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(54) Title: POWER AMPLIFIER CONTROL CIRCUITS

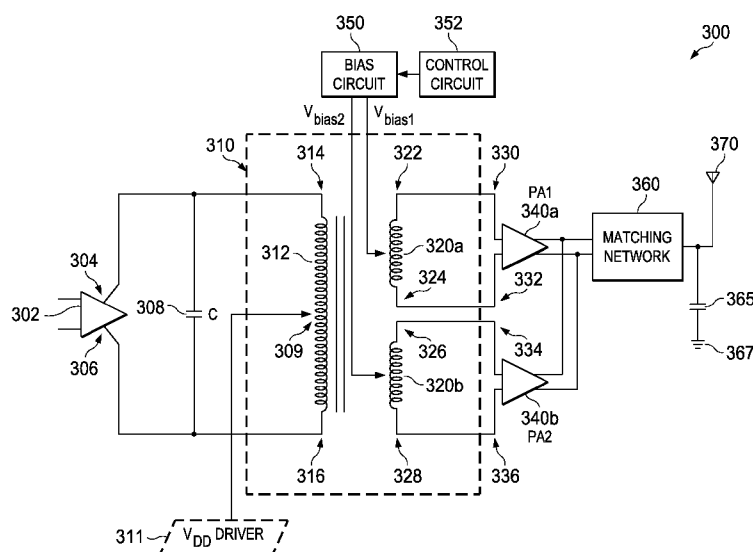


FIG. 3

(57) Abstract: In described examples, a coupling circuit (310) includes a primary winding (312), a first secondary winding (320a) and a second secondary winding (320b). The first secondary winding (320a) and the second secondary winding (320b) are inductively associated with the primary winding (312). The coupling circuit (310) is configured to provide a signal at output terminals (322, 324, 326, 328) of the first secondary winding (320a) and the second secondary winding (320b) in response to an input signal (314, 316) received at the primary winding (312). A first power amplifier circuit (340a) is coupled to output terminals (322, 324) of the first secondary winding (320a), and a second power amplifier circuit (340b) is coupled to output terminals (326, 328) of the second secondary winding (320b). Each power amplifier circuit (340a, 340b) is configured to be enabled or disabled based on a bias voltage (Vbias1, Vbias2) applied at a corresponding secondary winding (320a, 320b).



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## POWER AMPLIFIER CONTROL CIRCUITS

**[0001]** This relates in general to electronic circuits, and in particular to power amplifier control circuits.

### BACKGROUND

**[0002]** Wireless communication has changed the way people communicate and transfer data between devices. As more electronic devices are enabled for wireless and mobile communication, increasing the operational power efficiency of such devices is becoming increasingly important. In an example, transmitter circuitry is associated with a major percentage of energy requirement in such communication systems. For example, radio frequency (RF) transmission consumes considerable power, and a contributing factor to such power consumption is inefficient power amplifier operation in the RF transmitter circuitry. In one example, most of the energy is used by the power amplifiers in the RF transmitter circuitry. In view of the potential benefit of optimizing power efficiency in electronic devices having wireless capabilities, it is beneficial that transmitters deploying power amplifiers are as energy-efficient as possible.

### SUMMARY

**[0003]** In described examples, a coupling circuit includes a primary winding, a first secondary winding and a second secondary winding. The first secondary winding and the second secondary winding are inductively associated with the primary winding. The coupling circuit is configured to provide a signal at output terminals of the first secondary winding and the second secondary winding in response to an input signal received at the primary winding. A first power amplifier circuit is coupled to output terminals of the first secondary winding, and a second power amplifier circuit is coupled to output terminals of the second secondary winding. Each power amplifier circuit is configured to be enabled (e.g., switched ON) or disabled (e.g., switched OFF) based on a bias voltage applied at a corresponding secondary winding.

### BRIEF DESCRIPTION OF THE DRAWINGS

**[0004]** FIG. 1 is a circuit diagram of a circuit configured for power control of power amplifiers in a transmitter according to a first example.

[0005] FIG. 2 is a circuit diagram of a circuit configured for power control of power amplifiers in a transmitter according to a second example.

[0006] FIG. 3 is a circuit diagram of a circuit configured for power control of power amplifier circuits in a transmitter according to an embodiment.

[0007] FIG. 4 is a circuit diagram of a transmitter circuit configured for power control of power amplifier circuits according to an embodiment.

[0008] FIG. 5 is an example plan view layout of an example coupling circuit of a circuit configured for power control according to an embodiment.

#### DETAILED DESCRIPTION OF EXAMPLE EMBODIMENTS

[0009] In one example, a transmitter includes multiple power amplifiers that generate signals to be transmitted from an antenna. In a case, where a receiver is in close proximity of the transmitter, only few power amplifiers are capable of generating the required signal strength. However, in various cases, all of the power amplifiers in the transmitter are turned ON that causes unnecessary power consumption. Referring to FIG. 1, a first example is shown where two power amplifiers are coupled to a driver circuit, such as a power amplifier driver with the help of a coupling circuit. As shown in FIG. 1, a circuit 100 has a power amplifier driver 102 and a coupling circuit 110. The coupling circuit 110 includes a driver winding 112 (i.e., a primary winding coupled between input terminals 106 and 108) coupled to outputs of the power amplifier driver 102. A tuning circuit 104 is coupled between the terminals 106 and 108 of the coupling circuit 110. The coupling circuit 110 includes a power amplifier winding 114 (i.e., a secondary winding coupled between terminals 107 and 109) that is coupled to power amplifiers 122a and 122b. The driver winding 112 is inductively associated with the power amplifier winding 114. The driver winding 112 includes a center tap 105 connected to a voltage signal received from a VDD driver 111. A first power amplifier 122a is coupled to the power amplifier winding 114 by means of capacitors 120a and 120b. A second power amplifier 122b is coupled to the power amplifier winding 114 by means of capacitors 120c and 120d. A first bias voltage 116a (for example,  $V_{bias1}$ ) is provided to the first power amplifier 122a by means of resistors 118a and 118b. Similarly, the second power amplifier 122b is provided with a second bias voltage 116b (for example,  $V_{bias2}$ ) by means of resistors 118c and 118d. The power amplifiers 122a

and 122b are coupled to a matching network 124, such as a resistive network or a filter network. An output of the matching network 124 is fed to an antenna 126, such as a dipole antenna and the like. A capacitor 125 is coupled between the output of the matching network 124 and ground 123 to filter out any harmonic emissions generated by the circuit 100.

**[0010]** The bias voltages, such as the first bias voltage ( $V_{bias1}$ ) 116a and the second bias voltage ( $V_{bias2}$ ) 116b, are used to temporarily turn OFF either the first power amplifier 122a or the second power amplifier 122b, respectively, depending upon a requirement of a signal strength to be radiated from the antenna 126. In some applications, power required to transmit the signal from the antenna 126 is less, so the required power is generated by turning ON either the first power amplifier 122a or the second power amplifier 122b. In cases when the signal is being transmitted to a distant receiver, both of the power amplifiers 122a and 122b are enabled to meet the power requirement. The bias voltage (e.g.  $V_{bias1}$ ,  $V_{bias2}$ ) is selectively set to zero Volt (V) to power OFF either of the power amplifiers 122a or 122b.

**[0011]** In the example of FIG. 1, an alternating current (AC) coupling exists between the power amplifier winding 114 and the power amplifiers 122a and 122b, through the capacitances 120a-120d. Such AC coupling introduces parasitic capacitances that increase the power consumption of the power amplifiers 122a and 122b. The current consumed by the power amplifier driver 102 increases due to the capacitances 120a-120d. The large parasitic capacitance introduced by capacitors 120a-120d, reduces the inductance of the coupling circuit 110. The equivalent parallel resistances of the windings 112 and 114 decrease with decrease in the inductance of the coupling circuit 110. The gain of the power amplifier driver 102 reduces with the decrease in equivalent parallel resistances of the windings 112 and 114 for the same transconductance of the power amplifier driver 102. Such increased power consumption by the power amplifier driver 102 is a significant concern in wireless communication devices, such as wireless modems, mobile phones and laptops.

**[0012]** A second example circuit for power control in power amplifier circuits is shown in FIG. 2. As shown in FIG. 2, a circuit 200 for power control includes a power amplifier driver circuit 202, a tuning circuit 204, a first coupling circuit 206 including a

first driver winding 208 and a first power amplifier winding 210, a second coupling circuit 212 including a second driver winding 214 and a second power amplifier winding 216, a first power amplifier 222a, a second power amplifier 222b, a matching network 230, a capacitor 235 and an antenna 240.

**[0013]** The power amplifier driver circuit 202 provides a signal to the first driver winding 208 of the first coupling circuit 206 and the second driver winding 214 of the second coupling circuit 212. The signal is inductively coupled from the first driver winding 208 of the first coupling circuit 206 to the first power amplifier winding 210 of the first coupling circuit 206. The second driver winding 214 inductively couples the signal to the second power amplifier winding 216 of the second coupling circuit 212. A voltage signal received from a VDD driver 207 is applied at center taps 203 and 205 of the driver windings 208 and 214, respectively. The first power amplifier 222a is provided a signal from output terminals of the first power amplifier winding 210, and the second power amplifier 222b receives the signal from the second power amplifier winding 216. Amplified signals from the power amplifiers 222a and 222b are provided to the matching network 230, which is coupled to the antenna 240. The capacitor 235, coupled between the antenna 240 and ground 237, reduces the harmonic emissions introduced by the circuit 200. A first bias voltage 218 (e.g.,  $V_{bias1}$ ) for the first power amplifier 222a is provided at a center tap of the first power amplifier winding 210. The second power amplifier 222b is provided with a second bias voltage 220 (e.g.,  $V_{bias2}$ ), at the center tap of the second power amplifier winding 216. In this example, a zero bias voltage (e.g.,  $V_{bias1}$ ,  $V_{bias2}$ ) is provided at the center taps of power amplifier windings 210 and 216, respectively, to switch OFF the corresponding power amplifiers 222a and 222b. The first power amplifier 222a or the second power amplifier 222b are not required to be functional when the transmitting antenna 240 is near a receiver and either of the amplifiers 222a and 222b are powered OFF to save power. Such powering OFF the power amplifiers 222a and 222b helps in reducing power consumption of the power amplifier driver circuit.

**[0014]** By using two different coupling circuits 206 and 212 to couple the power amplifier driver circuit 202 with the power amplifiers 222a and 222b, the passive area of the circuit 200 increases. The power amplifier driver circuit 202 coupled to the first

driver winding 208 and the second driver winding 214 results in signal loss at the input terminal of the driver windings 208 and 214, due to plus and minus crossings of the driver windings 208 and 214.

**[0015]** Various embodiments of this technology, discussed in connection with FIGS. 3-5, provide solutions that are capable of reducing power consumption associated with power amplifiers in transmitter circuitries, and these solutions overcome various limitations and provide various benefits.

**[0016]** FIG. 3 illustrates a circuit 300 for power control of power amplifier circuits in a transmitter according to an embodiment. The circuit 300 includes a coupling circuit 310, a first power amplifier circuit 340a (PA1) and a second power amplifier circuit 340b (PA2). The circuit 300 represents a transmitter circuit. The coupling circuit 310 is configured to couple an input signal from input terminals 314 and 316 of the coupling circuit 310 to output terminals of the coupling circuit 310. In an example, the coupling circuit 310 includes a primary winding 312 and two secondary windings, such as a first secondary winding 320a and a second secondary winding 320b. In an example, the coupling circuit 310 is configured using a balun having coils wound around a core to form the primary winding 312, the first secondary winding 320a and the second secondary winding 320b. The coupling circuit 310 is also configured as a transformer including inductive coils (e.g., the primary winding 312 and the secondary windings 320a and 320b) wound on a core. The primary winding 312 couples the input signal inductively from input terminal (i.e., a positive input terminal 314 and a negative input terminal 316) of the primary winding 312 to output terminals (i.e., a positive terminal 322 and a negative terminal 324) of the first secondary winding 320a. The primary winding 312 also couples the input signal inductively from the input terminals (i.e., the positive input terminal 314 and the negative input terminal 316) of the primary winding 312 to output terminal (i.e., a positive terminal 326 and a negative terminal 328) of the second secondary winding 320b. In some examples, signal at the output terminals (output terminals 322 and 324 of the first secondary winding 320a and output terminals 326 and 328 of the second secondary winding 320b) of the secondary windings 320a and 320b are at different voltage levels, but primarily will be the same signal. The primary winding 312 has a center tap 309 that is provided a voltage signal from a VDD driver 311. The

VDD driver 311 provides a signal that is out-of-phase at the positive input terminal 314 and the negative input terminal 316 of the primary winding 312. The coupling circuit 310 is for example purposes only, and the coupling circuit 310 is configured in various other ways, such as by using a specific circuit element or combinations of circuit elements (e.g., amplifiers, diodes, capacitors, resistors, and the like).

**[0017]** In comparison to the circuit 200 of FIG. 2, the circuit 300 for power control uses a single coupling circuit 310 to couple the signal from the input terminals (i.e., the positive input terminal 314 and the negative input terminal 316) of the primary winding 312 to the output terminals (i.e., the positive terminals 322 and 326, the negative terminals 324, 328) of the secondary windings 320a and 320b, which reduces the passive area occupied by the coupling circuit 310. The complexity of the circuit 200 introduced by multiple coupling circuits 206 and 212 (FIG. 2) is reduced by the use of the coupling circuit 310 having the primary winding 312 and the secondary windings 320a and 320b.

**[0018]** PA1 and PA2 are radio frequency (RF) power amplifiers, and are connected to output terminals of the coupling circuit 310. For example, input terminals (a first terminal 330 and a second terminal 332) of PA1 are coupled to output terminals (the positive terminal 322 and the negative terminal 324) of the first secondary winding 320a. Similarly, input terminals (a first terminal 334 and a second terminal 336) of PA2 are coupled to output terminals (the positive terminal 326 and the negative terminal 328) of the second secondary winding 320b. In various embodiments, PA1 and PA2 are configured in various ways, such as by using a specific circuit element or combination of circuit elements such as transistor amplifiers, operational amplifiers, differential amplifiers, vacuum amplifiers, microwave amplifiers or combinations of circuit elements (e.g., amplifiers, diodes, capacitors, resistors, and the like). PA1 and PA2 are configured to convert a low power radio frequency signal (received from the secondary windings 320a and 320b, respectively) to an amplified signal of significant power. PA1 and PA2 are operated either in Class A, Class B, Class AB, Class C, Class D or Class H modes of operation based on a transistor bias voltage and the input signal. PA1 and PA2 are enabled/disabled (switched ON/OFF) based on bias voltages supplied to PA1 and PA2.

**[0019]** As discussed with reference to the circuit 100 of FIG. 1, direct current (DC) coupling of the secondary windings (320a and 320b) of the coupling circuit 310 with PA1

and PA2 reduces the parasitic capacitance of the circuit 300. The reduction of parasitic capacitances in the circuit 300 increases the gain of the circuit 300. The inductive coupling of the signal from the primary winding 312 to the secondary windings 320a and 320b is greatly enhanced due to the absence of capacitances (such as capacitances 120a-120d in FIG. 1) in the circuit 300.

**[0020]** In one embodiment, the circuit 300 includes a driver circuit 302 and a bias circuit 350. The driver circuit 302 has a positive output terminal 304 and a negative output terminal 306. The positive output terminal 304 is coupled to the positive input terminal 314 of the primary winding 312, and the negative output terminal 306 is coupled to the negative input terminal 316 of the primary winding 312. The driver circuit 302 is an electrical circuit or an electronic component that accepts signals and provides the signals to PA1 and PA2 for further transmission. The driver circuit 302 is configured in various ways, such as by using a specific circuit element or combinations of circuit elements (e.g., amplifiers, diodes, inductors, capacitors, resistors, and the like). In an embodiment, the driver circuit 302 is a power amplifier driver that increases the signal strength and provides it to the primary winding 312. The DC coupling of the secondary windings (320a and 320b) with PA1 and PA2 reduces the current consumption of the driver circuit 302.

**[0021]** The circuit 300 also includes a tuning circuit 308 coupled between the positive output terminal 304 and the negative output terminal 306 of the driver circuit 302. The tuning circuit 308 is configured to improve the noise performance associated with the coupling of the driver circuit 302 with PA1 and PA2. In the embodiment shown in FIG. 3, the tuning circuit 308 is shown as a capacitor (C). Moreover, the tuning circuit 308 is implemented using other types of electronic components, such as resistors, inductors and other resonant circuits.

**[0022]** The bias circuit 350 is configured to selectively provide bias voltages to the secondary windings 320a and 320b to control ON/OFF of PA1 and PA2. For example, the bias circuit 350 provides a first bias voltage ( $V_{bias1}$  in FIG. 3) to enable and disable (control ON/OFF) PA1 and a second bias voltage ( $V_{bias2}$  in FIG. 3) to enable and disable (control ON/OFF) PA2. In an embodiment, the first bias voltage is applied at the center tap of the first secondary winding 320a for PA1, and the second bias voltage is

applied at the center tap of the second secondary winding 320b for PA2. The bias circuit 350 provides the bias voltages to establish a predetermined voltage at the center tap of the first secondary winding 320a and the second secondary winding 320b.

**[0023]** In some embodiments, the bias voltages are controlled by a control circuit 352. The control circuit 352 is coupled to the bias circuit 350, and the control circuit 352 is configured to control the first bias voltage provided to the first secondary winding 320a and the second bias voltage provided to the second secondary winding 320b. PA1 is disabled (switched OFF) when the first bias voltage applied at the center tap of the first secondary winding 320a is of zero voltage. Similarly, PA2 is switched OFF when the Vbias2 applied at the center tap of the second secondary winding 320b is of zero voltage. Other voltages, such as a negative supply, is used as the Vbias1 and Vbias2 to switch OFF the PA1 and PA2, instead of the zero voltages. In various embodiments, the control circuit 352 is configured in various ways, such as by using a combination of circuit elements (e.g., amplifiers, diodes, capacitors, resistors, and the like) or a combination of various circuitries.

**[0024]** In some embodiments, the circuit 300 also includes a matching network 360, a filter circuit such as a capacitor 365, and an antenna 370. Examples of the matching network 360 include, but are not limited to, a resistive network, a reactive network and a filter network. Outputs of PA1 and PA2 are coupled to the matching network 360, so that the matching network 360 is configured to provide the amplified signal (received from PA1 and PA2) to an input terminal of the antenna 370. The matching network 360 is configured in various ways, such as by using a specific circuit element or combinations of circuit elements (e.g., inductors, capacitors, resistors and the like). The capacitor 365 coupled between the antenna 370 and ground 367, reduces the harmonic emissions introduced by the circuit 300. The capacitor 365 reduces the bandwidth of the amplified signals transmitted without loss of information by reducing the harmonic emissions of the circuit 300. The antenna 370 converts the amplified signal into radio waves and radiates energy in the form of electromagnetic waves. Examples of the antenna 370 include, but are not limited to, a wire antenna, a microstrip antenna, a reflector antenna, a travelling wave antenna, an aperture antenna, and a log periodic antenna.

**[0025]** When an input signal is transmitted to a receiver in a close proximity, an

amplification provided by either PA1 or PA2 would suffice. For example, when power provided by PA1 would be sufficient to transmit the input signal, PA2 is powered OFF to reduce the power consumption of power amplifier circuits (PA1 and PA2). The second bias voltage (Vbias2) is set to zero voltage at the center tap of the secondary winding 320b to switch OFF the PA2. For example, if the input signal has to be transmitted to a node at a distance of 100 meters from the antenna 370, the power required by the antenna 370 is 13 (decibel decibel-milliwatt) dBm, which is provided by PA1. This requires the control circuit 352 to provide the Vbias1 as 0.5 V (only an indicative number) to the center tap of the secondary winding 320a and a zero voltage as the Vbias2. The Vbias1 powers ON PA1 to amplify the input signal to be transmitted and powers OFF the PA2. This reduces the power consumption of power amplifier circuitry by switching OFF the PA2. The bias circuit 350 and the control circuit 352 are configured in various ways using voltage converters, voltage regulators, transistors, amplifiers, diodes and other passive devices, and the like.

**[0026]** If the transmission of an input signal to a distant node requires more power, then amplification is provided by both PA1 and PA2, so that both PA1 and PA2 are switched ON. For example, if the node is at a distance of 100 kilometers from the antenna 370, the power required is 250 dBm. The control circuit 352 directs the bias circuit 350 to provide the Vbias1 of 0.5V and the Vbias2 of 0.5V to PA2. The power amplifier circuits (PA1 and PA2) are enabled (switched ON) through the respective secondary windings (320a and 320b) by the bias circuit 350, and PA1 and PA2 provide the necessary power for the input signal to be transmitted to the distant node.

**[0027]** The driver circuit 302, the coupling circuit 310, the power amplifier circuits 340a and 340b, the matching network 360 and the antenna 370 are implemented as interconnections of electronic elements and circuits and modules, such as an application specific integrated circuit (ASIC), a field programmable gate array (FPGA), and the like. More than two power amplifiers are in the transmitter circuitry and are controlled for reducing power consumption therein, by using various embodiments. Another such example embodiment is described in connection with FIG. 4.

**[0028]** With reference to FIG. 4, a circuit 400 (for example, a transmitter circuit 400) shows a coupling circuit 410 coupled to power amplifier circuits (440a-440n) for power

control in a transmitter. The coupling circuit 410 includes a primary winding 412 and secondary windings 420a-420n inductively coupled to the primary winding 412. The coupling circuit 410 is configured to provide a signal at output terminals of the secondary windings 420a-420n in response to an input signal at a positive input terminal 414 and a negative input terminal 416 of the primary winding 412. Examples of the coupling circuit 410 include a balun or a transformer.

**[0029]** The power amplifier circuits 440a-440n are audio power amplifiers or video power amplifiers. The power amplifier circuits 440a-440n are coupled to the output terminals of the secondary windings 420a-420n. For example, terminals 430 and 432 of a first power amplifier circuit 440a are coupled to output terminals (a positive terminal 422 and a negative terminal 424) of a first secondary winding 420a of the secondary windings 420a-420n, and terminals 434 and 436 of a second power amplifier circuit 440b are coupled to output terminals (a positive terminal 426 and a negative terminal 428) of a second secondary winding 420b, and so on.

**[0030]** The circuit 400 also includes a driver circuit 402 coupled to input terminals of the coupling circuit 410. For example, output terminals (a positive output terminal 404 and a negative output terminal 406) of the driver circuit 402 are coupled to the input terminals (the positive input terminal 414 and the negative input terminal 416) of the primary winding 412. Examples of the driver circuit 402 include, but are not limited to, audio power amplifier driver and RF power amplifier driver. The primary winding 412 has a center tap 409 that is provided with a VDD driver 411. The voltage signal provides out-of-phase signals of same magnitude at the positive input terminal 414 and the negative input terminal 416 of the primary winding 412. The circuit 400 also includes a tuning circuit 408 for coupling the driver circuit 402 with the power amplifier circuits 440a-440n. The tuning circuit 408 is coupled between the output terminals (the positive output terminal 404 and the negative output terminal 406) of the driver circuit 402. Examples of the tuning circuit 408 include a capacitor (C) as shown in FIG. 4 or a parallel combination of inductor and capacitor.

**[0031]** Each power amplifier circuit of the power amplifier circuits 440a-440n is switched ON/OFF based on a power requirement of the input signal to be transmitted. For example, the power amplifier circuit 440a alone is enabled when the input signal is

transmitted to a receiver in a close proximity, so the power amplifier circuits 440b–440n are powered OFF. A bias circuit 450 provides bias voltages which control power ON/OFF of the power amplifier circuits 440a–440n. The bias circuit 450 selectively provides a bias voltage to each secondary winding of the secondary windings 420a–420n at a center tap of each secondary winding. For example, the bias circuit 450 provides a bias voltage for the power amplifier circuit 440a at the center tap of the secondary winding 420a to control ON/OFF of the power amplifier circuit 440a, and so on. The bias circuit 450 includes a control circuit 452 configured to provision the bias voltages so as to be selectively provided by the bias circuit 450. For example, the power amplifier circuit 440a is switched OFF when the control circuit 452 directs the bias circuit 450 to provide a zero bias voltage at the center tap of the secondary winding 420a to power OFF the power amplifier circuit 440a. When the input signal is being transmitted to a nearby node,  $m$  number of power amplifiers of the power amplifier circuits 440a–440n are powered OFF, where,  $n > m > 1$ . A distant node requires at most  $p$  power amplifier circuits of the power amplifier circuits 440a–440n to be powered OFF, where  $n > m > p \geq 1$ .

**[0032]** The circuit 400 includes a matching network 460, a filter circuit including a capacitor 465, and an antenna 470. The matching network 460 (e.g., resistive network, filters, and the like) is coupled to the output terminals of the power amplifier circuits 440a–440n. In this embodiment, the matching network 460 is configured to receive amplified signals from output terminals of the power amplifier circuits 440a–440n. The matching network 460 is configured to provide the amplified signals to the antenna 470 for transmission. The capacitor 465 is coupled between the antenna 470 and ground 467, and reduces the harmonic emissions introduced by the circuit 400. The capacitor 465 reduces the bandwidth of the amplified signals transmitted without loss of information by reducing the harmonic emissions of the circuit 400. The antenna 470 receives the amplified signals from the power amplifier circuits 440a–440n and converts the amplified signals to radio waves for wireless transmission.

**[0033]** Referring to FIG. 5, a layout 500 shows details of the coupling circuit 310 including the primary winding 312 and the secondary windings 320a and 320b according to an embodiment. The layout 500 of FIG. 5 is described for the connections of the

coupling circuit 310 (FIG. 3). The positive output terminal 304 of the driver circuit 302 is coupled to the positive input terminal 314 of the primary winding 312 (MIX\_P) and the negative output terminal 306 of the driver circuit 302 is coupled to the negative input terminal 316 of the primary winding 312 (MIX\_M). The secondary winding 320a is shown as a concentric shape within the primary winding 312. The positive terminal 322 (PA1\_P) and the negative terminal 324 (PA1\_M) of the secondary winding 320a are coupled to the first terminal 330 and the second terminal 332 of PA1. The secondary winding 320b is shown as another concentric shape within the primary winding 312. The positive terminal 326 (PA2\_P) and the negative terminal 328 (PA2\_M) of the secondary winding 320b are coupled to the first terminal 334 and second terminal 336 of PA2. The Vbias1 is provided at the center tap (502) of the secondary winding 320a, and the Vbias2 is provided at the center tap (504) of the secondary winding 320b. The primary winding 312 and the secondary windings 320a and 320b are arranged in concentric circles in a layout that reduces the area compared to a conventional scheme of FIG. 2. Use of concentric windings avoids the overlap of output terminals (a positive terminal and a negative terminal) of the driver circuit 202 with terminals (positive terminal and negative terminal) of the driver windings 208 and 214 in the coupling circuits 206 and 212.

**[0034]** In one or more of the example embodiments, a circuit is capable of providing power control of power amplifiers in a transmitter with a reduced area. The circuit consumes less power due to DC coupling of the coupling circuit with the power amplifier circuit. The circuit implementation uses a single coupling circuit having a primary winding and a plurality of secondary windings arranged in concentric shapes/circles, which reduces the area occupied by the coupling circuit and also avoids the negative and positive crossings. The gain of the circuit is considerably increased due to the absence of capacitances for coupling the secondary windings with the power amplifier circuits. The circuit is less complex compared to the conventional scheme. The circuit reduces the signal loss due to absence of overlapping terminals.

**[0035]** Modifications are possible in the described embodiments, and other embodiments are possible, within the scope of the claims.

## CLAIMS

What is claimed is:

1. A circuit for power control of power amplifier circuits, the circuit comprising:  
a coupling circuit including a primary winding, a first secondary winding and a second secondary winding, the first secondary winding and the second secondary winding inductively associated with the primary winding, the coupling circuit configured to provide a signal at output terminals of the first secondary winding and output terminals of the second secondary winding, in response to an input signal received at the primary winding;  
a first power amplifier circuit coupled to the output terminals of the first secondary winding, wherein the first power amplifier circuit is configured to be enabled and disabled based on a first bias voltage selectively applied at the first secondary winding; and  
a second power amplifier circuit coupled to the output terminals of the second secondary winding, wherein the second power amplifier circuit is configured to be enabled and disabled based on a second bias voltage selectively applied at the second secondary winding.
2. The circuit of claim 1, wherein the primary winding includes a positive input terminal and a negative input terminal, the circuit further comprising a driver circuit having a positive output terminal and a negative output terminal, the positive output terminal being coupled to the positive input terminal, and the negative output terminal being coupled to the negative input terminal, such that the driver circuit is electronically coupled to the primary winding and thereby configured to provide the input signal to the primary winding.
3. The circuit of claim 2, further comprising a tuning circuit coupled between the positive output terminal and the negative output terminal of the driver circuit to increase a gain of the driver circuit.
4. The circuit of claim 1, further comprising a bias circuit coupled to the first secondary winding and the second secondary winding, the bias circuit configured to selectively provide the first bias voltage to the first secondary winding and the second bias voltage to the second secondary winding.

5. The circuit of claim 4, further comprising a control circuit coupled to the bias circuit, the control circuit configured to provision the first bias voltage and the second bias voltage.
6. The circuit of claim 4, wherein each of the first secondary winding and the second secondary winding includes a center tap, the first bias voltage being applied at the center tap of first secondary winding, and the second bias voltage being applied at the center tap of the second secondary winding.
7. The circuit of claim 6, wherein the first power amplifier circuit is configured to be disabled when the first bias voltage applied at the first secondary winding is zero, and the second power amplifier circuit is configured to be disabled when the second bias voltage applied at the second secondary winding is zero.
8. The circuit of claim 1, wherein each of the first secondary winding and the second secondary winding includes a positive terminal and a negative terminal, and each of the first power amplifier circuit and the second power amplifier circuits includes a first terminal and a second terminal, the positive terminal of the first secondary winding and the positive terminal of the second secondary winding being coupled to the first terminal of the first power amplifier circuit and the first terminal of the second power amplifier circuit, respectively, and the negative terminal of the first secondary winding and the negative terminal of the second secondary winding being coupled to the second terminal of the first power amplifier circuit and the second terminal of the second power amplifier circuit, respectively.
9. The circuit of claim 1, further comprising a matching network coupled to the first power amplifier circuit and the second power amplifier circuit, the matching network configured to receive amplified signals from the first power amplifier circuit and the second power amplifier circuit.
10. The circuit of claim 9, further comprising an antenna coupled to the matching network, the antenna configured to receive the amplified signals from the matching network and wirelessly transmit the amplified signals.

11. A transmitter circuit, comprising:

a coupling circuit including a primary winding and a plurality of secondary windings inductively associated with the primary winding, the coupling circuit configured to provide a signal at output terminals of the plurality of secondary windings in response to an input signal received at the primary winding; and

a plurality of power amplifier circuits coupled to the output terminals of the plurality of secondary windings, wherein each power amplifier circuit is configured to be enabled and disabled based on a bias voltage selectively applied at a corresponding secondary winding.

12. The circuit of claim 11, wherein the primary winding includes positive and negative input terminals, the circuit further comprising a driver circuit having a positive output terminal and a negative output terminal, the positive output terminal being coupled to the positive input terminal, and the negative output terminal being coupled to the negative input terminal, such that the driver circuit is electronically coupled to the primary winding and thereby configured to provide the input signal to the primary winding.

13. The circuit of claim 12, further comprising a tuning circuit coupled between the positive output terminal and the negative output terminal of the driver circuit to enhance the gain of the driver circuit.

14. The circuit of claim 11, further comprising a bias circuit coupled to the plurality of secondary windings, the bias circuit configured to selectively provide the bias voltages to the plurality of secondary windings, wherein each bias voltage is configured to control a corresponding power amplifier circuit.

15. The circuit of claim 14, further comprising a control circuit coupled to the bias circuit, the control circuit configured to provision the bias voltages.

16. The circuit of claim 14, wherein the plurality of secondary windings include center taps, the bias voltage being applied at the center tap of the corresponding secondary winding.

17. The circuit of claim 16, wherein a power amplifier circuit of the plurality of power amplifier circuits is disabled when the bias voltage provided to the corresponding secondary winding of the power amplifier circuit is a zero.

18. The circuit of claim 11, wherein each secondary winding of the plurality of secondary windings includes positive and negative terminals, and each power amplifier circuit of the plurality of power amplifier circuits includes first and second terminals, the positive terminal of the secondary winding being coupled to the first terminal of the power amplifier circuit, and the negative terminal of the secondary winding being coupled to the second terminal of the power amplifier circuit.

19. The circuit of claim 11, further comprising a matching network coupled to the plurality of power amplifier circuits, the matching network configured to receive amplified signals from the power amplifier circuits.

20. The circuit of claim 19, further comprising an antenna circuit coupled to the matching network, the antenna configured to receive the amplified signals from the matching network and wirelessly transmit the amplified signals.

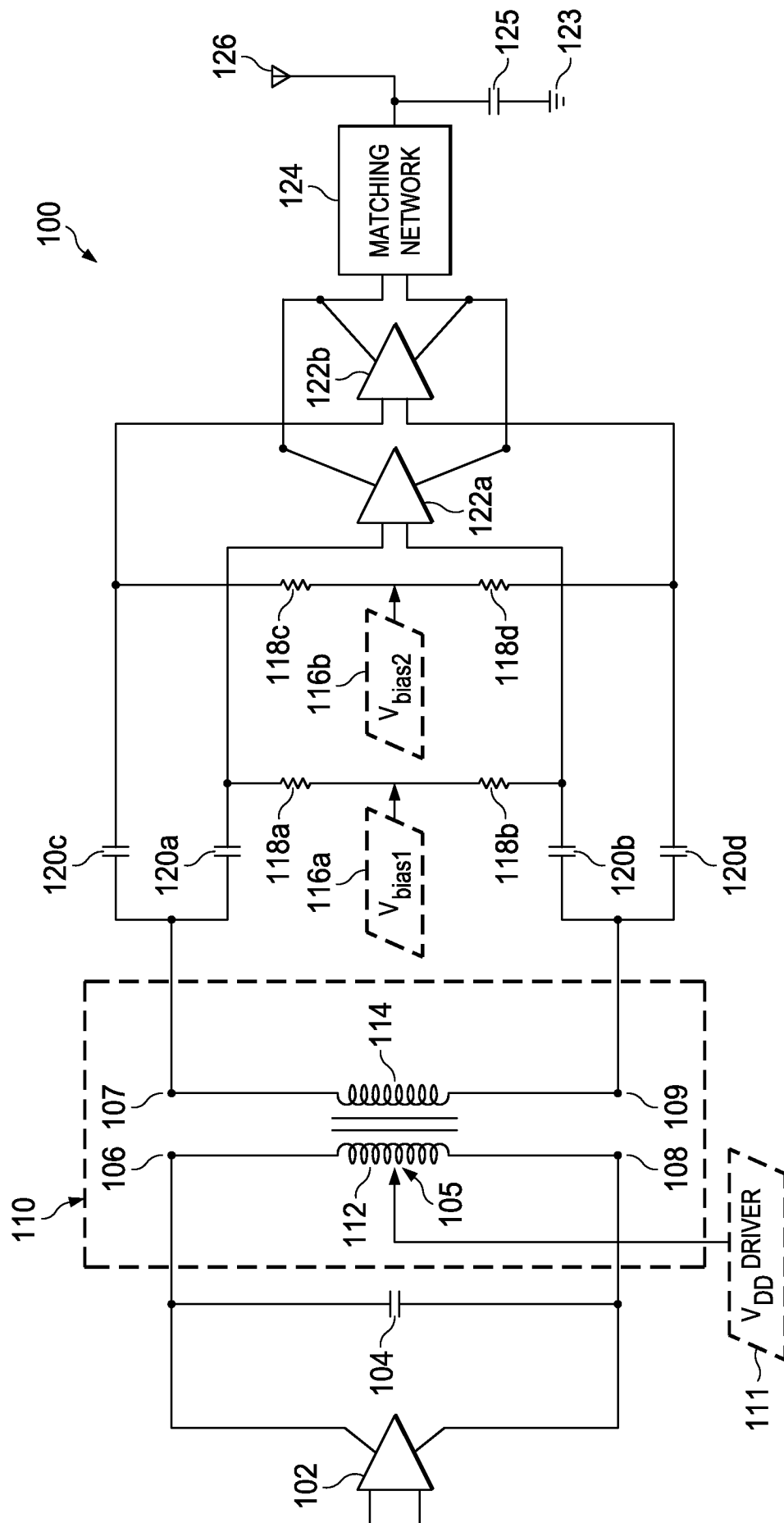


FIG. 1

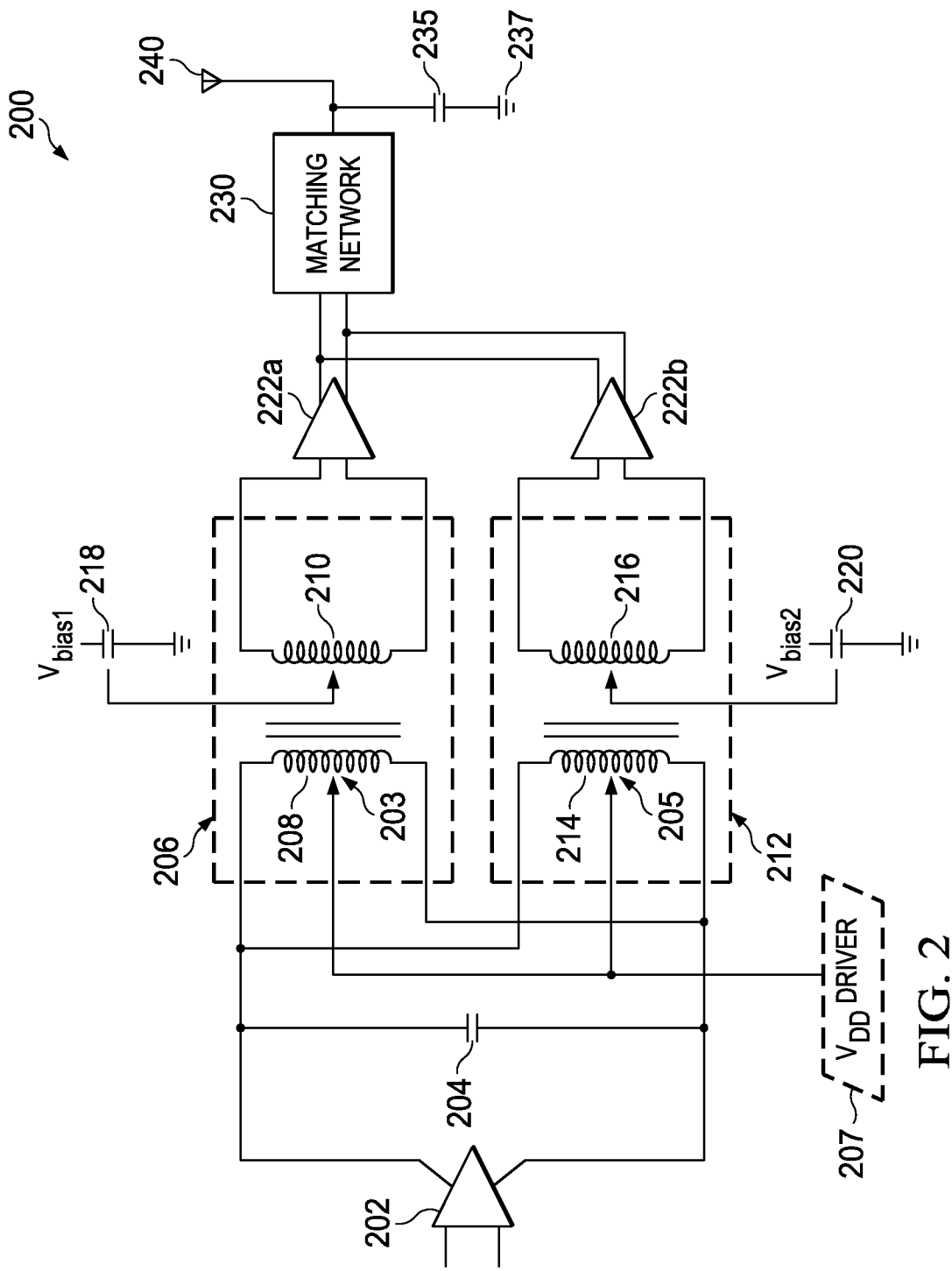


FIG. 2

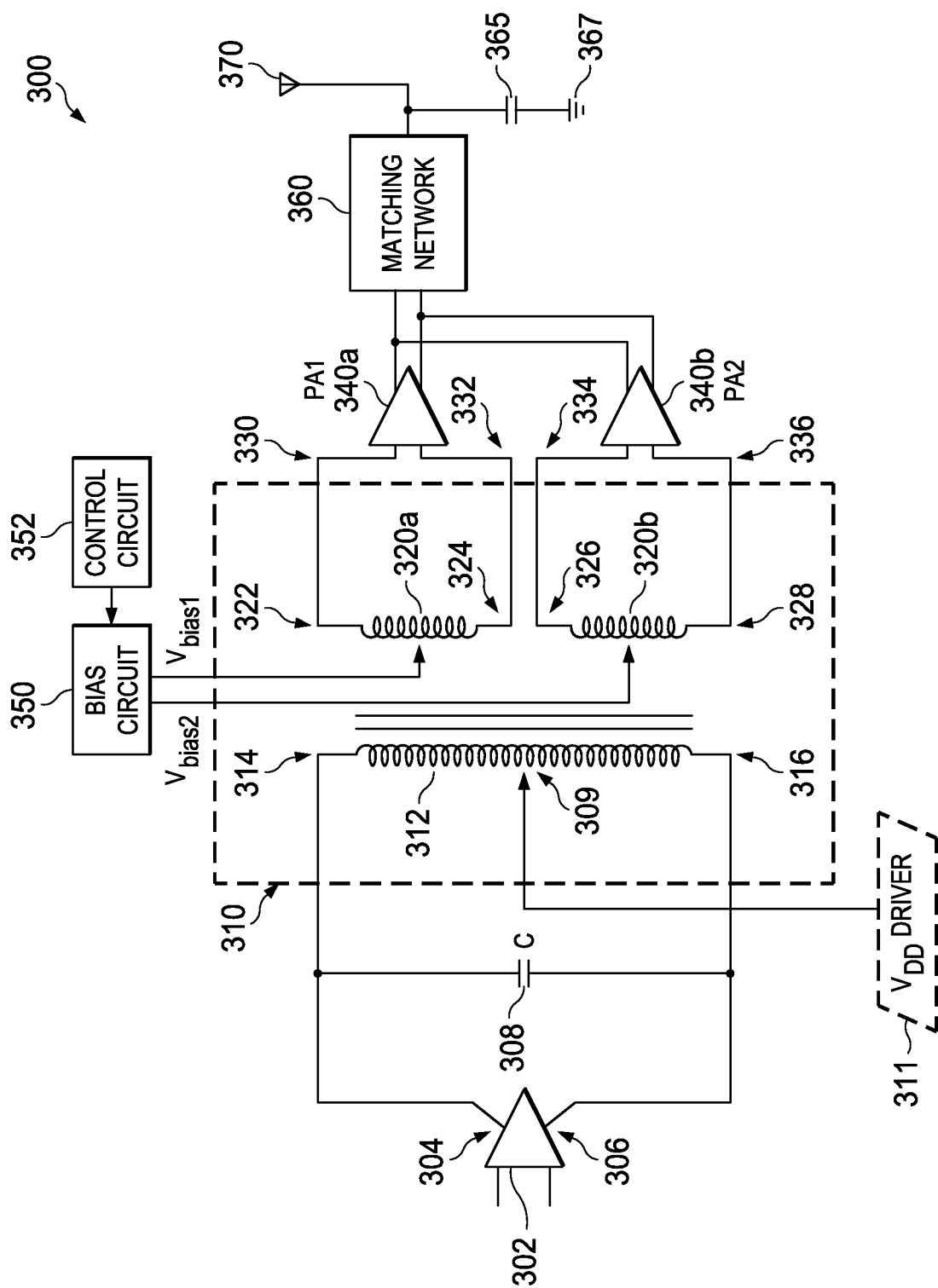


FIG. 3

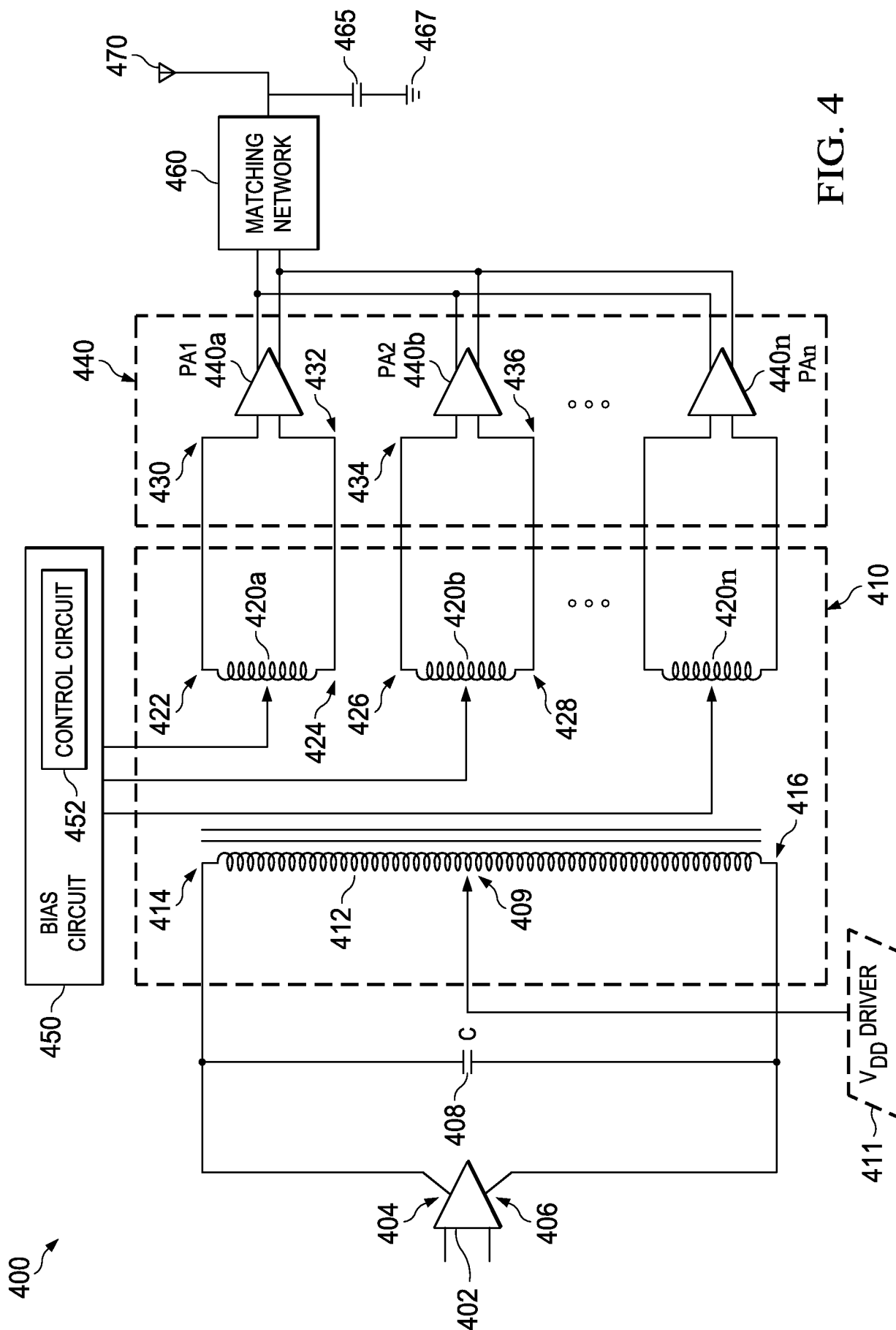
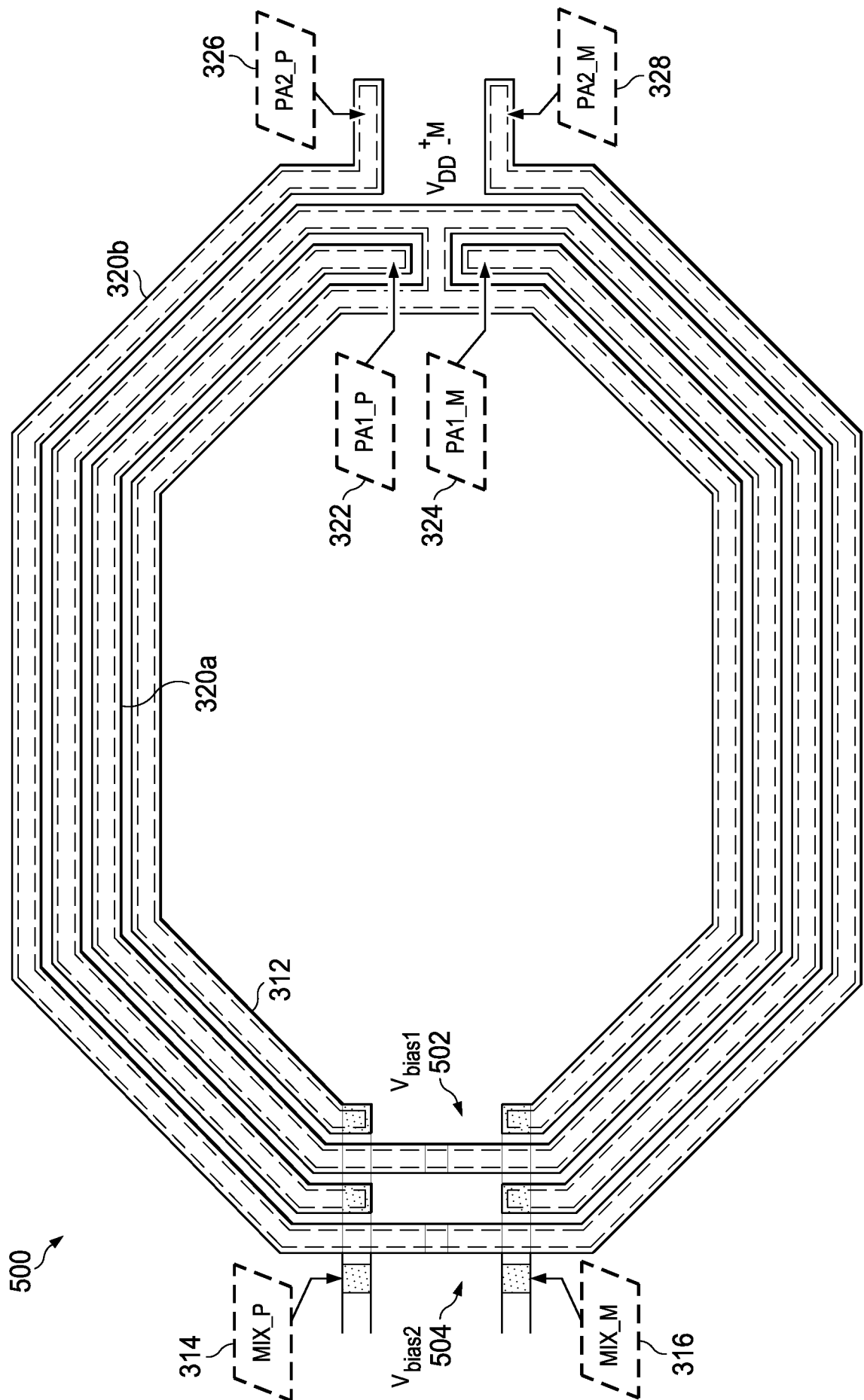


FIG. 4

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FIG. 5



**INTERNATIONAL SEARCH REPORT**

International application No.

PCT/US 2014/039552

|                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              |                                                                                                                                                                     |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          |
|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <b>A. CLASSIFICATION OF SUBJECT MATTER</b><br><div style="text-align: right; margin-right: 100px;"> <b><i>H03F 3/20 (2006.01)</i></b><br/> <b><i>H03F 3/72 (2006.01)</i></b> </div> According to International Patent Classification (IPC) or to both national classification and IPC                                                                                                                                                                                                                                                                                                                                                                                                                                        |                                                                                                                                                                     |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          |
| <b>B. FIELDS SEARCHED</b><br>Minimum documentation searched (classification system followed by classification symbols)<br><div style="text-align: center; margin-top: 10px;">                     H03F 3/00, 3/20, 3/72, 3/21, 3/217, 3/45, 3/60, 1/00, 1/30, 1/32                 </div> Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched<br><br>Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)<br><div style="text-align: center; margin-top: 10px;">                     PAJ, Espacenet, USPTO DB, Information Retrieval System of FIPS                 </div> |                                                                                                                                                                     |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          |
| <b>C. DOCUMENTS CONSIDERED TO BE RELEVANT</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                |                                                                                                                                                                     |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          |
| Category*                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    | Citation of document, with indication, where appropriate, of the relevant passages                                                                                  | Relevant to claim No.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    |
| X<br>Y                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       | WO 2009/126386 A1 (JAVELIN SEMICONDUCTOR, INC. et al.) 15.10.2009, fig. 3A, 3B, 12, paragraphs [0038] - [0041], [0071], [0072]                                      | 11-17, 19-20<br>1-10, 18                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 |
| Y                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            | US 2011/0074509 A1 (ANIL SAMAVEDAM et al.) 31.03.2011, fig. 12, paragraphs [0082], [0083], [0043]                                                                   | 1-10, 18                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 |
| A                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            | WO 2009/065068 A2 (INTERSIL AMERICAS INC. et al.) 22.05.2009                                                                                                        | 1-20                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     |
| A                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            | WO 2009/137160 A2 (JAVELIN SEMICONDUCTOR, INC. et al.) 12.11.2009                                                                                                   | 1-20                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     |
| <div style="display: flex; justify-content: space-between; align-items: flex-start;"> <div style="width: 45%;"> <input type="checkbox"/> Further documents are listed in the continuation of Box C.                         </div> <div style="width: 45%;"> <input type="checkbox"/> See patent family annex.                         </div> </div>                                                                                                                                                                                                                                                                                                                                                                         |                                                                                                                                                                     |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          |
| *                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            | Special categories of cited documents:                                                                                                                              | "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<br>"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<br>"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<br>"&" document member of the same patent family |
| "A"                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          | document defining the general state of the art which is not considered to be of particular relevance                                                                |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          |
| "E"                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          | earlier document but published on or after the international filing date                                                                                            |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          |
| "L"                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          | document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified) |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          |
| "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                                                                  |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          |
| Date of the actual completion of the international search<br><div style="text-align: center; margin-top: 10px;">07 October 2014 (07.10.2014)</div>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           |                                                                                                                                                                     | Date of mailing of the international search report<br><div style="text-align: center; margin-top: 10px;">23 October 2014 (23.10.2014)</div>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              |
| Name and mailing address of the ISA/RU:<br>FIPS,<br>Russia, 123995, Moscow, G-59, GSP-5,<br>Berezhkovskaya nab., 30-1<br>Facsimile No. +7 (499) 243-33-37                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    |                                                                                                                                                                     | Authorized officer<br><div style="text-align: center; margin-top: 10px;">M. Smirnov</div><br>Telephone No. (495)531-64-81                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                |