US 20250266752A1

(19) United States
(12) Patent Application Publication
(10) Pub. No.: US 2025/0266752 A1
(43) Pub. Date: Aug. 21, 2025
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(54) **GATE DRIVER FOR HYBRID POWER SWITCHES**

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(21) Appl. No.: **18/650,533**

(22) Filed: **Apr. 30, 2024**

Related U.S. Application Data

(60) Provisional application No. 63/554,287, filed on Feb. 16, 2024.

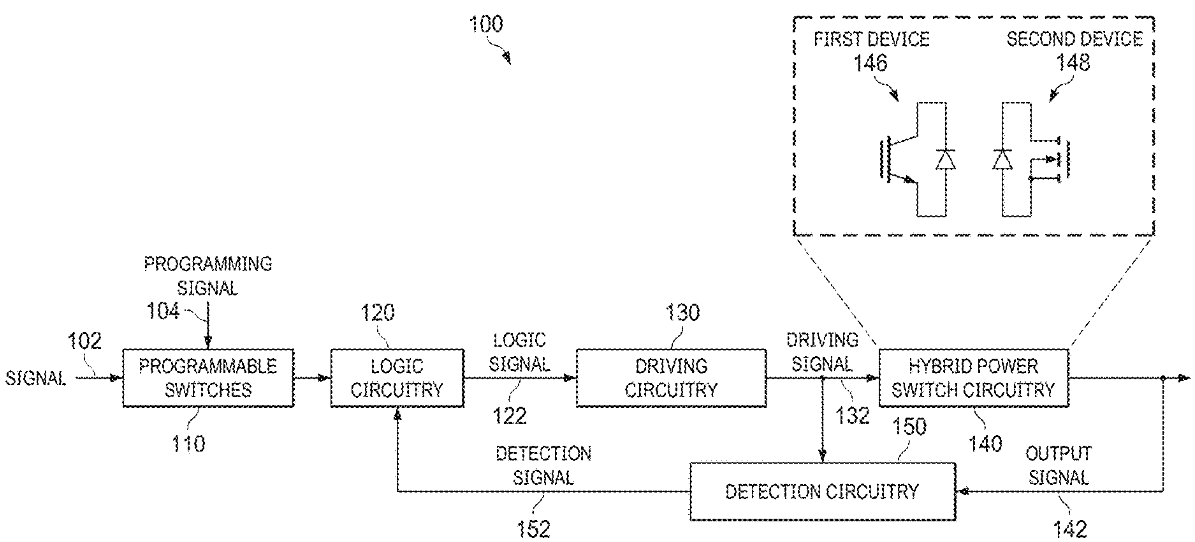
Publication Classification

(51) **Int. Cl.**
H02M 1/088 (2006.01)

(52) **U.S. Cl.**
CPC ***H02M 1/088*** (2013.01)

(57) **ABSTRACT**

A method includes receiving a signal to turn on a hybrid power switch circuitry when the received signal is asserted. The method further includes generating a first logic signal in response to a feedback signal and further in response to a signal received from one or more switches. The method also includes generating a second logic signal in response to the feedback signal and further in response to the signal received from the one or more switches. The method includes driving a silicon device based on the first logic signal. Moreover, the method includes driving a wide band-gap device based on the second logic signal. The method includes generating the feedback signal based on whether the silicon device or the wide bandgap device is on or off.



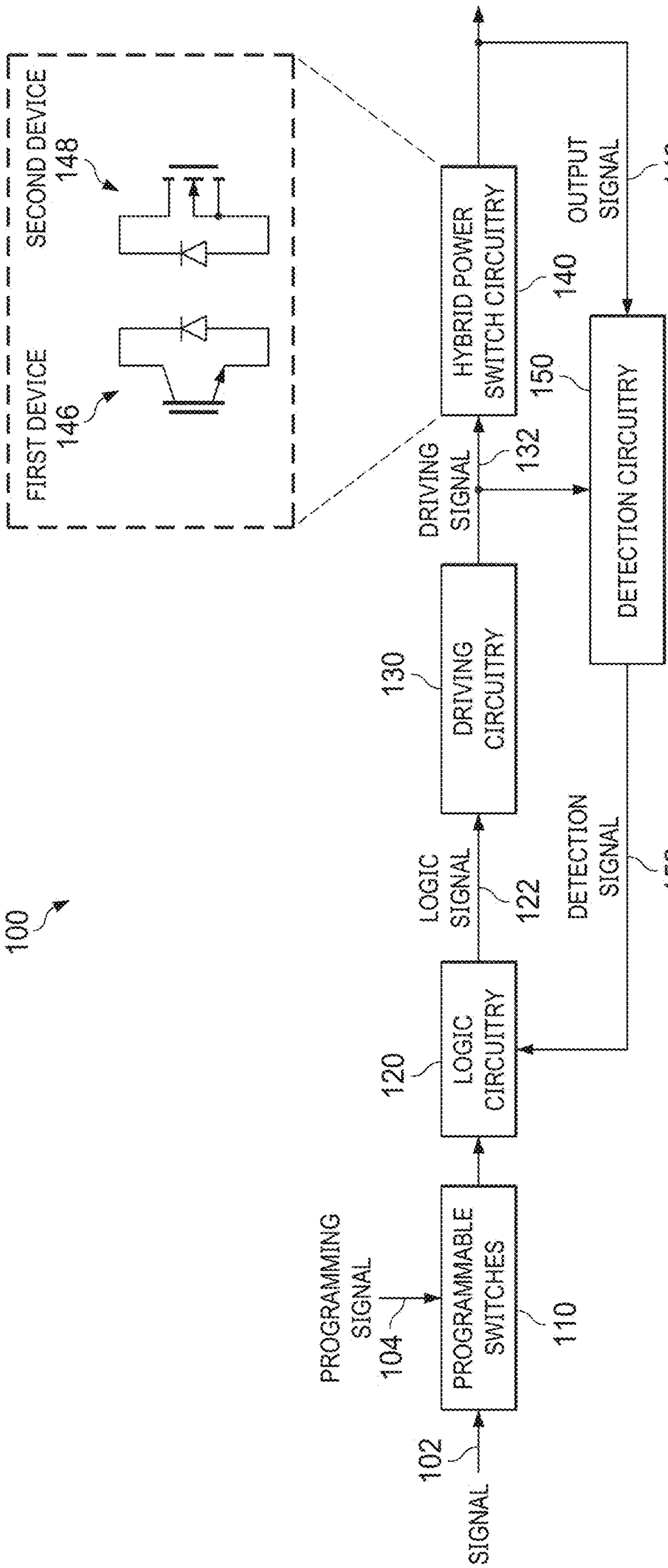

100
SIGNAL
102
PROGRAMMING SIGNAL
104
PROGRAMMABLE SWITCHES
110
LOGIC CIRCUITRY
120
LOGIC SIGNAL
122
DRIVING CIRCUITRY
130
DRIVING SIGNAL
132
HYBRID POWER SWITCH CIRCUITRY
140
FIRST DEVICE
146
SECOND DEVICE
148
OUTPUT SIGNAL
142
DETECTION CIRCUITRY
150
DETECTION SIGNAL
152

FIG. 1

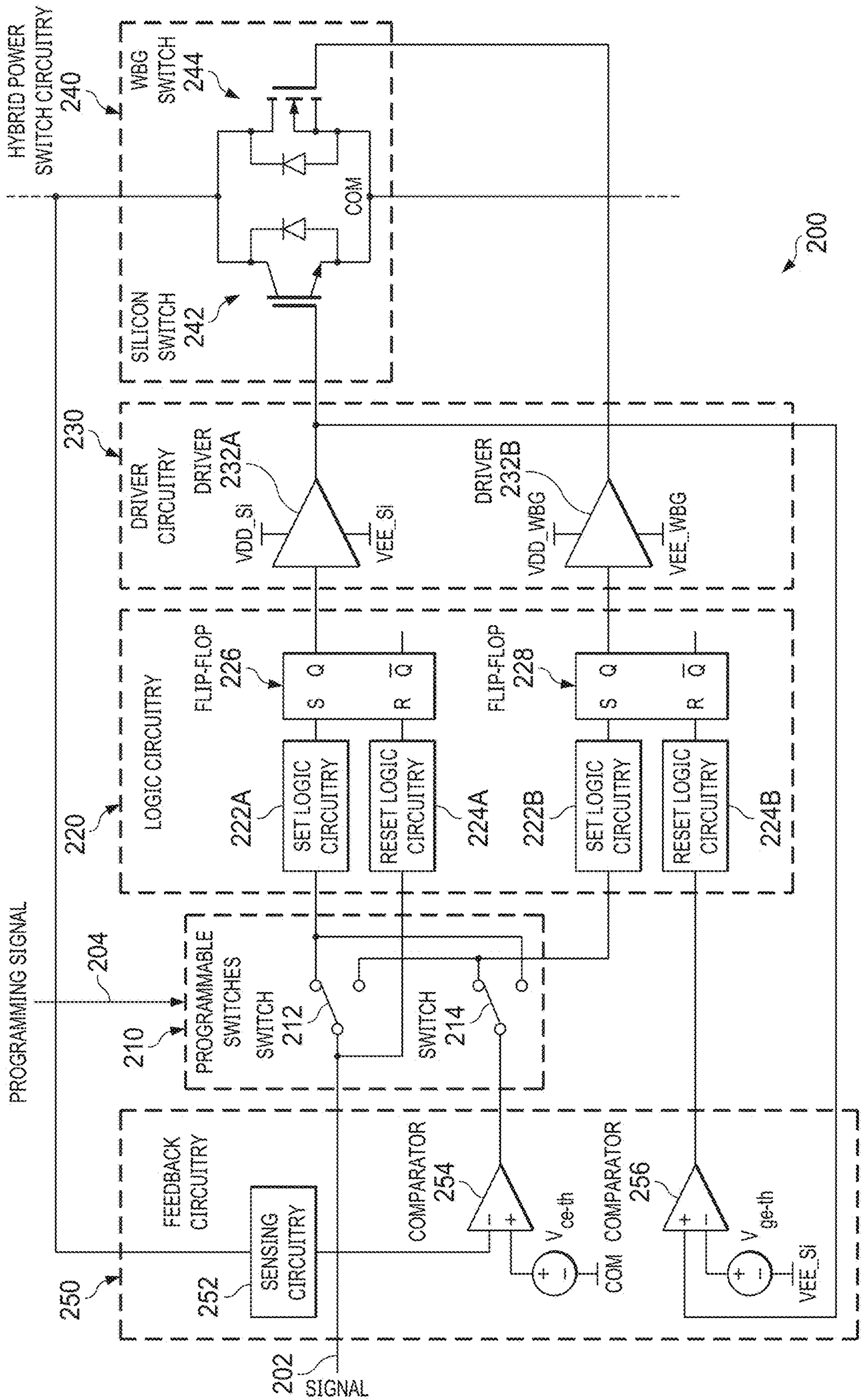

HYBRID POWER SWITCH CIRCUITRY
240
SILICON SWITCH
242
WBG SWITCH
244
COM
200
DRIVER CIRCUITRY
230
DRIVER
232A
VDD_SI
VEE_SI
DRIVER
232B
VDD_WBG
VEE_WBG
LOGIC CIRCUITRY
220
FLIP-FLOP
226
S
Q
R
Q̄
FLIP-FLOP
228
S
Q
R
Q̄
SET LOGIC CIRCUITRY
222A
RESET LOGIC CIRCUITRY
224A
SET LOGIC CIRCUITRY
222B
RESET LOGIC CIRCUITRY
224B
PROGRAMMING SIGNAL
204
PROGRAMMABLE SWITCHES
210
SWITCH
212
SWITCH
214
FEEDBACK CIRCUITRY
250
SENSING CIRCUITRY
252
COMPARATOR
254
V ce-th
COM
COMPARATOR
256
V ge-th
VEE_SI
202
SIGNAL

FIG. 2

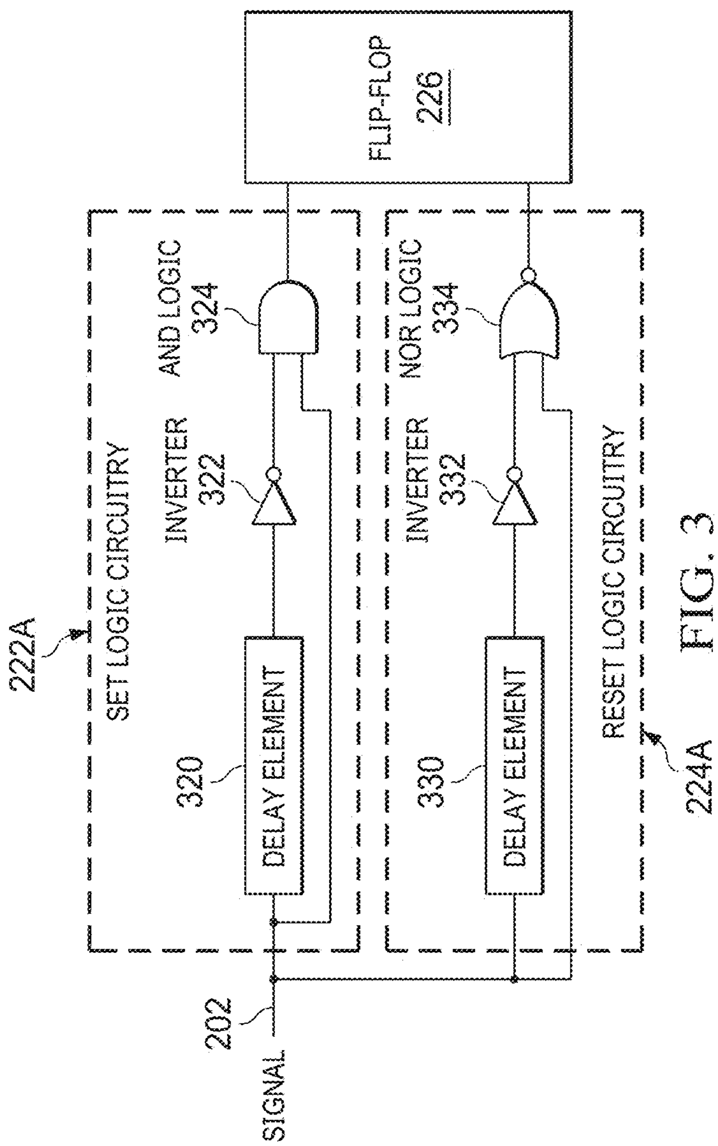

FLIP-FLOP
226
222A
SET LOGIC CIRCUITRY
AND LOGIC
324
INVERTER
322
DELAY ELEMENT
320
NOR LOGIC
334
INVERTER
332
DELAY ELEMENT
330
RESET LOGIC CIRCUITRY
224A
SIGNAL
202

FIG. 3

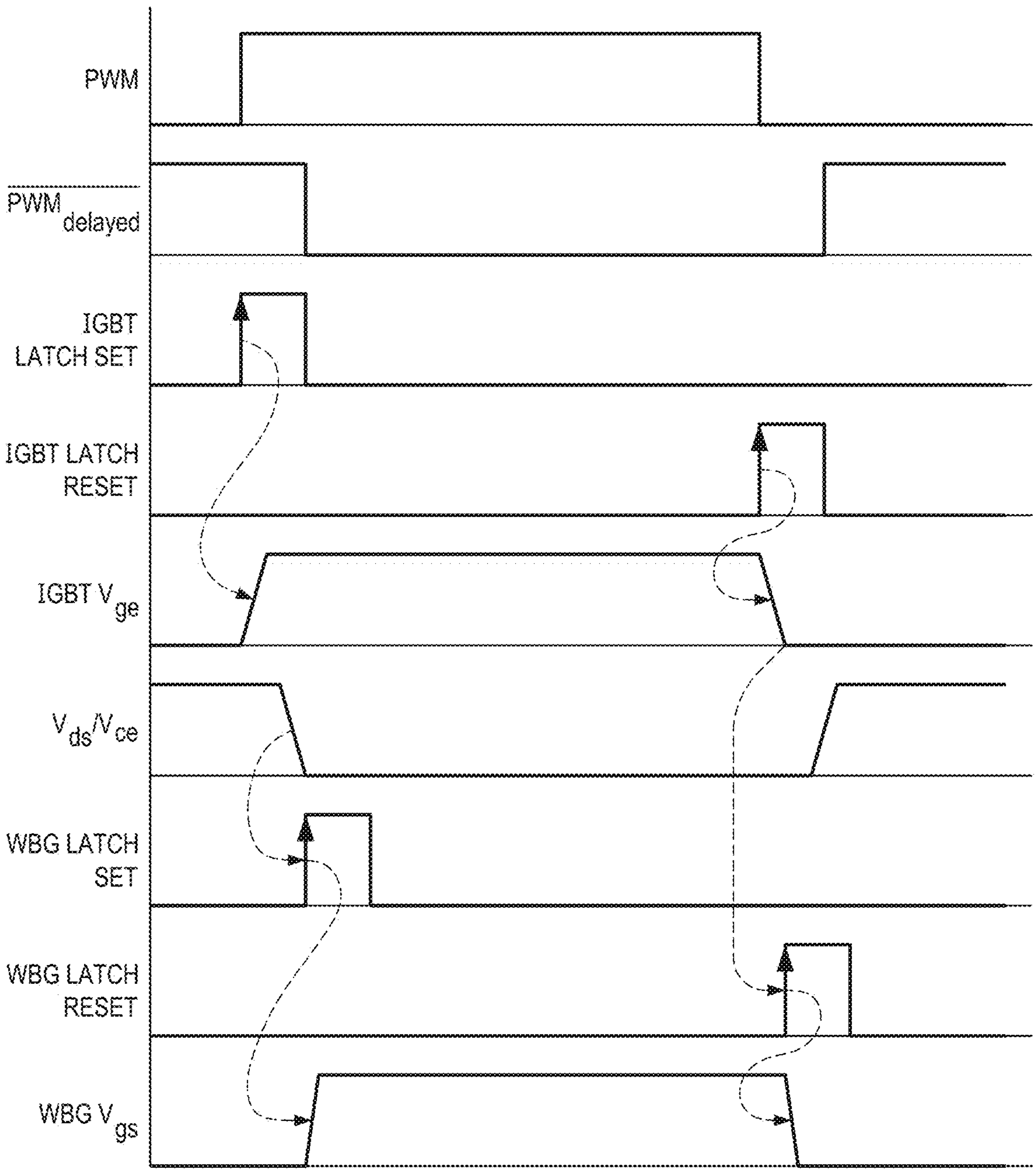

PWM
$\overline{PWM}_{delayed}$
IGBT LATCH SET
IGBT LATCH RESET
IGBT V_{ge}
V_{ds}/V_{ce}
WBG LATCH SET
WBG LATCH RESET
WBG V_{gs}

FIG. 4

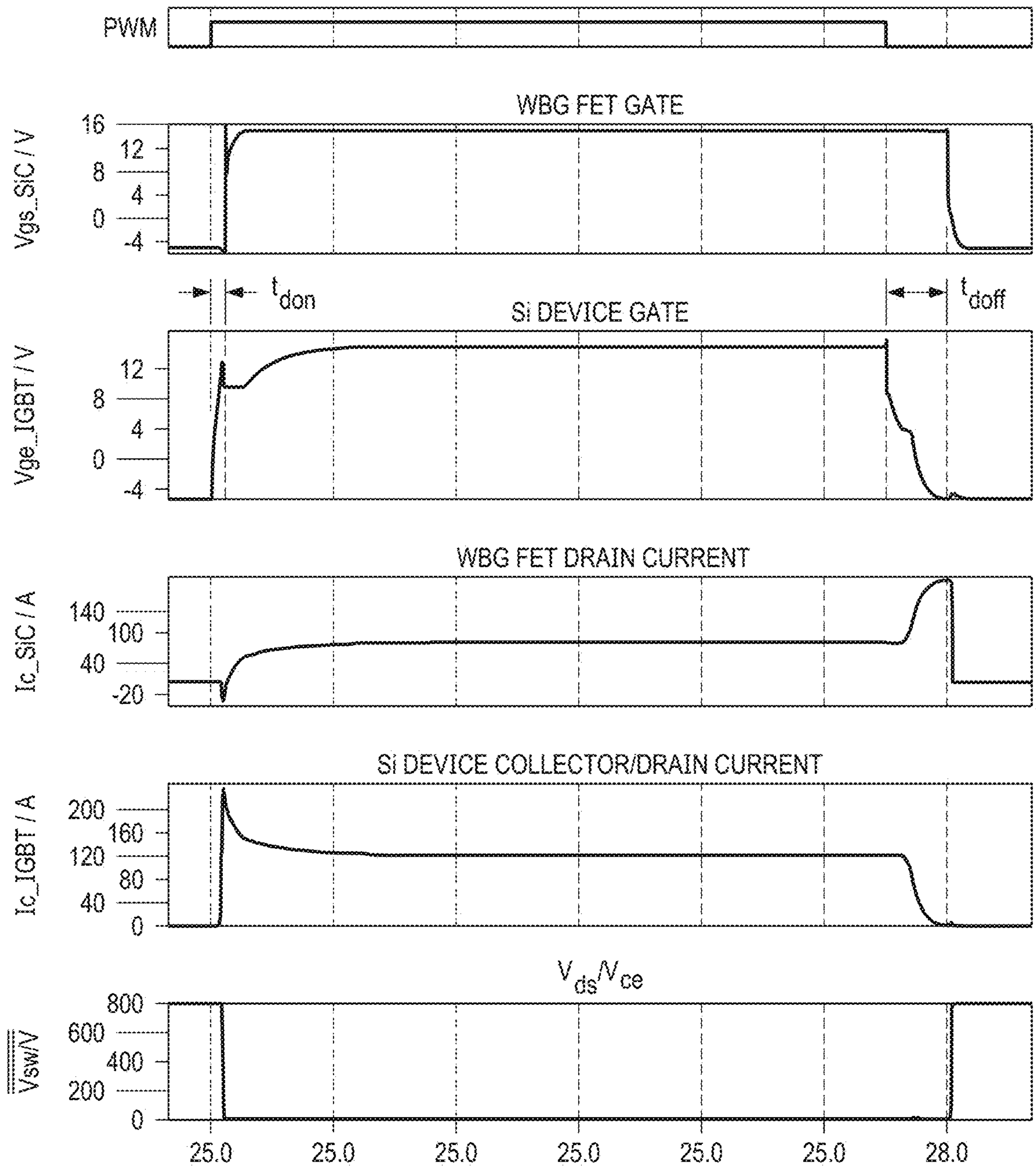

PWM
WBG FET GATE
Vgs_SiC / V
16
12
8
4
0
-4
t_{don}
t_{doff}
Si DEVICE GATE
Vge_IGBT / V
12
8
4
0
-4
WBG FET DRAIN CURRENT
Ic_SiC / A
140
100
40
-20
Si DEVICE COLLECTOR/DRAIN CURRENT
Ic_IGBT / A
200
160
120
80
40
0
V_{ds}/V_{ce}
Vsw/V
800
600
400
200
0
25.0
25.0
25.0
25.0
25.0
25.0
28.0

FIG. 5

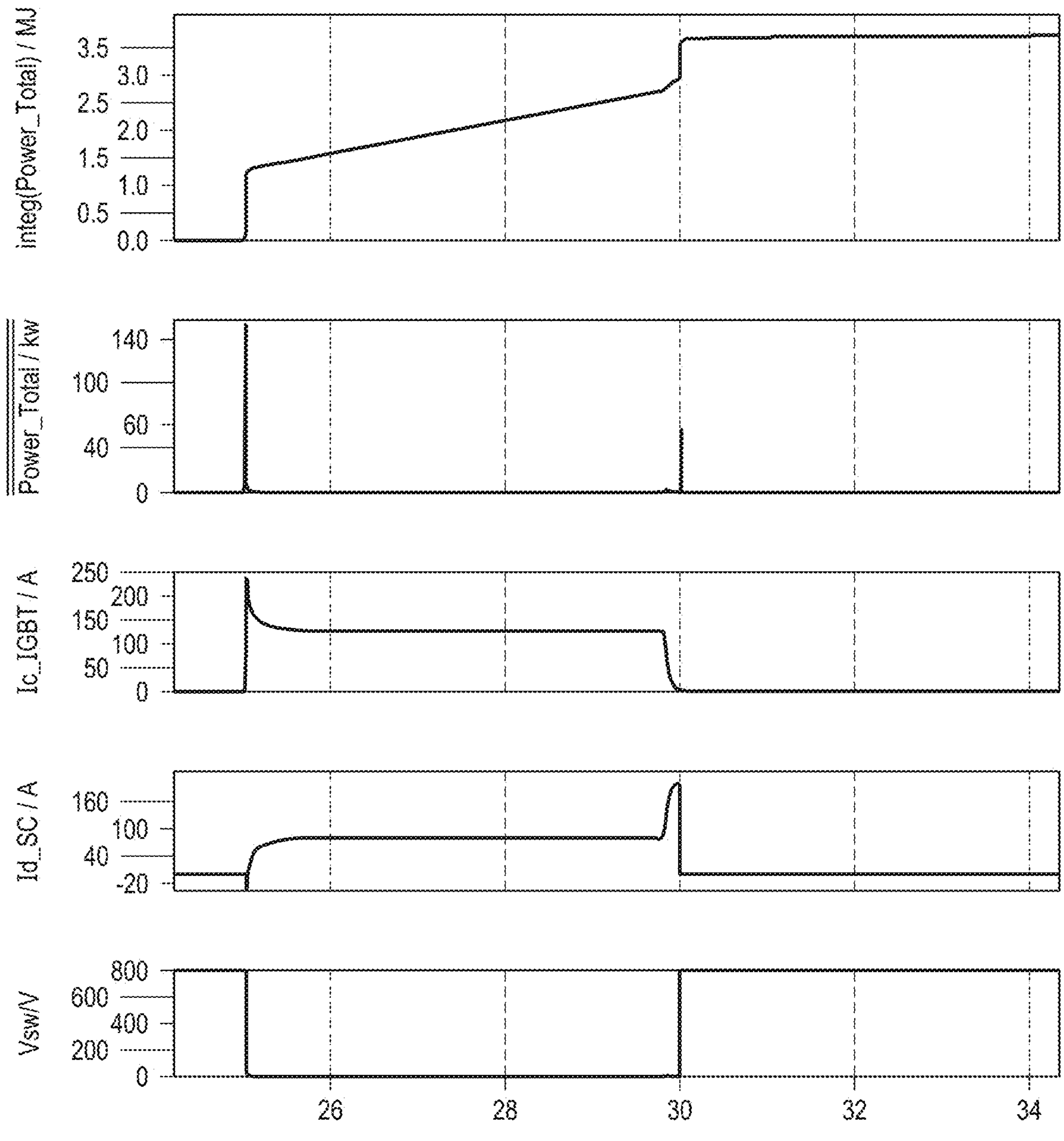

integ(Power_Total) / MJ
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
Power_Total / kw
140
100
60
40
0
Ic_IGBT / A
250
200
150
100
50
0
Id_SC / A
160
100
40
-20
Vsw/V
800
600
400
200
0
26
28
30
32
34

FIG. 6

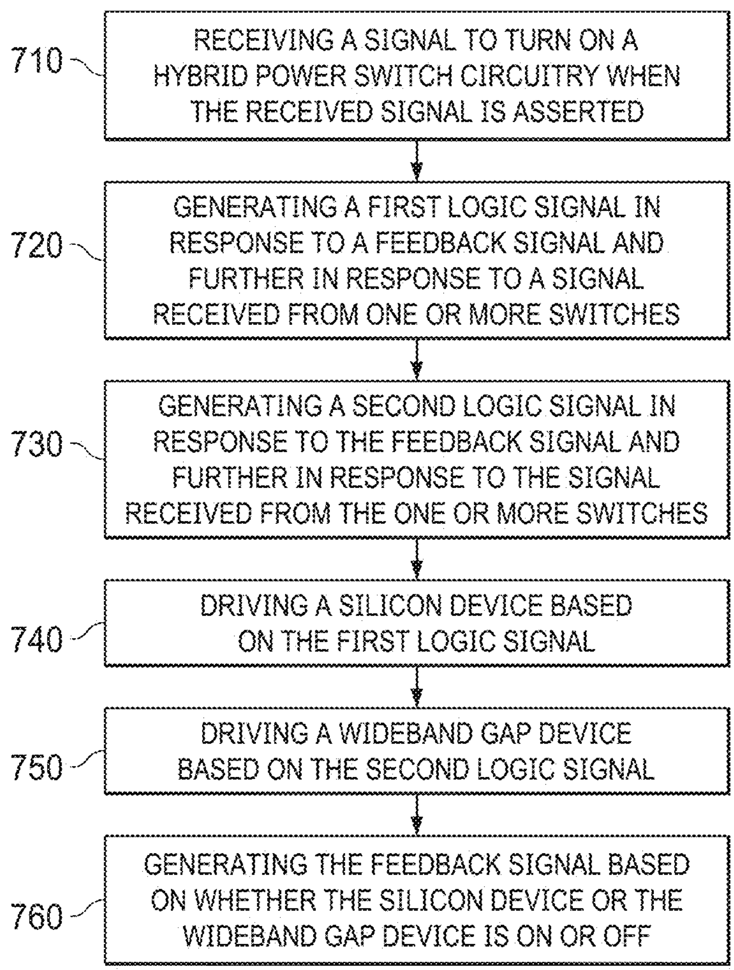

710
RECEIVING A SIGNAL TO TURN ON A HYBRID POWER SWITCH CIRCUITRY WHEN THE RECEIVED SIGNAL IS ASSERTED
720
GENERATING A FIRST LOGIC SIGNAL IN RESPONSE TO A FEEDBACK SIGNAL AND FURTHER IN RESPONSE TO A SIGNAL RECEIVED FROM ONE OR MORE SWITCHES
730
GENERATING A SECOND LOGIC SIGNAL IN RESPONSE TO THE FEEDBACK SIGNAL AND FURTHER IN RESPONSE TO THE SIGNAL RECEIVED FROM THE ONE OR MORE SWITCHES
740
DRIVING A SILICON DEVICE BASED ON THE FIRST LOGIC SIGNAL
750
DRIVING A WIDEBAND GAP DEVICE BASED ON THE SECOND LOGIC SIGNAL
760
GENERATING THE FEEDBACK SIGNAL BASED ON WHETHER THE SILICON DEVICE OR THE WIDEBAND GAP DEVICE IS ON OR OFF

FIG. 7

GATE DRIVER FOR HYBRID POWER SWITCHES

RELATED APPLICATIONS

[0001] The instant application claims the benefit and priority to the U.S. Provisional Application No. 63/554,287 that was filed on Feb. 16, 2024, which is incorporated herein by reference in its entirety.

BACKGROUND

[0002] High power applications have increased in recent years. For example, increasing number of electric vehicles has resulted in an increased number of high-power applications such as main power switches in electric vehicle inverters. Silicon based transistors such as insulated-gate bipolar transistors (IGBT) have traditionally been used but have significant power loss. Wide bandgap (WBG) devices such as silicon carbide have a higher efficiency in comparison to IGBT devices but are more expensive. Some applications use a hybrid approach that includes both an IGBT device and a WBG device to achieve a similar efficiency as a pure WBG device but with reduced cost. However, the hybrid approach increases the computational complexity and processing cost because the timing requirement to turn the IGBT and WBG devices on/off at the appropriate time.

SUMMARY

[0003] In an example, an apparatus includes one or more programmable switches, a logic circuitry, a driver circuitry, a hybrid power switch circuitry, and a detection circuitry. The one or more programmable switches after programming, turn on a first device and a second device within the hybrid power switch circuitry based on a selected ratio of the first device to the second device and further when a received signal to turn on the hybrid power switch circuitry is asserted. The first device is a device with a first type and the second device is a device with a second type. The logic circuitry is coupled to the one or more programmable switches that generates a logic signal to turn a driver circuitry on or off. The logic signal is generated based on a signal received from the one or more programmable switches and further based on a detection signal received from the detection circuitry. The driver circuitry is coupled to the logic circuitry. The driver circuitry generates a driving signal to the hybrid power switch circuitry and the detection circuitry based on the logic signal. The hybrid power switch circuitry includes the first device and the second device. The hybrid power switch circuitry receives the driving signal that controls a timing of turning the first device and the second device on and off. The detection circuitry receives a feedback signal associated with the hybrid power switch circuitry. The detection circuitry detects whether the second device is on or off and further whether the first device is on or off. The detection circuitry generates the detection signal to the logic circuitry.

[0004] In at least one example, an apparatus includes one or more programmable switches, a first logic circuit, a second logic circuit, a first driving circuit, a second driving circuit, and a feedback circuitry. The one or more programmable switches after programming turn on a wide bandgap device and a silicon device within a hybrid power switch circuitry based on a selected ratio of the silicon device to the wide bandgap device and further when a received signal to turn on the hybrid power switch circuitry is asserted. The first logic circuit is coupled to the one or more programmable switches. The first logic circuit generates a first logic signal. The first driving circuit is coupled to the first logic circuit to receive the first logic signal and in response thereto drive the silicon device of the hybrid power switch circuitry. The second logic circuit is coupled to the one or more programmable switches. The second logic circuit generates a second logic signal. The second driving circuit is coupled to the second logic circuit to receive the second logic signal and in response thereto drive the wide bandgap device of the hybrid power switch circuitry. The feedback circuitry receives a feedback signal associated with the hybrid power switch circuitry. The feedback circuitry generates a feedback signal based on an on/off status of the silicon device or the wide bandgap device. The feedback circuitry sends the feedback signal to the first logic circuit and the second logic circuit. The first logic circuit generates the first logic signal based on the feedback signal and further based on a signal received from the one or more programmable switches. The second logic circuit generates the second logic signal based on the feedback signal and further based on the signal received from the one or more programmable switches.

[0005] In at least one example, a method includes receiving a signal to turn on a hybrid power switch circuitry when the received signal is asserted. The method also includes generating a first logic signal in response to a feedback signal and further in response to a signal received from one or more switches. Moreover, a second logic signal is generated in response to the feedback signal and further in response to the signal received from the one or more switches. A silicon device is driven based on the first logic signal. A wide bandgap device is driven based on the second logic signal. The feedback signal is generated based on whether the silicon device or the wide bandgap device is on or off.

BRIEF DESCRIPTION OF THE DRAWINGS

[0006] FIG. **1** is a schematic diagram of an apparatus including a gate driver for hybrid power switches, in an example.

[0007] FIG. **2** is a schematic diagram of another apparatus including a gate driver for hybrid power switches, in an example.

[0008] FIG. **3** is a schematic diagram of a set and reset logic circuitry, in an example.

[0009] FIG. **4** is a timing diagram of the apparatus in FIG. **2**, in an example.

[0010] FIG. **5** is a waveform of timing simulation of an apparatus, in an example.

[0011] FIG. **6** is a simulation for an energy loss of an apparatus, in an example.

[0012] FIG. **7** is a flowchart illustrating operation of an apparatus with a gate driver for hybrid power switches, in an example.

DETAILED DESCRIPTION

[0013] The same reference numbers or other reference designators are used in the drawings to designate the same or similar (either by function and/or structure) features. Hybrid power switches have been used in high-power applications, such as traction inverters used in electric vehicles that convert a direct current (DC) supply from the vehicle's battery into alternating current (AC) output, high-power industrial motor drives, solar inverters and energy storage in solar power applications, etc. For example, a first device type such as a wide-bandgap device may be used in parallel with a second device type such as a silicon device, e.g., IGBT device, to reduce cost associated with use of a pure WBG device and resulting in significant power loss improvement over use of a pure silicon device.

[0014] Gate timing between a WBG device and a silicon device is important to improve efficiency. Some approaches have controlled the gate timing between a WBG device and a silicon device by using a microcontroller or other similar components, which leads to added complexity and cost such as higher silicon use, higher pin count, burdening the microcontroller with processing associated with the timing need in real time, etc. In certain cases, the gate timing has been controlled using register settings that are programmed and changed on the fly or alternatively separate gate drivers have been used to control the silicon device and the WBG device separately with their own gate signal timings. In other words, there is a tradeoff between the size of the device, the cost, the complexity of implementation, and efficiency.

[0015] According to one example, the gate timing between a WBG device and a silicon device is controlled by using a feedback signal associated with the hybrid power switches, enabling the gate driver to improve the timing between the WBG device and the silicon device in order to improve efficiency. As such, use of a microcontroller to control the gate timing between the WBG device and the silicon device is eliminated, which reduces the computational burden on the microcontroller as well as reducing the pin count and die area of the gate driver. Furthermore, controlling the gate timing using a feedback signal is performed automatically and results in high efficiency at reduced cost (e.g., smaller die size, reduced number of pin counts of gate driver, etc.).

[0016] FIG. **1** is a schematic diagram of an apparatus **100** including a gate driver for hybrid power switches **140**, in an example. The apparatus **100** includes a set of programmable switches **110**, a logic circuitry **120**, a driving circuitry **130**, a hybrid power switch circuitry **140**, and a detection circuitry **150**. According to one example, the programmable switches **110** are coupled to the logic circuitry **120** that is coupled to the driving circuitry **130** that is coupled to the hybrid power switch circuitry **140** that is coupled to the detection circuitry **150**.

[0017] The hybrid power switch circuitry **140** may include a first device **146** (switch) being a first type, e.g., a silicon type device such as an IGBT switch, and a second device **148** (switch) being a second type, e.g., a WBG device such as a silicon carbide switch. In this example, the first device **146** is coupled to the second device **148** in parallel.

[0018] According to some examples, replacing a small portion of a pure silicon device, in a high-power switch circuitry, with a WBG device results in the hybrid power switch circuitry with an increased efficiency and reduced cost, as described above. Similarly, replacing a portion of a pure WBG device, in a high-power switch circuitry, with a silicon device results in the hybrid power switch circuitry with an improved efficiency, at a reduced cost and smaller die size and reduced pin counts, etc. For illustrative purposes, in the example of FIG. **1**, a small portion of a pure silicon device is replaced with a WBG device to form the hybrid power switch circuitry **140**.

[0019] In one example, the programmable switches **110** may include a plurality of switches that may be set or programmed by a customer, e.g., electric vehicle manufacturer, solar power manufacturer, etc. For example, the programmable switches **110** may be programmed once using a programming signal **104**. Programming the programmable switches **110** once is for illustrative purposes and should not be construed as limiting the scope of the examples.

[0020] According to one example, programming the programmable switches **110** may be based on a ratio of a device of a first type, e.g., a silicon device such as an IGBT switch, to a device of a second type, e.g., a WBG device such as a WBG switch, in the hybrid power switch circuitry **140**. In this example, since a small portion of a silicon device is replaced with a WBG device, the ratio of silicon device to a WBG device has a higher ratio. The higher ratio may be used to program the programmable switches **110** via the programming signal **104**.

[0021] According to some examples, a silicon device such as an IGBT switch reacts slower, e.g., turns off slower, in comparison to a WBG device, e.g., a WBG switch. As such, the higher ratio of a silicon device to a WBG device may be used to improve efficiency and to reduce loss. For example, during turning on/off the hybrid power switch circuitry **140**, the device with a higher ratio (here and for illustrative purposes a silicon device) is to be turned on/off before (e.g., prior to) turning on/off the device with a lower ratio (here for illustrative purposes a WBG device). In contrast and for illustrative purposes, in a hybrid power switch circuitry **140** with a higher ratio of a WBG device to a silicon device, the WBG device is turned on/off before (e.g., prior to) turning the silicon device on/off in order to improve efficiency and to reduce loss. Programming the programmable switches **110** based on the ratio of the device type in the hybrid power switch circuitry **140** results in the full load of current being carried by the higher ratio device type during turn-on by turning on the device type with a higher ratio prior to turning on the device type with a lower ratio. According to an example, turn-on is when a device is being placed from a power off position to a power on position. During turn-off, the hybrid power switch circuitry **140**, turns off the device type with the higher ratio, e.g., a silicon device such as an IGBT switch in this example, before (e.g., prior to) turning off the device type with a lower ratio reduces (voltage current) VI overlap turn off loss, thereby increasing the efficiency.

[0022] Once programmed, the programmable switches **110** may receive a signal **102** to turn the hybrid power switch circuitry **140** on or off, as needed. In one example, the signal **102** may be a pulse width modulation signal that is received from a controller, e.g., a microcontroller unit. The signal **102** is routed through the programmable switches **110** based on the ratio of device types in the hybrid power switch circuitry **140**, as described above, such that a device type within the hybrid power switch circuitry **140** with a higher ratio is turned on first before turning on a device type with a lower ratio within the hybrid power switch circuitry **140**. The logic circuitry **120** receives the signal **102** routed through the programmable switches **110** and generates a logic signal **122**. The logic signal **122** may include one or more signals to set or reset in order to enable or disable a particular device type within the hybrid power switch circuitry **140**. In other words, the logic signal **122** controls the chronological ordering to turn a particular device type within the hybrid power switch circuitry **140** on/off.

[0023] In one example, the logic signal **122** is received by the driving circuit **130** and generates a driving signal **132**. The driving signal **132** drives the device types within the hybrid power switch circuitry **140** based on the received logic signal **122**. The driving signal **132** is sent to the hybrid power switch circuitry **140**, thereby turning devices, e.g., first device **146** and second device **148**, within the hybrid power switch circuitry **140** on/off based on their type. For example, the driving signal **132** may turn on the first device **146** when the signal **102** is asserted high before turning on the second device **148**. Similarly, the driving signal **132** may turn off the first device **146** before turning off the second device **148** when the signal **102** is asserted low.

[0024] According to one example, the detection circuitry **150** receives one or more signals associated with the hybrid power switch circuitry **140**. For example, the driving signal **132** may be sent to the detection circuitry **150** and may include the gate voltage feedback. Moreover, the output signal **142** from the hybrid power switch circuitry **140** may be sent to the detection circuitry **150** and may include the drain-source (or collector-emitter) voltage feedback. The detection circuitry **150** may use the driving signal **132** and/or the output signal **142** to determine whether the second device **148** is to be turned on (during powering on of the hybrid power switch circuitry **140**). For example, the detection circuitry **150** may determine whether the first device **146** is on and if so to generate a detection signal **152** to turn on the second device **148** during powering on of the hybrid power switch circuitry **140**. As such, the full load current is carried by the first device **146** that has a higher ratio in comparison to the second device **148**. Moreover, the detection circuitry **150** may use the driving signal **132** and/or the output signal **142** to determine whether the second device **148** is to remain on when the first device **146** is turning off. For example, the detection circuitry **150** may determine that the first device **146** is not off and therefore may generate the detection signal **152** to maintain the second device **148** on until the first device **146** is off before the second device **148** is turned off. As such, voltage-current (VI) overlap turn off loss is reduced.

[0025] Accordingly, turning devices on/off within the hybrid power switch circuitry **140** based on the device type during powering the hybrid power switch circuitry **140** on/off is controlled automatically through a feedback signal rather than using a microcontroller. In other words, the gate timing between a WBG device and a silicon device is controlled by using a feedback signal associated with the hybrid power switch circuitry **140**.

[0026] FIG. **2** is a schematic diagram of another apparatus **200** including a gate driver for hybrid power switches, in an example. Apparatus **200** includes programmable switches **210** coupled to a logic circuitry **220** coupled to a driver circuitry **230** coupled to a hybrid power switch circuitry **240** coupled to a feedback circuitry **250**. The programmable switches **210** are similar to the programmable switches **110** of FIG. **1** and operate similar to the programmable switches **110**. The logic circuitry **220** is similar to the logic circuitry **120** of FIG. **1** and operates similar to the logic circuitry **120**. The driving circuitry **230** is similar to the driving circuitry **130** of FIG. **1** and operates similar to the driving circuitry **130**. The hybrid power switch circuitry **240** is similar to the hybrid power switch circuitry **140** of FIG. **1** and operates similar to the power switch circuitry **140**. The hybrid power switch circuitry **240** includes two device types that are connected in parallel to one another. The first device type may be a silicon switch **242** and the second device type may be a WBG switch **244**. Similar to FIG. **1**, the ratio of the silicon switch **242** to the WBG switch **244** is higher for illustrative purposes. The feedback circuitry **250** is similar to the detection circuitry **150** of FIG. **1** and operates similar to the detection circuitry **150**. Signal **202** is similar to signal **102**.

[0027] The programmable switches **210** include switches **212** and **214** in one example for illustrative purposes. In another example, more than two switches in a different configuration may be used. The programmable switch **210** receives a programming signal **204**, e.g., from a customer, to program the switches **212** and **214** (e.g., positioning the switches **212** and **214**). The programming signal **204** may be similar to the programming signal **104**. In this example, the switch **212** is switched to a positioned to cause the silicon switch **242** to turn on before turning on the WBG switch **244** in order to cause the full load to be carried by the silicon switch **242** when turning on the hybrid power switch circuitry **240** because the silicon switch **242** in the hybrid power switch circuitry **240** has a higher ratio in comparison to the WBG switch **244**. The switch **214** is switched to a position to cause the WBG switch **244** to remain on when turning off the hybrid power switch circuitry **240** until the silicon switch **242** is turned off completely in order to reduce the VI overlap turn off loss since the silicon switch **242** is the hybrid power switch circuitry **240** has a higher ratio in comparison to the WBG switch **244**.

[0028] The logic circuitry **220** may include a set of set and reset logic circuitries as well as a set of flip-flops. In one example, the logic circuitry **220** may include a set logic circuitry **222**A coupled to a set input of a flip-flop **226** circuitry to cause the silicon switch **242** to turn on based on the signal **202** being asserted high when routed through the programmable switches **210** and further based on a feedback signal received from the feedback circuitry **250**. In other words, the set logic circuitry **222**A in combination with the set input of the flip-flop **226** circuitry generates a set signal to turn on the silicon switch **242** based on the signal **202** being asserted high and as routed through the programmable switches **210** and further based on a feedback signal received from the feedback circuitry **250**. In one example, the logic circuitry **220** may include a reset logic circuitry **224**A coupled to a reset input of a flip-flop **226** circuitry to cause the silicon switch **242** to turn off based on the signal **202** being asserted low when routed through the programmable switches **210** and further based on a feedback signal received from the feedback circuitry **250**. In other words, the reset logic circuitry **224**A in combination with the reset input of the flip-flop **226** circuitry generate a reset signal to turn off the silicon switch **242** off based on the signal **202** being asserted low and as routed through the programmable switches **210** and further based on a feedback signal received from the feedback circuitry **250**.

[0029] In one example, the logic circuitry **220** may include a set logic circuitry **222**B coupled to a set input of a flip-flop **228** circuitry to cause the WBG switch **244** to turn on based on the signal **202** being asserted high when routed through the programmable switches **210** and further based on a feedback signal received from the feedback circuitry **250**

(e.g., after the silicon switch **242** is turned on in order to cause the full load to be carried by the silicon switch **242** since the silicon switch **242** has a higher ratio to the WBG switch **244**). In other words, the set logic circuitry **222**B in combination with the set input of the flip-flop **228** circuitry generates a set signal to turn on the WBG switch **244** on based on the signal **202** being asserted high and as routed through the programmable switches **210** and further based on a feedback signal received from the feedback circuitry **250**. In one example, the logic circuitry **220** may include a reset logic circuitry **224**B coupled to a reset input of a flip-flop **228** circuitry to cause the WBG switch **244** to turn off based on the signal **202** being asserted low when routed through the programmable switches **210** and further based on a feedback signal received from the feedback circuitry **250** (e.g., the WBG switch **244** is kept on to reduce the VI overlap turn off loss until the silicon switch **242** is turned off). In other words, the reset logic circuitry **224**B in combination with the reset input of the flip-flop **228** circuitry generates a reset signal to turn off the WBG switch **242** off based on the signal **202** being asserted low and as routed through the programmable switches **210** and further based on a feedback signal received from the feedback circuitry **250**.

[0030] In one example, the logic signal generated by the logic circuitry **220** is sent to the driving circuitry **230**. The driving circuitry **230** may include a driver **232**A for driving the silicon switch **242** on/off based on the received logic signal from the logic circuitry **220**. For example, the driver **232**A may drive the voltage to VDD_Si to turn on the silicon switch **242** in response to the logic signal received from the logic circuitry **220**. In contrast, the driver **232**A may drive the voltage to VEE_Si to turn off the silicon switch **242** in response to the logic signal received from the logic circuitry **220**. In one example, the driving circuitry **230** may further include a driver **232**B for driving the WBG switch **244** on/off based on the received logic signal from the logic circuitry **220**. For example, the driver **232**B may drive the voltage to VDD_WBG to turn on the WBG switch **244** in response to the logic signal received from the logic circuitry **220**. In contrast, the driver **232**B may drive the voltage to VEE_WBG to turn off the WBG switch **244** in response to the logic signal received from the logic circuitry **220**.

[0031] In one example, one or more signals associated with the hybrid power switch circuitry **240** is transmitted as a feedback signal to the feedback circuitry **250**. The feedback circuitry **250** may include a sensing circuitry **252**, a comparator **254**, and a comparator **256**. In this example, the drain-source (or collector-emitter) voltage of the hybrid power switch circuitry **240** is sent as a feedback signal to the feedback circuitry **250** to determine whether the silicon switch **242** is turned on, via the sensing circuitry **252**. The sensing circuitry **252** may output a voltage to the comparator **254** that compares the output voltage to a ground voltage to determine whether the silicon switch **242** is turned on, thereby carrying full load. If the silicon switch **242** is turned on it is carrying full load and since the ratio of silicon switch **242** to the WBG switch **244** is high then to improve efficiency the WBG switch **244** can be turned on. As such, the output of the comparator **254** is input to the set logic circuitry **222**B to turn on the WBG switch **244** if the silicon switch **242** is turned on. However, if the output of the sensing circuitry **252** is low then the output of the comparator **254** is asserted low and therefore the set logic circuitry **222**B does not generate a signal asserted high to cause the WBG switch **244** to turn off and remains in an off position.

[0032] In one example, the signal on the gate of the silicon switch **242** (e.g., driving signal for driving the silicon switch **242**) may be sent to the feedback circuitry **250** where the signal is compared to VEE_Si via the comparator **256** to determine whether the silicon switch **242** is on or off. If the silicon switch **242** is not off yet, then the WBG switch **244** is maintained in an on position in order to reduce VI overlap turn off loss. However, if the silicon switch **242** is determined to be off (e.g., no voltage on its gate), then the WBG switch **244** can be turned off. As such, the output of the comparator **256** generates a signal to cause the reset logic circuitry **224**B to generate an asserted high signal for the reset input of flipflop **228** to cause the driver **232**B to drive the WBG switch **244** low or turn off.

[0033] Accordingly, the silicon device is turned on during the rising edge of the pulse width modulation signal and turned off during the falling edge of the pulse width modulation signal. Moreover, the collector voltage falling turns on the WBG device whereas the falling voltage of the gate for the silicon device turns off the WBG device.

[0034] Accordingly, a dual output gate driver, as described, adapts the timing between the gate waveforms of the parallel silicon device and the WBG device using the feedback signal from the switch node and the gate voltage. The gate driver optimizes the timing to turn the switches on/off to achieve higher efficiency, thereby eliminating the need to control the timing using a microcontroller. In other words, the chronological ordering of turning the silicon device and the WBG device is controlled using the feedback signal rather than using a microcontroller. As such, the computational cost and burden on the microcontroller is reduced while reducing the pin counts and die area of the gate drivers.

[0035] FIG. **3** is a schematic diagram of a set and reset logic circuitry, in an example. The set logic circuitry **222**A may include a delay element **320** coupled to an inverter **322** coupled to an AND logic **324**. The signal **202** is sent to one input of the AND logic **324** while the signal **202** is sent through the delay element **320** coupled to the inverter **322** and coupled to a second input of the AND logic **324**. The output of the AND logic **324** may be coupled to a set input of the flipflop **226**. The reset logic circuitry **224**A may include a delay element **330** coupled to an inverter **323** coupled to a NOR logic **334**. The signal **202** is sent to one input of the NOR logic **334** while the signal **202** is sent through the delay element **330** coupled to the inverter **332** and coupled to a second input of the NOR logic **334**. The output of the NOR logic **334** may be coupled to a reset input of the flipflop **226**.

[0036] FIG. **4** is a timing diagram of the apparatus in FIG. **2**, in an example. A pulse width modulation (PWM) is shown. When the PWM signal goes high, the inversion of the PWM signal after a delay goes low. The PWM signal asserting high causes the set input of the set logic circuitry **222**A to be asserted high (e.g., IGBT latch set). As such, the output of the driver **232**A is asserted high causing the silicon device **242**, e.g., IGBT, to turn on such that the IGBT voltage gate to emitter (V_{ge}) goes high. The output of the hybrid power switch circuitry **240** is compared to a ground voltage by the comparator **254**, e.g., voltage of drain to source to voltage of collector to emitter (V_{ds}/V_{ce}). The output of the comparator **254** causes the set input of the flipflop **228** (e.g., WBG latch set) to be set high by the set logic circuitry **222**B when the silicon device **242** is turned on. As such, the driver **232**B drives the WBG device **244** to turn on as shown by WBG V_{gs}.

[0037] After a certain amount of time, the PWM signal may be deasserted. When the PWM signal goes low, the inversion of the PWM signal after a delay goes high. The PWM signal asserting low causes the reset input of the reset logic circuitry **224**A to be asserted high (e.g., IGBT latch reset). As such, the output of the driver **232**A is asserted low causing the silicon device **242**, e.g., IGBT, to turn off, e.g., IGBT V_{ge} goes low. The output of the hybrid power switch circuitry **240** is compared to a ground voltage by the comparator **256**, e.g., voltage of drain to source to voltage of collector to emitter (V_{ds}/V_{ce}). The output of the comparator **256** causes the reset input of the flipflop **228** (e.g., WBG latch reset) to be set high by the reset logic circuitry **224**B when the silicon device **242** is turned off. As such, the driver **232**B drives the WBG device **244** to turn off as shown by WBG V_{gs}.

[0038] As illustrated, the apparatus **200** is programmed via the programmable switches **210** according to the ratio of silicon switch to the WBG switch. In one example, since the silicon switch reacts slower in comparison to the WBG switch and because the ratio of the silicon switch to the WBG switch is higher, then the programmable switches **210** are programmed to turn the silicon switch on/off before turning the WBG switch on/off. Such programming during turning on the hybrid power switch circuitry enables the silicon switch that has a higher ratio than the WBG switch to carry the full load. Moreover, such programming during turn-off of the hybrid power switch circuitry enables the WBG switch to remain on until the silicon switch is turned off to reduce VI turnover loss.

[0039] According to some examples, the programmable switches may be programmed differently from the one described in FIGS. **1-3**. In other words, specific programming of the programmable switches and configuration of the logic circuitry has been provided for illustrative purposes and should not be construed as limiting the scope of the examples.

[0040] FIG. **5** is a waveform of timing simulation of an apparatus, in an example. The simulation illustrates voltage on the gate of the WBG device and a silicon device. The simulation illustrates an increase in WBG drain current when the current of the collector/drain of the silicon device decreases. As such, voltage of the drain/source to collector/emitter is reduced, thereby reducing the VI overlap loss. According to one example, the architecture of FIGS. **1-4**, adapts the relative delay times between the silicon device and WBG device automatically (without using the microcontroller) based on the collector (or drain) voltage and gate voltage of the silicon device, thereby improving efficiency and reducing computational cost and complexity at a smaller dies size, reduce pin input, lower gate drive cost, etc.

[0041] FIG. **6** is a simulation for an energy loss of an apparatus, in an example. The energy loss over an entire switching cycle of the hybrid power switching circuitry may be calculated according to the following equation:

$$\int_{t_0}^{t_{pd}} v_{ce/ds} \times (i_c + i_d)dt$$

where $V_{ce/ds}$ is the voltage of collector emitter to drain source of the hybrid power switching circuitry, i_c is the collector current of the silicon device and i_d is the drain current of the WBG device. As illustrated, the energy loss calculation includes turning on and off IV overlap loss as well as conduction loss, thereby improving efficiency.

[0042] FIG. **7** is a flowchart illustrating operation of an apparatus with a gate driver for hybrid power switches, in an example. At step **710**, a signal is received to turn on a hybrid power switch circuitry on when the received signal is asserted, e.g., high. At step **720**, a first logic signal is generated in response to a feedback signal and further in response to a signal received from one or more switches (e.g., programmable switches). At step **730**, a second logic signal is generated in response to the feedback signal and further in response to the signal received from the one or more switches. At step **740**, a silicon device is driven based on the first logic signal. At step **750**, a wide bandgap device is driven based on the second logic signal. At step **760**, the feedback signal is generated based on whether the silicon device or the wide bandgap device is on or off.

[0043] In this description, the term "couple" may cover connections, communications, or signal paths that enable a functional relationship consistent with this description. For example, if device A generates a signal to control device B to perform an action: (a) in a first example, device A is coupled to device B by direct connection; or (b) in a second example, device A is coupled to device B through intervening component C if intervening component C does not alter the functional relationship between device A and device B, such that device B is controlled by device A via the control signal generated by device A.

[0044] Also, in this description, the recitation "based on" means "based at least in part on." Therefore, if X is based on Y, then X may be a function of Y and any number of other factors.

[0045] A device that is "configured to" perform a task or function may be configured (e.g., programmed and/or hardwired) at a time of manufacturing by a manufacturer to perform the function and/or may be configurable (or reconfigurable) by a user after manufacturing to perform the function and/or other additional or alternative functions. The configuring may be through firmware and/or software programming of the device, through a construction and/or layout of hardware components and interconnections of the device, or a combination thereof.

[0046] Modifications are possible in the described embodiments, and other embodiments are possible, within the scope of the claims.

What is claimed is:

1. An apparatus comprising:

one or more programmable switches that after programming turn on a first device and a second device within a hybrid power switch circuitry based on a selected ratio of the first device to the second device and further when a received signal to turn on the hybrid power switch circuitry is asserted, wherein the first device is a device with a first type and wherein the second device is a device with a second type;

a logic circuitry coupled to the one or more programmable switches that generates a logic signal to turn a driver circuitry on or off, wherein the logic signal is generated based on a signal received from the one or more programmable switches and further based on a detection signal received from a detection circuitry;

a driver circuitry coupled to the logic circuitry, wherein the driver circuitry generates a driving signal to the hybrid power switch circuitry and the detection circuitry based on the logic signal;

the hybrid power switch circuitry that includes the first device and the second device, wherein the hybrid power switch circuitry receives the driving signal that controls a timing of turning the first device and the second device on and off; and

the detection circuitry that receives a feedback signal associated with the hybrid power switch circuitry, wherein the detection circuitry detects whether the second device is on or off and further whether the first device is on or off, and wherein the detection circuitry generates the detection signal to the logic circuitry.

2. The apparatus of claim **1**, wherein the received signal by the one or more programmable switches is a pulse width modulation signal.

3. The apparatus of claim **2**, wherein the pulse width modulation signal is generated by a microcontroller.

4. The apparatus of claim **1**, wherein the logic circuitry comprises a first portion that generates a first logic signal to control driving the first device on or off and a second portion that generates a second logic signal to control driving the second device.

5. The apparatus of claim **1**, wherein the driver circuitry comprises a first portion that drives the first device and a second portion that drives the second device.

6. The apparatus of claim **1**, wherein the selected ratio reflects more first device in comparison to the second device, and wherein the first device is turned on first when the received signal to turn on the hybrid switch circuitry is asserted before turning on the second device, and wherein the second device remains on when the first device is turning off and wherein the second device is turned off after the first device is turned off.

7. The apparatus of claim **6**, wherein the detection circuitry comprises a comparator to determine whether the first device is on and wherein the detection circuitry generates the feedback signal to turn on the second device in response to determining that the first device is on.

8. The apparatus of claim **6**, wherein the detection circuitry comprises a comparator to determine whether the first device is off and wherein the detection circuitry generates the feedback signal to turn off the second device in response to determining that the first device is off.

9. The apparatus of claim **1**, wherein the second device is a wide bandgap device that includes a wide bandgap field effect transistor (FET) switch and wherein the first device is a silicon device that includes a silicon FET switch.

10. The apparatus of claim **1**, wherein the detection circuitry comprises a comparator.

11. An apparatus comprising:

one or more programmable switches that after programming turn on a wide bandgap device and a silicon device within a hybrid power switch circuitry based on a selected ratio of the silicon device to the wide bandgap device and further when a received signal to turn on the hybrid power switch circuitry is asserted;

a first logic circuit coupled to the one or more programmable switches, wherein the first logic circuit generates a first logic signal;

a first driving circuit coupled to the first logic circuit to receive the first logic signal and in response thereto drive the silicon device of the hybrid power switch circuitry;

a second logic circuit coupled to the one or more programmable switches, wherein the second logic circuit generates a second logic signal;

a second driving circuit coupled to the second logic circuit to receive the second logic signal and in response thereto drive the wide bandgap device of the hybrid power switch circuitry; and

a feedback circuitry that receives a feedback signal associated with the hybrid power switch circuitry, wherein the feedback circuitry generates a feedback signal based on an on/off status of the silicon device or the wide bandgap device, wherein the feedback circuitry sends the feedback signal to the first logic circuit and the second logic circuit,

wherein the first logic circuit generates the first logic signal based on the feedback signal and further based on a signal received from the one or more programmable switches,

wherein the second logic circuit generates the second logic signal based on the feedback signal and further based on the signal received from the one or more programmable switches.

12. The apparatus of claim **11**, wherein the received signal by the one or more programmable switches is a pulse width modulation signal.

13. The apparatus of claim **12**, wherein the pulse width modulation signal is generated by a microcontroller.

14. The apparatus of claim **11**, wherein the selected ratio reflects more silicon device in comparison to the wide bandgap device, and wherein the silicon device is turned on first when the received signal to turn on the hybrid switch circuitry is asserted before turning on the wide bandgap device, and wherein the wide bandgap device remains on when the silicon device is turning off and wherein the wide bandgap device is turned off after the silicon device is turned off.

15. The apparatus of claim **14**, wherein the feedback circuitry comprises a comparator to determine whether the silicon device is on and wherein the feedback circuitry generates the feedback signal to turn on the wide bandgap device in response to determining that the silicon device is on.

16. The apparatus of claim **14**, wherein the feedback circuitry comprises a comparator to determine whether the silicon device is off and wherein the feedback circuitry generates the feedback signal to turn off the wide bandgap device in response to determining that the silicon device is off.

17. A method comprising:

receiving a signal to turn on a hybrid power switch circuitry when the received signal is asserted;

generating a first logic signal in response to a feedback signal and further in response to a signal received from one or more switches;

generating a second logic signal in response to the feedback signal and further in response to the signal received from the one or more switches;

driving a silicon device based on the first logic signal;

driving a wide bandgap device based on the second logic signal; and generating the feedback signal based on whether the silicon device or the wide bandgap device is on or off.

18. The method of claim **17** wherein generating the feedback signal comprises comparing a voltage at a gate of the silicon device to a threshold voltage that turns on the silicon device to determine whether the silicon device is turned off or comparing a voltage at a gate of the wide bandgap device to a threshold voltage that turns on the wide bandgap device to determine whether the wide bandgap device is turned off.

19. The method of claim **17** wherein generating the feedback signal comprises comparing a voltage output of the silicon device to a ground to determine whether the silicon device is turned on or comparing a voltage output of the wide bandgap device to determine whether the wide bandgap device is turned on.

20. The method of claim **17** further comprising programming the one or more switches according to ratio of the silicon device to the wide bandgap device within the hybrid power switch circuitry.

21. The method of claim **17** further comprising controlling a timing of turning the wide bandgap device and silicon device on and off based on a positioning of the one or more switches and further based on the signal received to turn the hybrid power switch circuitry on or off.

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