coupling an additional inductor may be more desirable. Typically, the inductors can be used to provide a bias for the pin diode, which can save on component count.

As noted above, tank circuit 700 shown in FIG. 7 can be used as a bandpass filter. Tank circuit 700 can also be adopted for used in a VCO. Specifically, tank circuit 700 can be modified to include varactors and other necessary biasing and bypassing elements, similar to those shown in FIG. 3.

FIGS. 5 and 7 show two different tank circuits that can be used as a bandpass filter, and which can be switched between two different center frequencies. The tank circuit in FIG. 5 selectively couples a second inductor in parallel with a first inductor. The tank circuit in FIG. 7 selectively couples a second capacitor in parallel with a first capacitor. Other variations of the tank circuit can also be designed. For example, a second inductor (or capacitor) can be selectively coupled in series with a first inductor (capacitor).

Broadly stated, a reactive component is selectively coupled into the tank circuit to alter the characteristics of the tank circuit in a particular desired manner. The tank circuit includes three or more reactive elements and switching means. The first and second reactive elements operatively couple between a pair of nodes and have first and second reactance values, respectively. The second reactance value is opposite in polarity from the first reactance value. For example, if the first reactive element is a capacitor (having a negative reactance value), the second reactive element is an inductor (having a positive reactive value). The third reactive element selectively and operatively couples to the second reactive element via the switching means. The switching means selectively couples the third reactive element to the second reactive element. The third reactive element can be an inductor or a capacitor, and can be coupled in parallel or in series with the second reactive element.

FIG. 8 shows a schematic diagram of an embodiment of a switch 800. Switch 800 can be used in any of the tank circuits described above. Switch 800 includes a transistor 810 having its emitter coupled to circuit ground and its collector coupled to the series resistor (e.g., resistor 340 in FIG. 3). The base of transistor 810 couples to one end of a resistor 812, and the other end of resistor 812 receives the control signal MODE. Resistor 812 limits the amount of current flowing into the base of the transistor. Transistor 810 can be implemented within the same integrated circuit to which the tank circuit couples (e.g., the same integrated circuit that implements active circuit 420 in FIG. 4).

The switch can also be implemented with various other circuit elements. For example, the switch can be implemented with different types of transistor enumerated below. Moreover, the switch can be implemented with a hardware switch, a solid state switch, a relay, an optical switch, and other types of switches.

Some embodiments of the invention have been described with circuitry implemented using BJTs. The invention can also be implemented with other circuits including FETs, MOSFETs, MESFETs, HBTs, P-HEMTs, and others. Also, P-MOS and N-MOS can be used to implement the invention. As used herein, "transistor" generically refers to any active circuit, and is not limited to a BJT.

The foregoing description of the preferred embodiments is provided to enable any person skilled in the art to make or use the present invention. Various modifications to these embodiments will be readily apparent to those skilled in the art, and the generic principles defined herein may be applied to other embodiments without the use of the inventive faculty. Thus, the present invention is not intended to be limited to the embodiments shown herein but is to be accorded the widest scope consistent with the principles and novel features disclosed herein.

WE CLAIM:

CLAIMS

1. A tank circuit comprising:

a variable capacitor;

a first inductor operatively coupled in parallel with the variable capacitor;

a second inductor selectively and operatively coupled in parallel with the first inductor; and

a switching means coupled in series with the second inductor.

2. The tank circuit of claim 1, wherein the switching means comprises a pin diode that is selectively biased on or off.

3. The tank circuit of claim 2, wherein the switching means further comprises

a transistor operatively coupled to the pin diode.

4. The tank circuit of claim 1, wherein the tank circuit is implemented as a differential circuit.

5. A tank circuit comprising:

a first reactive element operatively coupled between a first node and a second node and having a first reactance value;

a second reactive element operatively coupled between the first and second nodes and having a second reactance value, wherein the second reactance value is opposite in polarity from the first reactance value;

a third reactive element selectively and operatively coupled to the second reactive element; and

switching means operatively coupled to the third reactive element, wherein the switching means is configured to selectively couple the third reactive element to the second reactive element.

6. The tank circuit of claim 5, wherein the first reactive element comprises a capacitor and the second reactive element comprises an inductor.

7. The tank circuit of claim 5, wherein the third reactive element comprises an inductor.

8. The tank circuit of claim 5, wherein the third reactive element is selectively coupled in parallel with the second reactive element.

9. The tank circuit of claim 5, wherein the third reactive element is selectively coupled in series with the second reactive element.

10. The tank circuit of claim 5, wherein the switching means comprises
a pin diode that is selectively biased on or off.

11. The tank circuit of claim 10, wherein the switching means further comprises
a transistor operatively coupled to the pin diode.

12. The tank circuit of claim 5, wherein the tank circuit is implemented as a differential circuit.

13. A voltage control oscillator (VCO) comprising:
a tank circuit;
an active circuit coupled to the tank circuit; and
a buffer coupled to the active circuit,
wherein the tank circuit includes
a variable capacitor,
a first inductor operatively coupled to the variable capacitor,
a reactive element selectively and operatively coupled to the variable capacitor or the inductor, and
switching means coupled to the reactive element, wherein the switching means selectively couples the reactive element to the tank circuit.

14. The VCO of claim 13, wherein the active circuit includes
a first pair of transistors configured as a differential amplifier, wherein the tank circuit couples to the differential amplifier.

15. The VCO of claim 14, wherein the active circuit further includes
a second pair of transistors cross-coupled with the first pair of transistors.

16. The VCO of claim 13, wherein values of the variable capacitor and first inductor are selected to provide a first frequency of oscillation, and

wherein values of the variable capacitor, first inductor, and reactive element are selected to provide a second frequency of oscillation.

17. The VCO of claim 16, wherein the first and second frequencies of oscillation differ by more than an octave.

18. The VCO of claim 13, wherein the reactive element is an inductor.

19. The VCO of claim 13, wherein the reactive element is a capacitor.

20. A filter for a modulated signal comprising:

a capacitor coupled between a first node and a second node;

an inductor operatively coupled in parallel with the capacitor;

a reactive element selectively and operatively coupled to the inductor or capacitor; and

switching means coupled to the reactive element, wherein the switching means selectively couples the reactive element to the inductor or capacitor.

21. A transmitter in a cellular telephone comprising:

a modulator configured to receive and modulate an information bearing signal with a first carrier signal to generate a modulated signal;

a filter operatively coupled to the modulator, the filter configured to receive and filter the modulated signal to generate a filtered signal; and

a mixer operatively coupled to filter, the mixer configured to receive and upconvert the filtered signal with a second carrier signal to generate an output signal,

wherein the filter includes

a capacitor coupled between a first node and a second node,

an inductor operatively coupled in parallel with the capacitor,

a reactive element selectively and operatively coupled to the inductor or the capacitor, and

switching means coupled to the reactive element, wherein the switching means selectively couples the reactive element to the inductor or capacitor.

22. The transmitter of claim 21, further comprising;

a voltage control oscillator (VCO) coupled to the modulator or the mixer and configured to provide either the first carrier signal or the second carrier signal.

23. The transmitter of claim 22, wherein the VCO includes

a tank circuit;

an active circuit coupled to the tank circuit; and

a buffer coupled to the active circuit,

wherein the tank circuit includes

a variable capacitor,

a first inductor operatively coupled to the variable capacitor,

a reactive element selectively and operatively coupled to the variable capacitor or the inductor, and

a switching means coupled to the reactive element.

24. A receiver in a cellular telephone comprising:

a mixer configured to receive and downconvert a modulated signal with a first carrier signal to generate a downconverted signal;

a filter operatively coupled to the mixer, the filter configured to receive and filter the demodulated signal to generate a filtered signal; and

a demodulator coupled to the filter and configured to receive and demodulate the filtered signal with a second carrier signal to generate a demodulated signal,

wherein the filter includes

a capacitor coupled between a first node and a second node,

an inductor operatively coupled in parallel with the capacitor,

a reactive element selectively and operatively coupled to the inductor or the capacitor, and

switching means coupled to the reactive element, wherein the switching means selectively couples the reactive element to the inductor or capacitor.

25. The receiver of claim 24, further comprising;

a voltage control oscillator (VCO) coupled to the modulator or the mixer and configured to provide either the first carrier signal or the second carrier signal.

26. The receiver of claim 25, wherein the VCO includes

a tank circuit;

an active circuit coupled to the tank circuit; and

a buffer coupled to the active circuit,

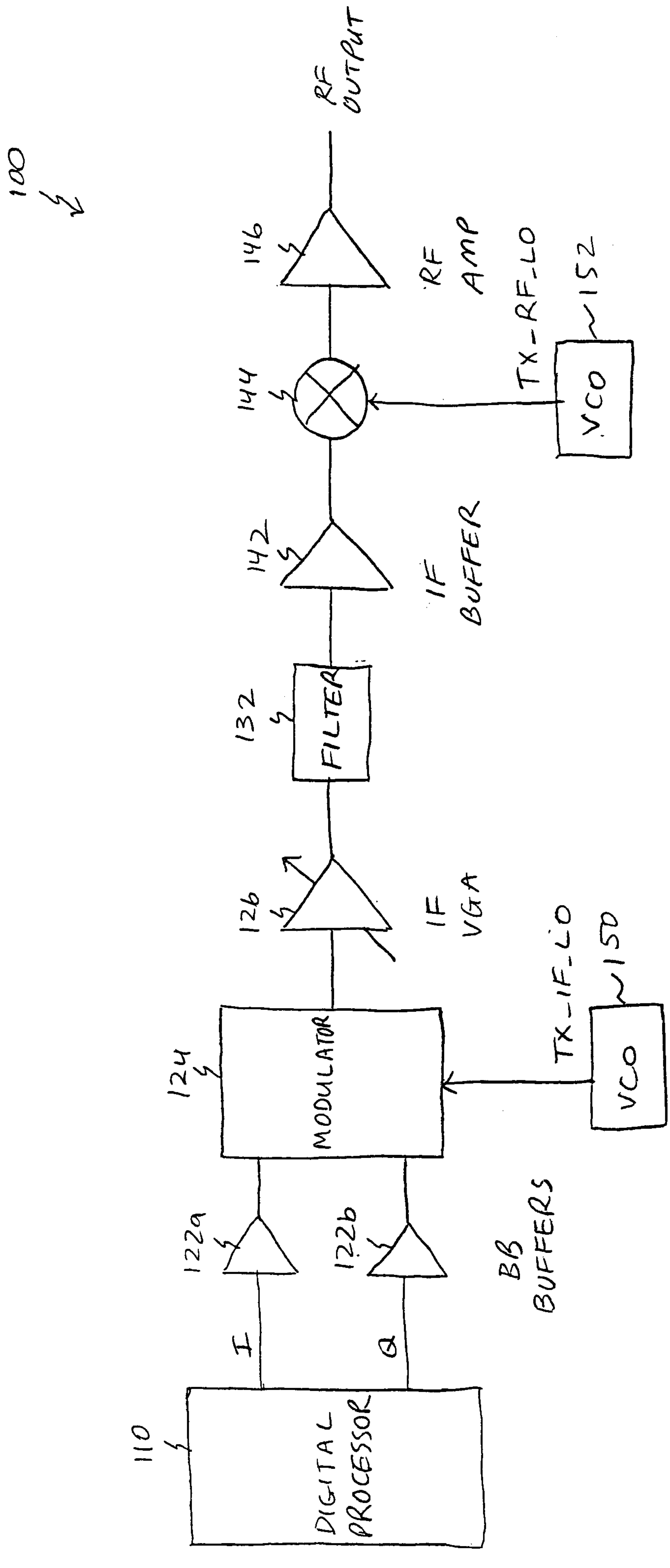
wherein the tank circuit includes

a variable capacitor,

a first inductor operatively coupled to the variable capacitor,

a reactive element selectively and operatively coupled to the variable capacitor or the inductor, and

a switching means coupled to the reactive element.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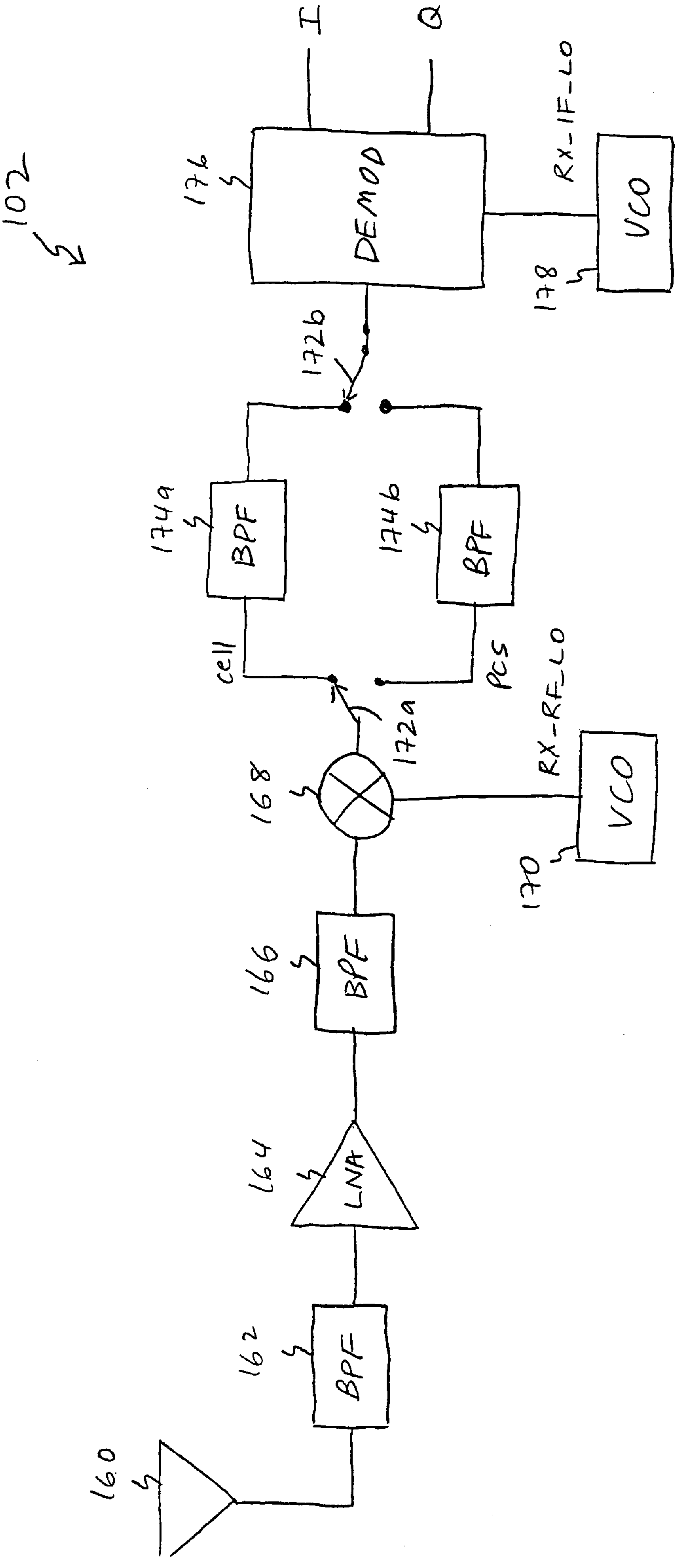
FILTER
142
IF BUFFER
144
TX_RF_LO
152
VCO
146
RF AMP
RF OUTPUT

FIG. 1A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BPF
160

FIG. 1B

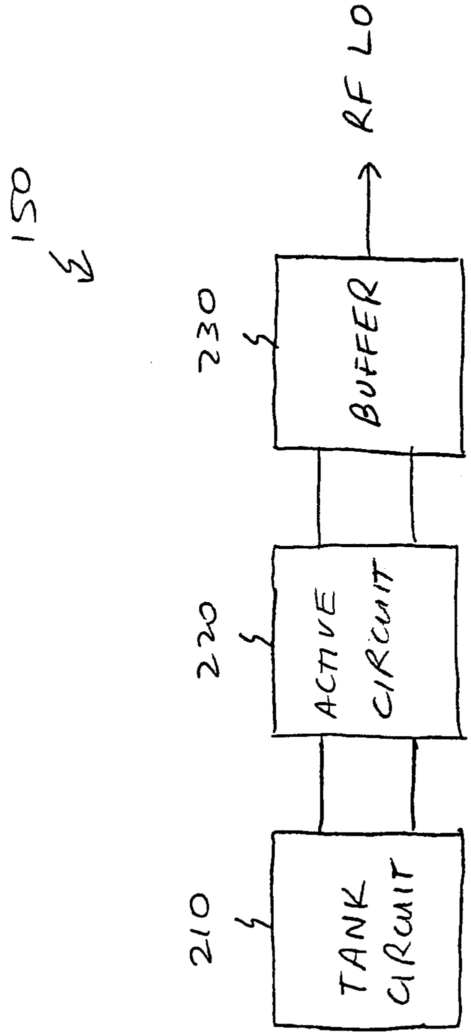
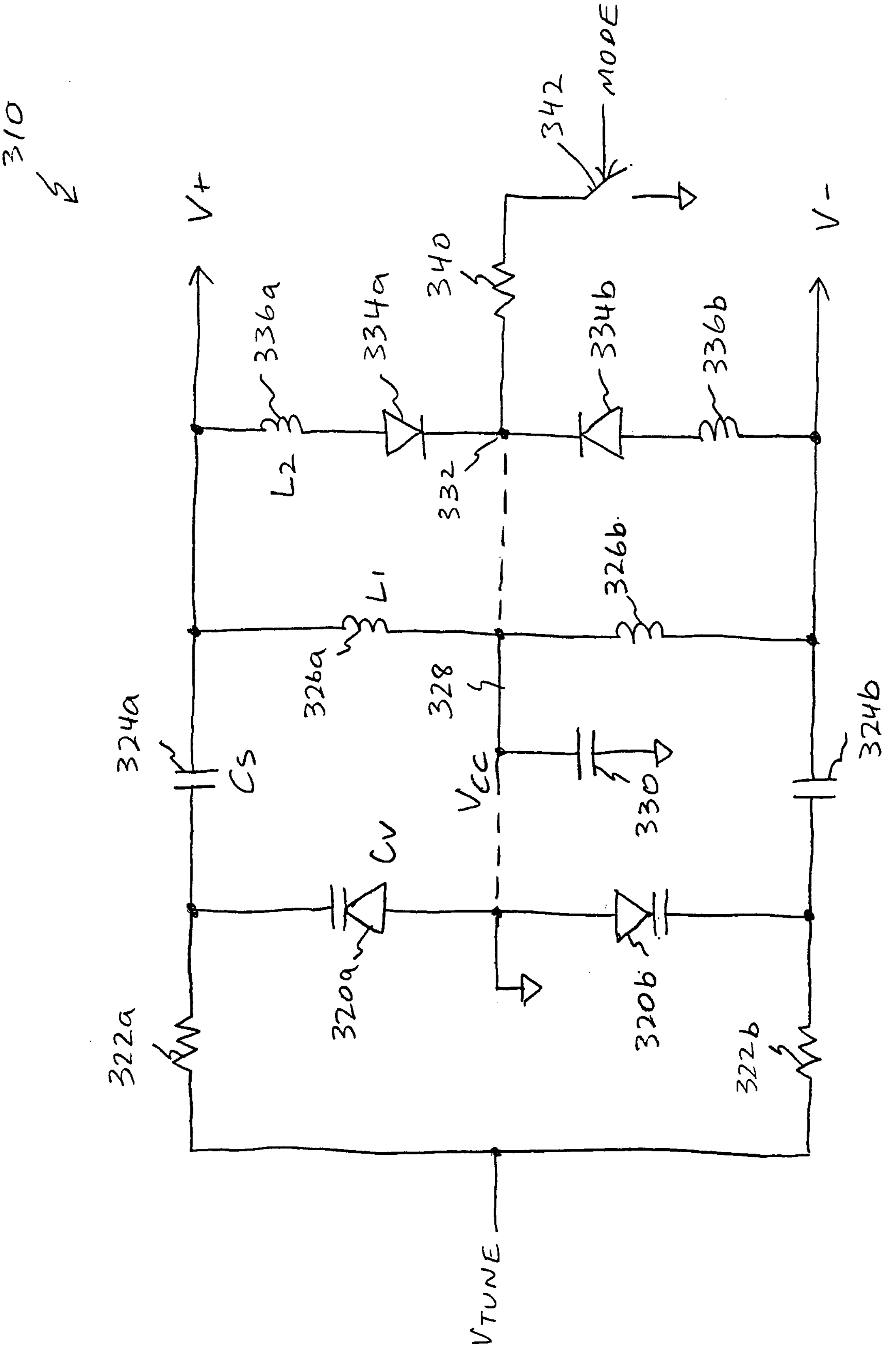


FIG. 2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L1
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Vcc
330
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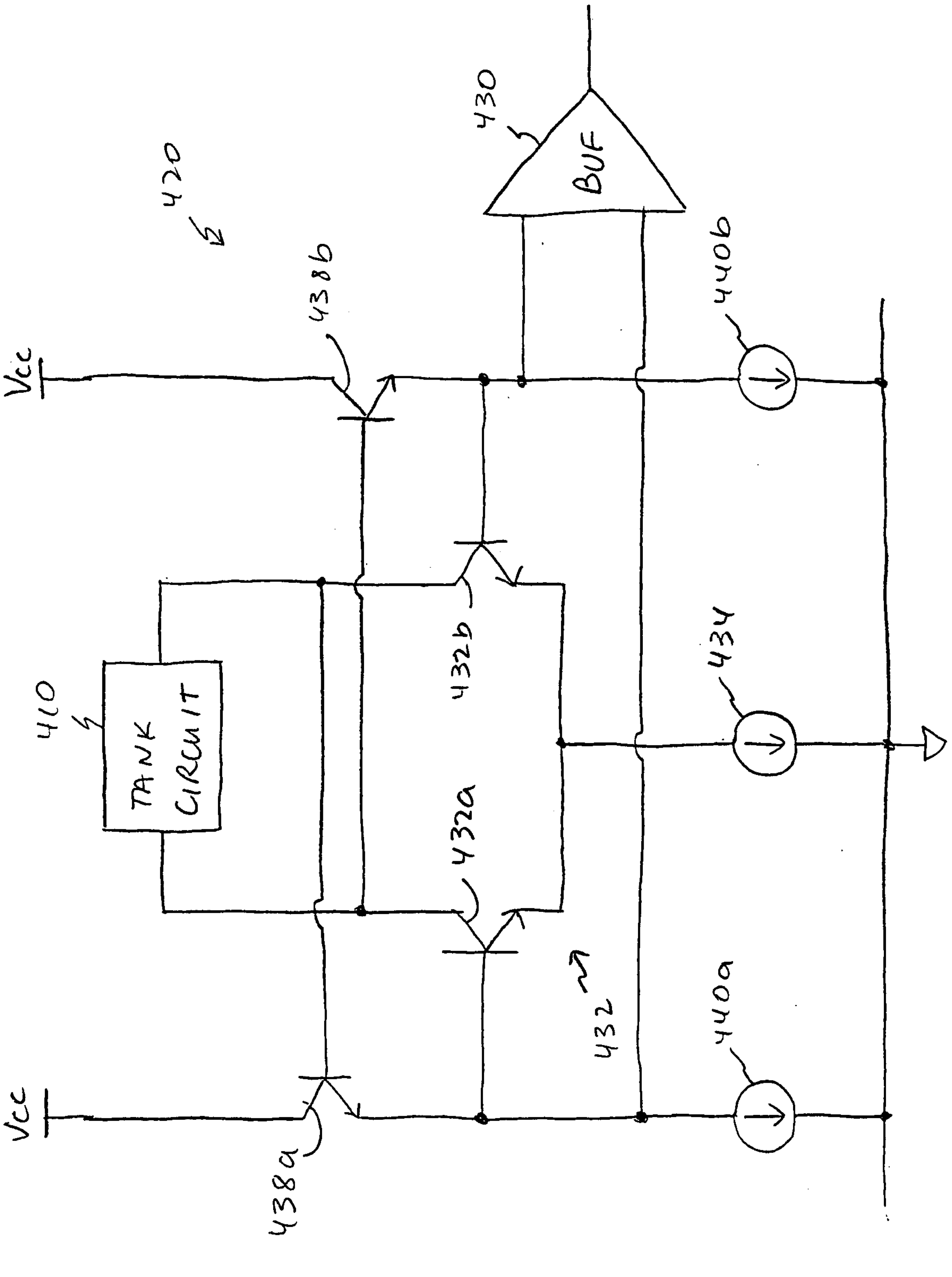
Cv
320a
320b
322a
322b
VTUNE

FIG. 3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BUF
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420
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432
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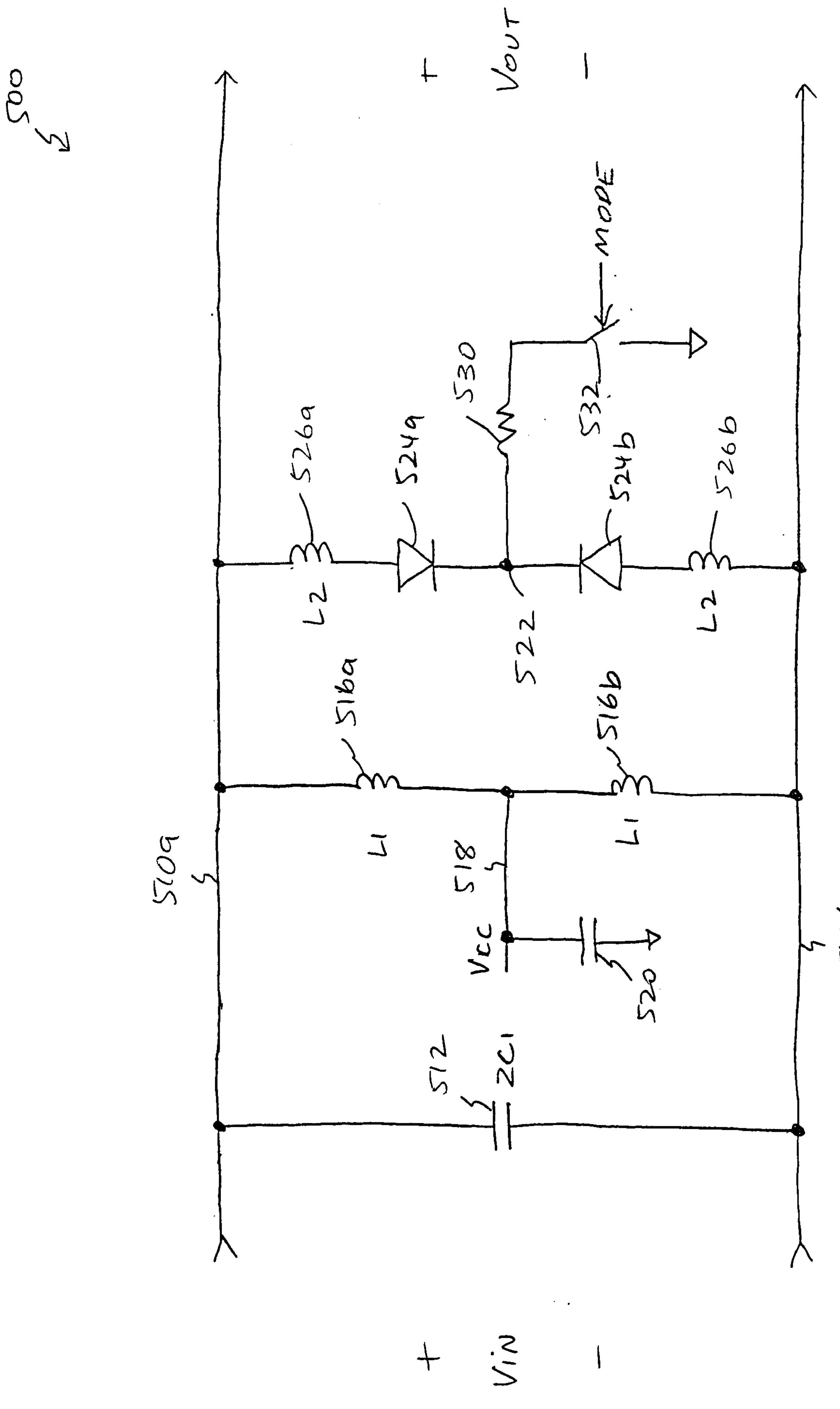
432b
434
438a
438b
440a
440b

FIG. 4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VIN
+
−

FIG. 5

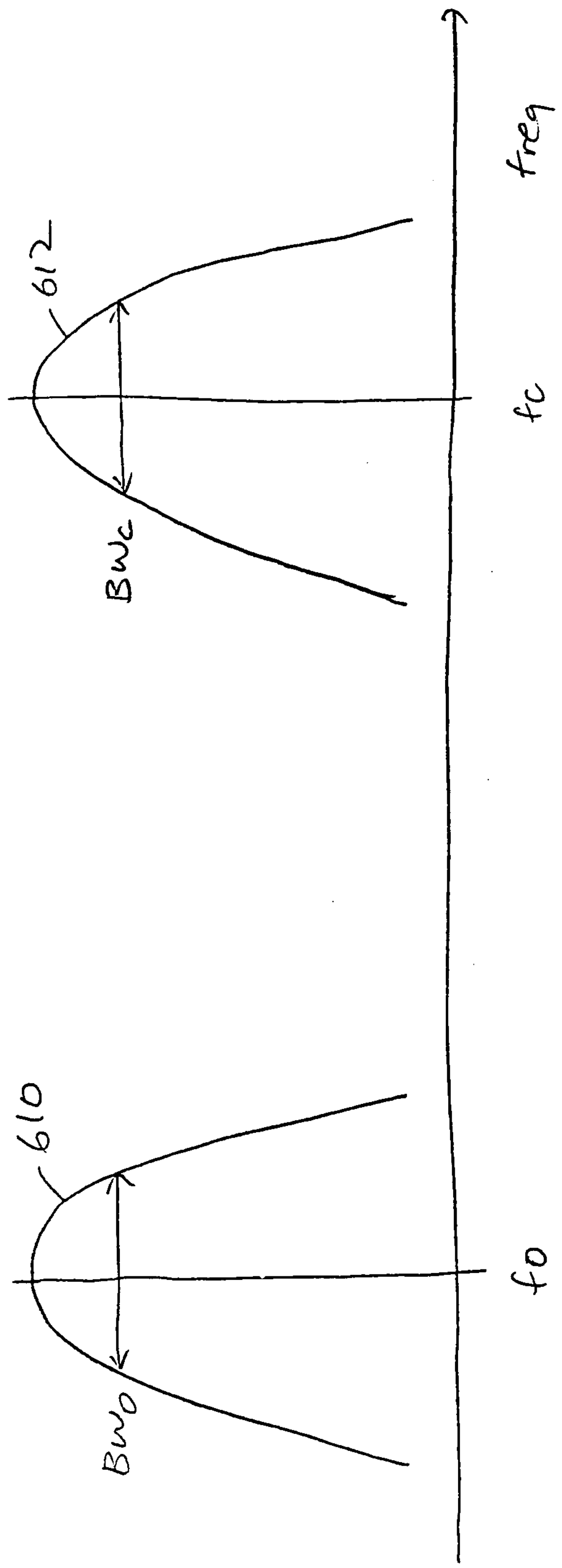
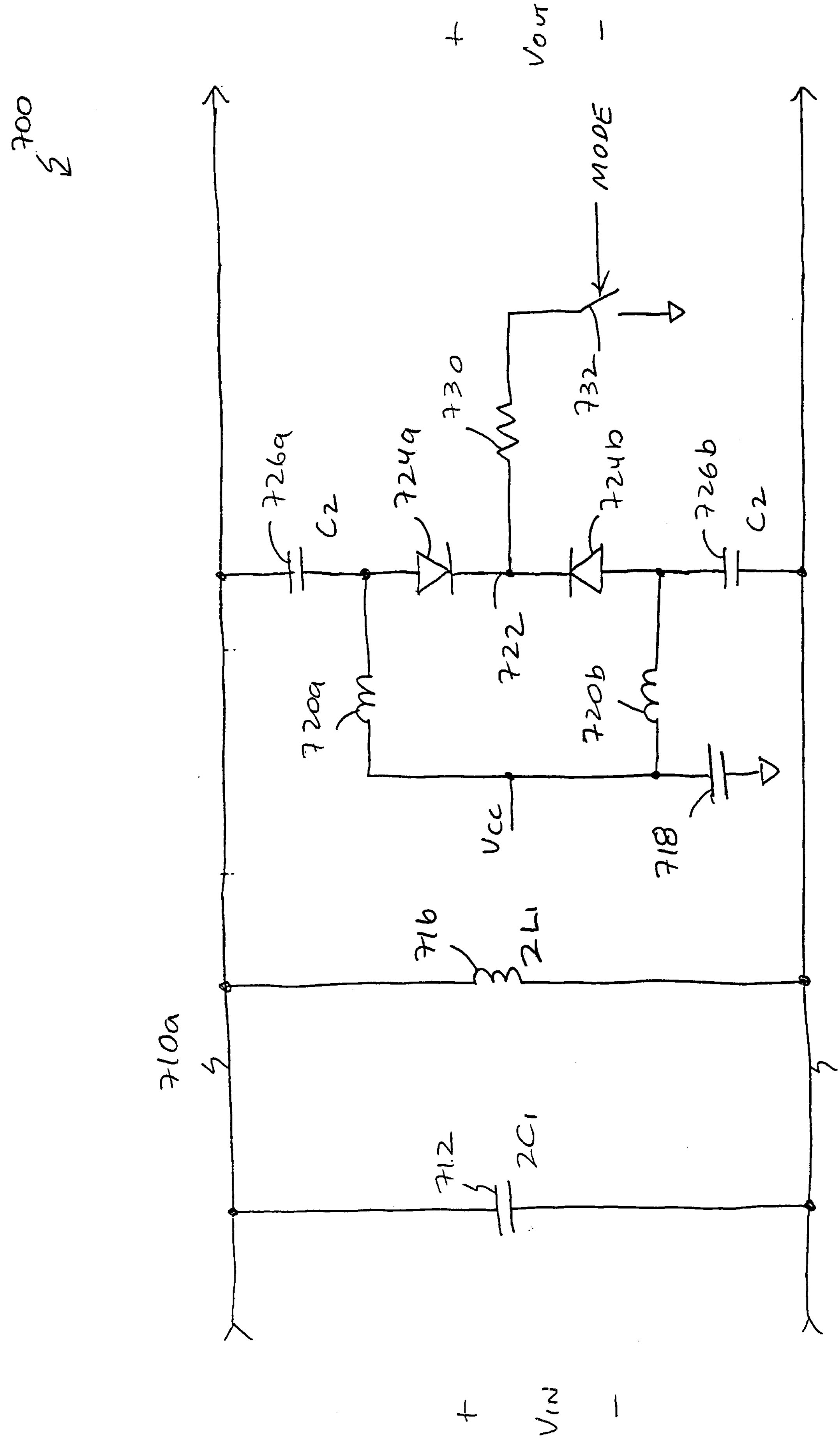


FIG. 6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710b
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2C1
+ VIN −

FIG. 7

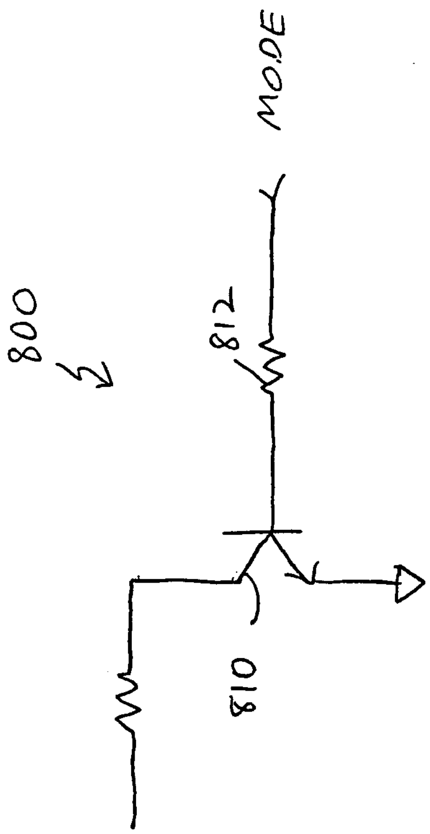

FIG. 8

INTERNATIONAL SEARCH REPORT

Intern ıal Application No
PCT/US 00/23419

A. CLASSIFICATION OF SUBJECT MATTER
IPC 7 H03B5/12

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 7 H03B

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 practical, search terms used)

EPO-Internal

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	EP 0 911 960 A (ALPS ELECTRIC CO LTD) 28 April 1999 (1999-04-28)	1-8, 10-16, 18,20
	the whole document	
A		21-26
X	US 5 745 013 A (HOHMANN HENNING) 28 April 1998 (1998-04-28)	5-7, 9-14, 16-18
	the whole document	

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

☒ Patent family members are listed in annex.

° Special categories of cited documents :

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"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"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	Date of mailing of the international search report
12 December 2000	19/12/2000

Name and mailing address of the ISA	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL – 2280 HV Rijswijk Tel. (+31-70) 340-2040, Tx. 31 651 epo nl, Fax: (+31-70) 340-3016	Beasley-Suffolk, D

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INTERNATIONAL SEARCH REPORT

…ormation on patent family members

Intern… al Application No
PCT/US 00/23419

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		WO 9533307 A	07-12-1995
		EP 0761038 A	12-03-1997
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