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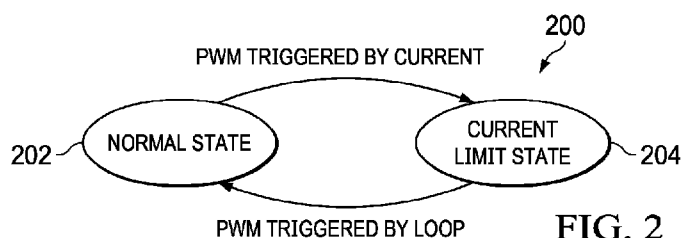
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- as to applicant's entitlement to apply for and be granted a patent (Rule 4.17(ii))
- as to the applicant's entitlement to claim the priority of the earlier application (Rule 4.17(iii))

(54) Title: POWER CONVERTER CONTROL

**FIG. 2**

(57) **Abstract:** In some examples, a circuit includes a state machine. The state machine is configured to operate in a first state (202) in which the state machine gates a pulse width modulation (PWM) signal provided for control of a power converter according to a first signal provided by a voltage control loop. The state machine is configured to operate in a second state (204) in which the state machine gates the PWM signal according to a second signal provided by a current limit comparator. The state machine is configured to transition from the first state to the second state responsive to the second signal being asserted after the first signal is asserted in a switching cycle of the power converter. The state machine is configured to transition from the current state to the first state responsive to the first signal being asserted after the second signal in a switching cycle of the power converter.



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POWER CONVERTER CONTROL

BACKGROUND

[0001] A switched mode power supply (SMPS) transfers power from an input power source to a load by switching one or more power transistors or other switching elements coupled through a switch node/terminal to an energy storage element (such as an inductor, an inductance of a transformer, and/or a capacitor), which is capable of coupling to the load. The power transistors can be included in a power converter that includes, or is capable of coupling to, the energy storage element. A SMPS can include a SMPS controller to provide one or more gate drive signals to switch the power transistor(s). Switching of the power transistor(s) can be controlled based on a current flowing through the power converter.

SUMMARY

[0002] In some examples, a circuit includes a state machine. The state machine is configured to operate in a first state in which the state machine gates a pulse width modulation (PWM) signal provided for control of a power converter according to a first signal provided by a voltage control loop. The state machine is configured to operate in a second state in which the state machine gates the PWM signal according to a second signal provided by a current limit comparator. The state machine is configured to transition from the first state to the second state responsive to the second signal being asserted after the first signal is asserted in a switching cycle of the power converter. The state machine is configured to transition from the current state to the first state responsive to the first signal being asserted after the second signal in a switching cycle of the power converter.

[0003] In some examples, a circuit includes a first comparator, a current sense element, a second comparator, and a state machine. The first comparator has a first output, a first input, and a second input, the first input adapted to be coupled to an output of a power converter and the second input configured to receive a voltage ramp signal. The current sense element has a current sense input and a current sense output, the current sense input adapted to be coupled to a power converter. The second comparator has a second output, a third input, a fourth input, and a blanking input, the third input coupled to the current sense output, the fourth input configured to receive a current limit threshold signal, and the blanking input configured to receive a blanking signal. The state machine

is coupled to the first output and the second output and configured to provide a PWM signal for controlling the power converter based on a signal at the first output and a signal at the second output.

[0004] In some examples, a system includes a load and a switched mode power supply (SMPS). The SMPS is coupled to the load and including a power converter configured to switch power to the load based on control exerted by the SMPS. The SMPS is configured to implement a state machine configured to operate in a first state in which the state machine gates a PWM signal provided for control of a power converter according to a first signal. The state machine is configured to operate in a second state in which the state machine gates the PWM signal according to a second signal. The state machine is configured to transition from the first state to the second state responsive to the second signal being asserted after the first signal is asserted in a switching cycle of the power converter. The state machine is configured to transition from the current state to the first state responsive to the first signal being asserted after the second signal in a switching cycle of the power converter.

BRIEF DESCRIPTION OF THE DRAWINGS

[0005] FIG. 1 is a block diagram of an example system.

[0006] FIG. 2 is an example state diagram of a state machine.

[0007] FIG. 3 is an example signal diagram of signals that may be provided in a SMPS.

[0008] FIG. 4 is an example signal diagram of signals that may be provided in a SMPS.

DETAILED DESCRIPTION OF EXAMPLE EMBODIMENTS

[0009] In some device architectures, a switched mode power supply (SMPS) includes, or is capable of coupling to, an output capacitor in parallel with the load. A SMPS controller switches power transistor(s) to form circuit arrangements with energy storage element(s) to supply a load current to the load and/or to the output capacitor to maintain a regulated output voltage. Alternatively, though not shown herein, at least some of the power transistors may be implemented as passive switches, such as diodes. A power transistor can be coupled through the switch node/terminal to an energy storage inductor during charging and/or discharging switching states of a power converter. In at least some examples, the energy storage inductor is switched by the SMPS controller between charge and discharge switching states to supply inductor current (e.g., current through the energy storage inductor) to the load and to the output capacitor to maintain the regulated output voltage. As described above, in at least some examples, one or more of the power transistors are replaced by passive switches that react based on characteristics of a received input signal and are

not switched by the SMPS controller. In some examples, a SMPS can be configured for operation as a constant current source with an energy storage element but with no output capacitor. Power converters periodically repeat sequences of switching states (such as “on” and “off” states). A single on/off cycle may be called a switching cycle.

[0010] The power transistors can be implemented as field effect transistors (FETs), such as metal-oxide field effect transistors (MOSFETs) or any other suitable solid-state transistor devices (e.g., such as bipolar junction transistors (BJTs)). Power converters can be of various architectures, each having certain functionality, such as buck, boost, and buck-boost, among others. Depending on the application in which a buck-boost converter is used, the input voltage (V_{IN}) and/or the output voltage (V_{OUT}) of the power converter may vary. To address this, the SMPS controller will control the buck-boost converter to operate in different modes of operation. For example, based on V_{IN} being greater than V_{OUT} , the SMPS controller will cause the power converter to operate in a buck mode of operation. Based on V_{IN} being less than V_{OUT} , the SMPS controller will cause the power converter to operate in a boost mode of operation. Based on V_{IN} being approximately equal to V_{OUT} , the SMPS controller will cause the power converter to operate in a buck-boost mode of operation, or in alternate cycles of buck-mode and boost-mode operation. The above examples are non-exclusive and apply generally to a power converter of buck-boost topology or architecture. However, at least some of the above examples also apply to power converters of other topologies or architectures, such as buck or boost, operating under certain modes of control.

[0011] To control a mode of operation of the power converter, the SMPS controller provides gate control signals to one or more power transistors of the power converter. The gate control signals received by a power transistor control whether the power transistor is in a conductive state (e.g., turned on) or in a non-conductive state (e.g., turned off). Each state of a power converter involves a specific combination of transistors that are in conducting states and transistors that are in non-conducting states. To change a mode of operation of the power converter, the SMPS controller modifies the sequence of switching states that it commands the transistors to assume. In at least some examples, the SMPS controller implements a state machine or other logic such that values of the gate control signals are determined based on a mode of operation of or for the power converter. Also, while remaining in a mode of operation of the power converter, the SMPS controller may modify a value of one or more of the gate control signals to alternatively turn on and turn off one or more power transistors.

[0012] In some examples, the energy storage element may become saturated. For example, when the energy storage element is an inductor, the energy storage element may become saturated such that magnetic flux of the inductor does not incrementally increase as current through the inductor increases. Saturation of an inductor in this manner creates a potential for an uncontrolled increase in inductor current. The uncontrolled increase in inductor current, in turn, has a potential for damaging, or otherwise adversely affecting, a load receiving VOUT from the SMPS. Further, repeated saturation of an inductor can cause operational characteristics of the inductor to change (such as its saturation point) and may damage or adversely affect the inductor. To protect against saturation of the energy storage element, current limits may be implemented in the SMPS. For example, the SMPS may implement valley or peak sensed current limits for the energy storage element. However, control based on sensed current limits can sometimes have certain disadvantages, such as at low duty cycle operation or while operating at high switching frequencies. For example, in each operational circumstance, a delay between sensing a current and making a control decision based on the sensed current may be greater than an available amount of time before the SMPS controller has provided a pulse width modulation (PWM) signal that causes a current of the energy storage element to overshoot the programmed current limit.

[0013] Described herein are various examples of a control scheme for controlling a power converter. In some examples, the power converter may be a component of a SMPS. The control scheme may be implemented in a controller that may also be a component of the SMPS or may be adapted to be coupled to the SMPS. For example, the controller may implement a state machine, such as a digital finite state machine, to control the power converter according to the control scheme of this description. In at least some examples of the control scheme of this description, two operation modes are defined. The first operation mode is a normal operation mode and the second operation mode is a current limit operation mode. In at least some examples, the state machine may receive input signals from a PWM comparator that compares a signal having a value based on an output voltage of the power converter to a reference signal, such as a voltage ramp signal (Vramp). The state machine may also receive input signals from a current limit comparator that compares a sensed current of an energy storage element of the power converter to a programmed current limit threshold. The PWM comparator may provide a signal LOOP and the current limit comparator may provide a signal CURRENT, each of which is an active low signal for the purposes of this description.

[0014] The current limit comparator may be gated by a blanking signal (BLANK), which is also

an active low signal for the purposes of this description. For example, while BLANK is asserted, the current limit comparator may be prevented from providing CURRENT as having an asserted value, irrespective of values of the sensed current of the energy storage element of the power converter or the current limit threshold. By modifying an amount of time for which BLANK is asserted, the current limit comparator may be blocked for the programmed time of BLANK, irrespective of a minimum on time of the power converter. The programmed time may be based on a switching frequency of the power converter, thereby increasing accuracy of current limit control of the power converter, such as by increasing noise immunity of control of the power converter. In some examples, assertion of BLANK may further take into consideration other circuit conditions. For example, whether or not to assert BLANK may be at least partially determined according to a sensor output, signal, various programmed circuit protection or operation schemes, etc. For example, a microcontroller or other processing component(s), such as digital logic devices, may receive signals and provide BLANK having a value determined based on those received signals and a particular use case in which BLANK is used.

[0015] In at least some examples, the state machine may be configured to provide a PWM signal having an asserted value responsive to a second of LOOP and CURRENT becoming asserted during a switching cycle of the power converter. During the normal operation mode described above, a PWM signal provided by the state machine for firing a pulse of the power converter is gated by LOOP. For example, CURRENT may become asserted followed by LOOP becoming asserted. In at least some examples, CURRENT may only become asserted while BLANK is also asserted. In the normal operation mode, the PWM signal provided by the state machine may become asserted based on LOOP becoming asserted. Also, while operating in the normal operation mode, BLANK may become asserted at a falling edge (e.g., deassertion) of the PWM signal provided by the state machine and may become deasserted responsive to CURRENT becoming deasserted. If CURRENT becomes asserted after LOOP becomes asserted, the PWM signal provided by the state machine may become asserted based on the assertion of OCP_RAW and the state machine may move to the current limit operation mode. In the current limit operation mode, the PWM signal provided by the state machine may become asserted based on CURRENT becoming asserted. Also while operating in the current limit operation mode, an amount of time for which BLANK is asserted may be programmable to prevent OCP_BLANK from becoming asserted during the programmed amount of time. If LOOP becomes asserted after CURRENT becomes asserted, the PWM signal provided

by the state machine may again become asserted based on the assertion of LOOP and the state machine may return to the normal operation mode. In at least some examples, the programmability of BLANK facilitates operation of the power converter across various switching frequencies, providing for accurate control based on CURRENT while limiting adverse effects to transient performance of the power converter.

[0016] FIG. 1 shows a block diagram of an example system 100. In at least one example, the system 100 includes a SMPS 102 that includes a controller 104 and a power converter 106. The SMPS 102, through the power converter 106, switches power provided to the SMPS 102 as VIN to a load 108. In some examples, the SMPS is adapted to be coupled to the load 108 at an output terminal of the SMPS 102. In some examples, the power converter 106 is a buck power converter. In other examples, the power converter 106 is a buck-boost power converter that is capable of operating according to a buck mode of operation, a boost mode of operation, and/or a buck-boost mode of operation. In other examples, the power converter 106 is a boost power converter. A buck power converter implementation is assumed for description herein. In at least one example, the controller 104 includes, or is adapted to be coupled to, a PWM comparator 111, a current limit comparator 112, and a state machine 114. In some examples, the power converter 106 is also adapted to be coupled to a capacitor 115. The controller 104 may further include, or be adapted to be coupled to, a driver 116 and a current sense element 118. In other examples, the current sense element 118 is a component of the power converter 106. The power converter 106 includes a power transistor 120, a power transistor 122, and is adapted to be coupled to an inductor 124. The SMPS 102 of this description is shown and described as implementing valley mode constant on time control over the power converter 106. However, other control methods are possible, such as peak current mode control, average current mode control, voltage mode control, or any other suitable form of control implemented in a fixed frequency method, variable frequency method, constant time method (e.g., constant Ton or constant Toff), etc.

[0017] At least one example of the SMPS 102 includes at least some aspects of the controller 104 and the power converter 106 on a same semiconductor die and/or in a same component package (or encapsulation), while in other examples the controller 104 and the power converter 106 may be fabricated separately and adapted to be coupled together. For example, at least some aspects of the controller 104 may be fabricated separately and coupled together. Accordingly, while shown as including the driver 116, in at least one example the controller 104 does not include the driver 116,

but rather is adapted to be coupled to the driver 116. Similarly, other components shown as being included in the controller 104 may be adapted to be coupled, in whole or in part, to the controller 104 and not be included on a same semiconductor die and/or in a same component package as the controller 104. Similarly, components shown or described in this description as being included in the power converter 106 (such as an inductor) may be adapted to be coupled, in whole or in part, to the power converter 106 and not be included on a same semiconductor die and/or in a same component package as the power converter 106.

[0018] In at least one example architecture of the system 100, the PWM comparator 111 has a first input terminal (e.g., a positive or non-inverting input terminal), a second input terminal (e.g., a negative or inverting input terminal), and an output terminal. The first input terminal of the PWM comparator 111 is coupled to a node 125 at which VOUT is provided, the second input terminal of the PWM comparator 111 is configured to receive V_{ramp}, and the output terminal of the PWM comparator 111 is coupled to the state machine 114. In at least some examples, the node 125 is the output terminal of the SMPS 102. In at least some examples, one or more components or circuits are coupled between the first input terminal of the PWM comparator 111 and the node 125, such as a loop compensation circuit or component, a slope compensation circuit or component, etc. The current limit comparator 112 has a first input terminal (e.g., a positive or non-inverting input terminal), a second input terminal (e.g., a negative or inverting input terminal), and an output terminal. The first input terminal of the current limit comparator 112 is coupled to the current sense element 118, the second input terminal of the current limit comparator 112 is configured to receive a current limit threshold signal (indicated in FIG. 1 as CURRENT_LIMIT), and the output terminal of the current limit comparator 112 is coupled to the state machine 114. The current limit comparator 112 further has a control input configured to receive BLANK. The state machine 114 has an output terminal adapted to be coupled to an input terminal of the driver 116, which has an output terminal adapted to be coupled to a node 125. The capacitor 115 is adapted to be coupled between the node 125 and ground. The power transistor 120 has a gate terminal adapted to be coupled to the node 125, a drain terminal configured to receive VIN, and a source terminal coupled to a node 126. The power transistor 122 has a gate terminal adapted to be coupled to the node 125, a drain terminal adapted to be coupled to ground, and a source terminal coupled to the node 126. The inductor 124 is adapted to be coupled between the node 126 and the node 125. The current sense element 118 is adapted to be coupled to, or otherwise sense a current of, the inductor 124. In at least some examples,

the controller 104, or any one or more components of the controller 104, and/or the current sense element 118 may be collectively referred to as a voltage control loop, such that a voltage provided at the node 125 (or PWM, on which the voltage provided at the node 125 is based) is controlled by the voltage control loop.

[0019] In an example of operation of the system 100, the state machine 114 provides PWM based on decisions that are made by the state machine 114 based at least partially on LOOP and CURRENT. Based on PWM, the driver 116 is configured to drive the power transistor 120 and the power transistor 122. For example, responsive to assertion of PWM, the driver 116 is configured to drive the power transistor 120 to cause the power transistor 120 to be conductive, conducting current from a power source from which VIN is received to the node 126 to energize the inductor 124. While PWM is asserted, the driver 116 is also configured to drive the power transistor 122 to cause the power transistor 122 to be non-conductive between the node 126 and ground. Responsive to deassertion of PWM, the driver 116 is configured to drive the power transistor 120 to cause the power transistor 120 to be non-conductive between the power source from which VIN is received and the node 126. Also while PWM is deasserted, the driver 116 is configured to drive the power transistor 122 to cause the power transistor 122 to be conductive between the node 126 and ground to de-energize the inductor 124.

[0020] The PWM comparator 111 receives a signal representative of VOUT (or, in some examples, receives VOUT) at the first input terminal of the PWM comparator 111. The PWM comparator 111 compares the signal representative of VOUT to Vramp. Responsive to the signal representative of VOUT having a value that does not exceed a value of Vramp, the PWM comparator 111 provides LOOP having an asserted value. Responsive to the signal representative of VOUT having a value that exceeds the value of Vramp, the PWM comparator 111 provides LOOP having a deasserted value. The current limit comparator 112 receives a signal, shown in FIG. 1 as IL, representative of an inductor current of the inductor 124 from the current sense element 118 at the first input terminal of the current limit comparator 112. The current limit comparator 112 compares IL to CURRENT_LIMIT. Responsive to IL having a value that does not exceed CURRENT_LIMIT, and while BLANK has an asserted value, the current limit comparator 112 provides CURRENT having an asserted value. Responsive to IL having a value that exceeds CURRENT_LIMIT, and while BLANK has an asserted value, the current limit comparator 112 provides CURRENT having a deasserted value. Responsive to BLANK having a deasserted value,

the current limit comparator 112 provides CURRENT having a deasserted value.

[0021] In at least some examples, the state machine 114 is configured to provide PWM having an asserted value responsive to a second of LOOP and CURRENT being received having an asserted value. Operation of the state machine 114 is further described below with respect to FIG. 2.

[0022] FIG. 2 shows an example state diagram 200 of the state machine 114. The state diagram 200, in at least some examples, represents states and state transitions of at least one implementation of the state machine 114 of FIG. 1. At least some examples of the state machine 114 are configured to implement a normal state 202 and a current limit state 204.

[0023] While operating in the normal state 202, the state machine 114 is configured to control the power converter 106 to operate in a normal operation mode in which the state machine 114 gates PWM according to LOOP. For example, while operating in the normal state 202, in a given switching cycle of the power converter 106 the state machine 114 may receive LOOP having an asserted value after having already received CURRENT having an asserted value in the same switching cycle. Based on receiving LOOP as the second of LOOP and CURRENT to be asserted, the state machine 114 provides PWM having an asserted value. In some examples of operation in the normal state 202, the state machine 114 receives CURRENT as the second of LOOP and CURRENT to be asserted. Responsive to receiving CURRENT as the second of LOOP and CURRENT to be asserted, the state machine 114 transitions from the normal state 202 to the current limit state 204.

[0024] While operating in the current limit state 204, the state machine 114 is configured to control the power converter 106 to operate in a current limit operation mode in which the state machine 114 gates PWM according to CURRENT. For example, while operating in the current limit state 204, in a given switching cycle of the power converter 106 the state machine 114 may receive CURRENT having an asserted value after having already received LOOP having an asserted value in the same switching cycle. Based on receiving CURRENT as the second of LOOP and CURRENT to be asserted, the state machine 114 provides PWM having an asserted value. Responsive to the state machine 114 receiving LOOP as the second of LOOP and CURRENT to be asserted, the state machine 114 transitions from the current limit state 204 back to the normal state 202.

[0025] FIG. 3 shows an example signal diagram 300 of signals that may be provided in the SMPS 102. The signal diagram 300, in at least some examples, shows PWM, BLANK, CURRENT, LOOP, IL, and CURRENT_LIMIT, each as described above. The signal diagram 300, in at least some

examples, corresponds to operation of the state machine 114 beginning in the normal state 202 and transitioning to the current limit state 204.

[0026] As shown by the signal diagram 300, in the normal state 202, the state machine 114 provides PWM for a pulsed duration based on assertion of LOOP. While operating in the normal state 202, BLANK is configured to be asserted responsive to deassertion (e.g., a falling edge) of PWM. While BLANK is asserted, CURRENT is permitted to be asserted by the current limit comparator 112. For example, while BLANK is asserted and responsive to IL being less than or equal to CURRENT_LIMIT, CURRENT may be asserted for a pulsed duration. While BLANK is not asserted, the current limit comparator 112 is prohibited or blocked from providing CURRENT having an asserted value.

[0027] As further shown by the signal diagram 300, responsive to assertion of CURRENT becoming delayed such that it becomes the second of LOOP and CURRENT to be asserted, the state machine 114 provides PWM based on assertion of CURRENT. For example, responsive to a current drawn by the load 108 increasing, IL also increases. As IL increases, assertion of CURRENT begins to be delayed. Similarly, if the current drawn by the load 108 is greater than CURRENT_LIMIT, a frequency of assertion of LOOP may increase to provide a greater amount of energy to the load 108. Responsive to the state machine 114 providing PWM based on assertion of CURRENT, the state machine 114 transitions from the normal state 202 to the current limit state 204, as shown by the signal diagram 300. While operating in the current limit state 204, a time period for which BLANK is not asserted, thereby blocking assertion of CURRENT, is modified according to a programmed value. The programmed value may be determined based on any suitable factors, such as switching frequency of the power converter 106, duty cycle of PWM, board noise for a circuit board including at least some components of the SMPS 102, etc.

[0028] In at least some examples, modifying the time period for which BLANK is not asserted provides a degree of noise immunity to the SMPS 102. For example, in a system that does not include BLANK, CURRENT may become asserted responsive to IL momentarily crossing the threshold of CURRENT_LIMIT due to signal noise or other outside influence. In some examples, when an inductor, such as the inductor 124, in a power converter has a high inductance, the inductor may energize and de-energize with a current having a small slope. Such examples may be susceptible to incorrect assertion of CURRENT in the absence of BLANK as described herein. These assertions of CURRENT resulting from signal noise can cause IL to increase beyond a value

for which the SMPS 102 is configured, potentially damaging components of the SMPS 102 and/or the load 108. Also, by preventing assertions of CURRENT for a programmable amount of time, the state machine 114 is prevented from providing PWM having an asserted value. In at least some examples, this is advantageous in low-duty cycle or high switching frequency applications of the SMPS 102. For example, in low-duty cycle or high switching frequency applications, a delay may exist between a change in current of the inductor 124 and rendering of a decision (provided as the value of CURRENT) by the current limit comparator 112 based on IL and CURRENT_LIMIT. This delay may mean that by the time the current limit comparator 112 has rendered its decision, the state machine 114 may have already provided another asserted pulse of PWM. However, the state machine 114 may then receive the delayed assertion of CURRENT following PWM becoming deasserted, causing the state machine 114 to provide yet another asserted pulse of PWM shortly after (or immediately following) a minimum off time for the power converter 106 responsive to LOOP being asserted. This may cause a current of the power converter 106 to overshoot, sometimes by large amounts, a programmed value set based on CURRENT_LIMIT, potentially damaging the SMPS 102 and/or the load 108. By preventing assertion of CURRENT for the programmed time according to BLANK, this overshoot may be prevented.

[0029] FIG. 4 shows an example signal diagram 400 of signals that may be provided in the SMPS 102. The signal diagram 400, in at least some examples, shows PWM, BLANK, CURRENT, LOOP, IL, and CURRENT_LIMIT, each as described above. The signal diagram 400, in at least some examples, corresponds to operation of the state machine 114 beginning in the current limit state 204 and transitioning to the normal state 202.

[0030] As shown by the signal diagram 400, in the current limit state 204, the state machine 114 provides PWM for a pulsed duration based on assertion of CURRENT. While operating in the current limit state 204, BLANK is configured to be asserted a programmed time after deassertion, which occurs substantially concurrently with deassertion of CURRENT. While BLANK is asserted, CURRENT is permitted to be asserted by the current limit comparator 112. For example, while BLANK is asserted and responsive to IL being less than or equal to CURRENT_LIMIT, CURRENT may be asserted for a pulsed duration. While BLANK is not asserted, the current limit comparator 112 is prohibited or blocked from providing CURRENT having an asserted value. In at least some examples, such blocking prevents the current limit comparator 112 from incorrectly providing multiple assertions of CURRENT substantially back-to-back. Such incorrectly provided multiple

assertions of CURRENT may result from an accurate decision of the current limit comparator 112 (and assertion of CURRENT) followed by one or more inaccurate decisions of the current limit comparator 112 (and assertions of CURRENT), such as resulting from a noisiness of IL.

[0031] As further shown by the signal diagram 400, responsive to assertion of LOOP becoming delayed such that it becomes the second of CURRENT and LOOP to be asserted, the state machine 114 provides PWM based on assertion of LOOP. Responsive to the state machine 114 providing PWM based on assertion of LOOP, the state machine 114 transitions back from the current limit state 204 to the normal state 202, as shown by the signal diagram 400. While operating in the normal state 202, BLANK may become asserted responsive to deassertion (e.g., a falling edge) of PWM and may become deasserted responsive to deassertion of CURRENT.

[0032] 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 provides a signal to control device B to perform an action, then: (a) in a first example, device A is directly coupled to device B; or (b) in a second example, device A is indirectly coupled to device B through intervening component C if intervening component C does not substantially alter the functional relationship between device A and device B, so device B is controlled by device A via the control signal provided by device A.

[0033] 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.

[0034] A circuit or device that is described herein as including certain components may be adapted to be coupled to those components to form the described circuitry or device. For example, a structure described as including one or more semiconductor elements (such as transistors), one or more passive elements (such as resistors, capacitors and/or inductors), and/or one or more sources (such as voltage and/or current sources) may include only the semiconductor elements within a single physical device (e.g., a semiconductor die and/or integrated circuit (IC) package) and may be adapted to be coupled to at least some of the passive elements and/or the sources to form the described structure either at a time of manufacture or after a time of manufacture, for example by an end-user

and/or a third party.

[0035] While certain components may be described herein as being of a particular process technology, these components may be exchanged for components of other process technologies. Circuits described herein are reconfigurable to include the replaced components to provide functionality at least partially similar to functionality available prior to the component replacement. Components shown as resistors, unless otherwise stated, are generally representative of any one or more elements coupled in series and/or parallel to provide an amount of impedance represented by the shown resistor. For example, a resistor or capacitor shown and described herein as a single component may instead be multiple resistors or capacitors, respectively, coupled in series or in parallel between the same two nodes as the single resistor or capacitor.

[0036] Uses of the phrase “ground voltage potential” in this description include a chassis ground, an Earth ground, a floating ground, a virtual ground, a digital ground, a common ground, and/or any other form of ground connection applicable to, or suitable for, the teachings of this description. Unless otherwise stated, “about,” “approximately,” or “substantially” preceding a value means +/- 10 percent of the stated value.

[0037] Modifications are possible in the described examples, and other examples are possible, within the scope of the claims.

CLAIMS

What is claimed is:

1. A circuit, comprising:
a state machine configured to:
operate in a first state in which the state machine gates a pulse width modulation (PWM) signal provided for control of a power converter according to a first signal provided by a voltage control loop;
operate in a second state in which the state machine gates the PWM signal according to a second signal provided by a current limit comparator;
transition from the first state to the second state responsive to the second signal being asserted after the first signal is asserted in a switching cycle of the power converter; and
transition from the second state to the first state responsive to the first signal being asserted after the second signal in a switching cycle of the power converter.
2. The circuit of claim 1, wherein the voltage control loop is configured to compare an output voltage of the power converter to a voltage ramp to determine an output to provide as the first signal.
3. The circuit of claim 1, wherein the current limit comparator is configured to compare a value of a signal representative of a current flowing through the power converter to a current limit threshold to determine an output to provide as the second signal.
4. The circuit of claim 3, wherein the current limit comparator is configured to be gated by a blanking signal.
5. The circuit of claim 4, wherein in the first state the blanking signal is asserted responsive to deassertion of the PWM signal and deasserted a programmed amount of time after assertion.
6. The circuit of claim 4, wherein in the second state the blanking signal is deasserted responsive to deassertion of the second signal and asserted a programmed amount of time after assertion.
7. The circuit of claim 4, wherein the current limit comparator is configured to be blocked from providing the second signal having an asserted value while the blanking signal has an asserted value.
8. A circuit, comprising:
a first comparator having a first output, a first input, and a second input, the first input adapted to be coupled to an output of a power converter and the second input configured to receive a voltage ramp signal;

a current sense element having a current sense input and a current sense output, the current sense input adapted to be coupled to the power converter;

a second comparator having a second output, a third input, a fourth input, and a blanking input, the third input coupled to the current sense output, the fourth input configured to receive a current limit threshold signal, and the blanking input configured to receive a blanking signal; and

a state machine coupled to the first output and the second output and configured to provide a pulse width modulation (PWM) signal for controlling the power converter based on a signal at the first output and a signal at the second output.

9. The circuit of claim 8, wherein the second comparator is configured to be prevented from asserting the signal at the second output responsive to the blanking signal being asserted.

10. The circuit of claim 8, wherein the state machine is configured to operate in a first state responsive to the PWM signal being provided based on the signal at the first output.

11. The circuit of claim 10, wherein, while the state machine is operating in the first state, the blanking signal is asserted for a pulsed duration responsive to deassertion of the PWM signal.

12. The circuit of claim 8, wherein the state machine is configured to operate in a second state responsive to the PWM signal being provided based on the signal at the second output.

13. The circuit of claim 12, wherein while the state machine is operating in the second state the blanking signal is deasserted responsive to deassertion of the signal at the second output and asserted a programmed amount of time after deassertion.

14. A system, comprising:

a load; and

a switched mode power supply (SMPS) coupled to the load and including a power converter configured to switch power to the load based on control exerted by the SMPS, wherein the SMPS is configured to implement a state machine configured to:

operate in a first state in which the state machine gates a pulse width modulation (PWM) signal provided for control of the power converter according to a first signal provided by a voltage control loop;

operate in a second state in which the state machine gates the PWM signal according to a second signal provided by a current limit comparator;

transition from the first state to the second state responsive to the

second signal being asserted after the first signal is asserted in a switching cycle of the power converter; and

transition from the current state to the first state responsive to the first signal being asserted after the second signal in a switching cycle of the power converter.

15. The system of claim 14, wherein the voltage control loop is configured to compare an output voltage of the power converter to a voltage ramp to determine an output to provide as the first signal.

16. The system of claim 14, wherein the current limit comparator is configured to compare a value of a signal representative of a current flowing through the power converter to a current limit threshold to determine an output to provide as the second signal.

17. The system of claim 16, wherein the current limit comparator is configured to be gated by a blanking signal.

18. The system of claim 17, wherein, in the first state, the blanking signal is asserted responsive to deassertion of the PWM signal and deasserted a programmed amount of time after assertion.

19. The system of claim 17, wherein in the second state the blanking signal is deasserted responsive to deassertion of the second signal and asserted a programmed amount of time after assertion.

20. The system of claim 17, wherein the current limit comparator is configured to be blocked from providing the second signal having an asserted value while the blanking signal has an asserted value.

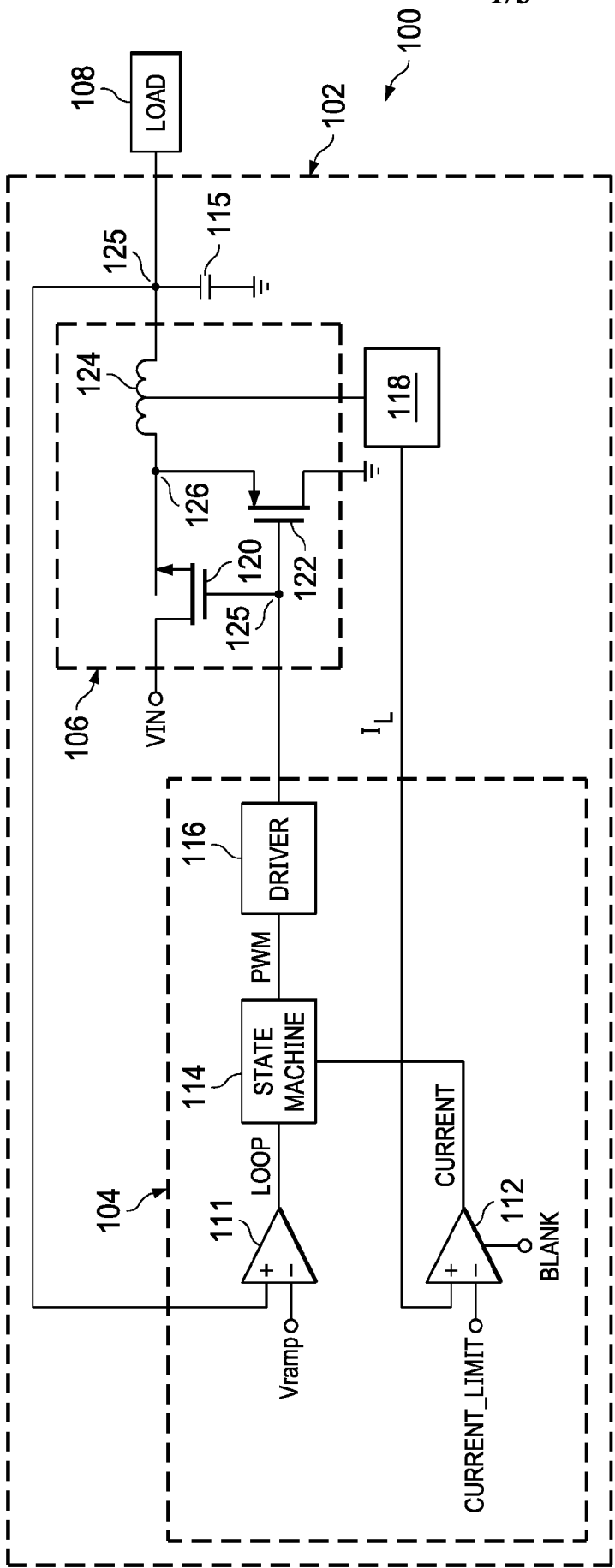


FIG. 1

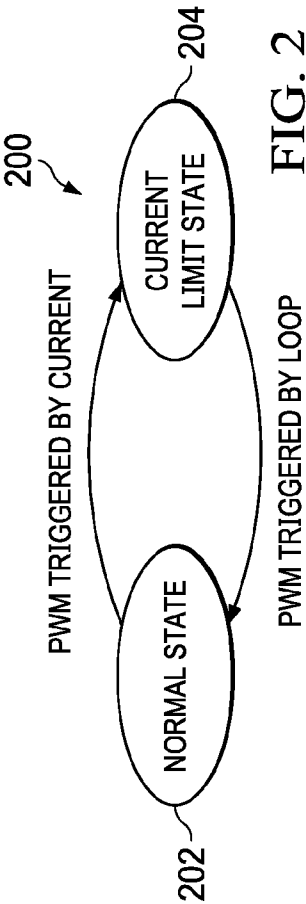


FIG. 2

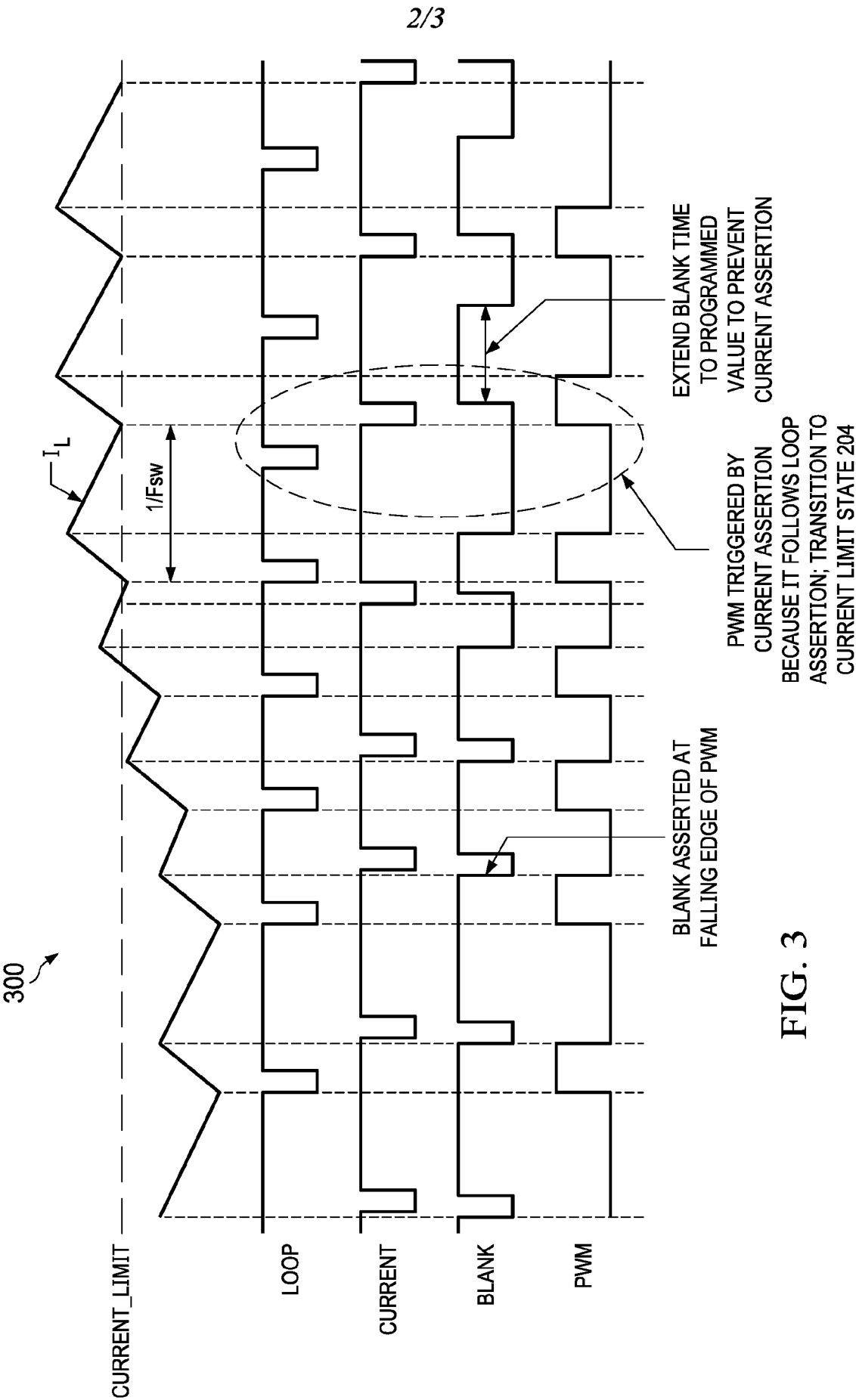
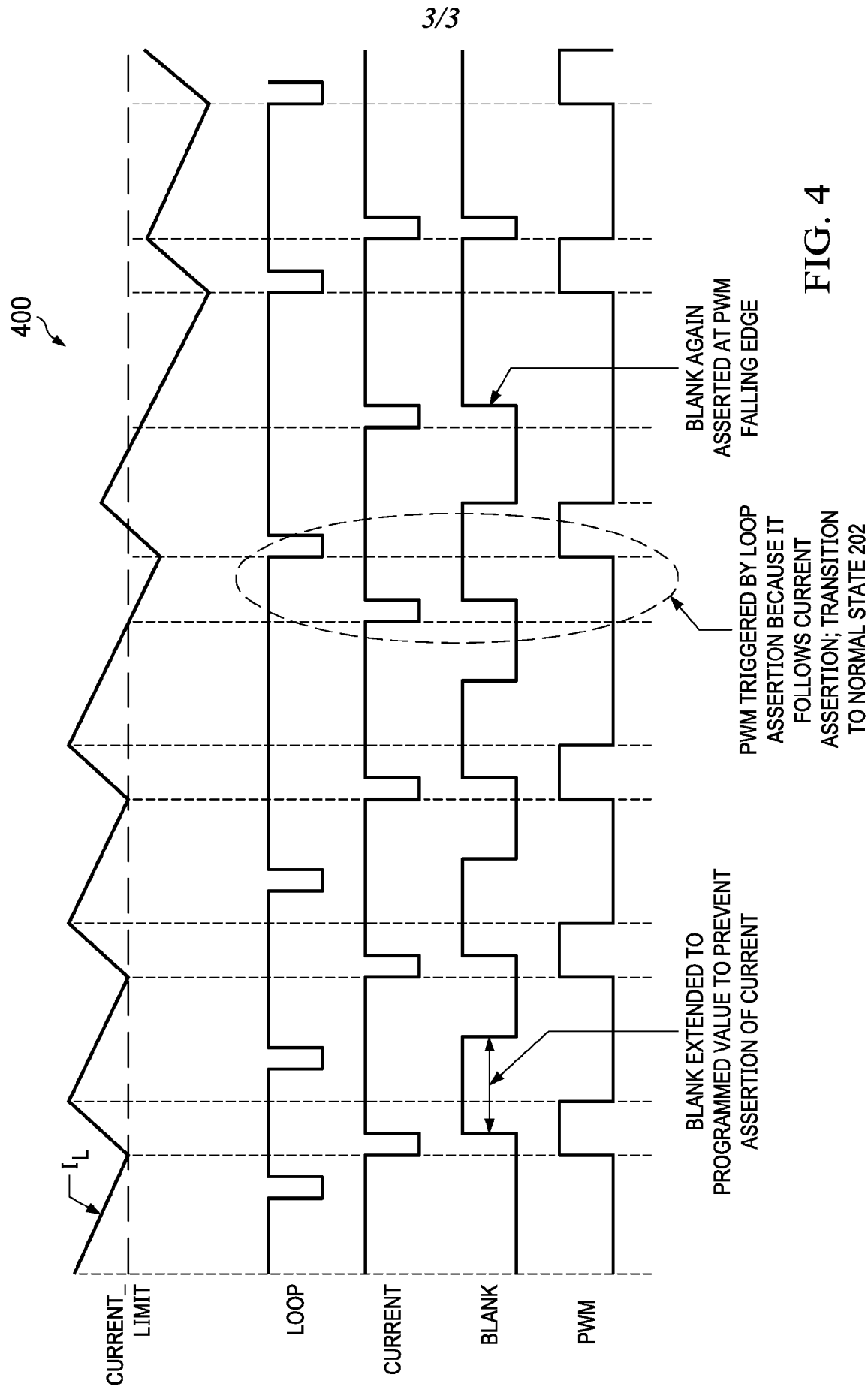


FIG. 3



INTERNATIONAL SEARCH REPORT

International application No.

PCT/US 2021/065269

A. CLASSIFICATION OF SUBJECT MATTER <i>H02M 3/156 (2006.01)</i>		
According to International Patent Classification (IPC) or to both national classification and IPC		
B. FIELDS SEARCHED		
Minimum documentation searched (classification system followed by classification symbols)		
H02M		
Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched		
Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)		
PatSearch (RUPTO internal), USPTO, PAJ, Esp@cenet, DWPI, EAPATIS, PATENTSCOPE		
C. DOCUMENTS CONSIDERED TO BE RELEVANT		
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 2020/0321872 A1 (ALPHA & OMEGA SEMICONDUCTOR CAYMAN LTD) 08.10.2020	1-20
A	US 2019/222122 A1 (APPLE INC) 18.07.2019	1-20
A	US 8686767 B1 (TEXAS INSTRUMENTS INC) 01.04.2014	1-20
☐ Further documents are listed in the continuation of Box C. ☐ See patent family annex.		
* Special categories of cited documents: “A” document defining the general state of the art which is not considered to be of particular relevance “D” document cited by the applicant in the international application “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	“T” later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention “X” document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone “Y” document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art “&” document member of the same patent family	
Date of the actual completion of the international search 06 April 2022 (06.04.2022)	Date of mailing of the international search report 28 April 2022 (28.04.2022)	
Name and mailing address of the ISA/RU: Federal Institute of Industrial Property, Berezhkovskaya nab., 30-1, Moscow, G-59, GSP-3, Russia, 125993 Facsimile No: (8-495) 531-63-18, (8-499) 243-33-37	Authorized officer S. Pudov Telephone No. 8 499 240 25 91	