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- (71) Applicant: TEXAS INSTRUMENTS INCORPORATED [US/US]; P.O. Box 655474, Mail Station 3999, Dallas, TX 75265-5474 (US).
- (71) Applicant (for JP only): TEXAS INSTRUMENTS JAPAN LIMITED [JP/JP]; 24-1, Nishi-shinjuku 6-chome, Shinjuku Tokyo, 160-8366 (JP).
- (72) Inventors: LU, Bing; 4 Baldwin Lane, Bedford, NH 03110 (US). GOERKE, Ulrich B.; 9 Snows Court, Dover, NH 03820 (US).

(74) Agents: DAVIS, Michael, A., Jr. et al.; Texas Instruments Incorporated, P.O. Box 655474, Mail Station 3999, Dallas, TX 75265-5474 (US).

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[Continued on next page]

(54) Title: VOLTAGE CONVERTER COMPENSATION APPARATUS AND METHODS

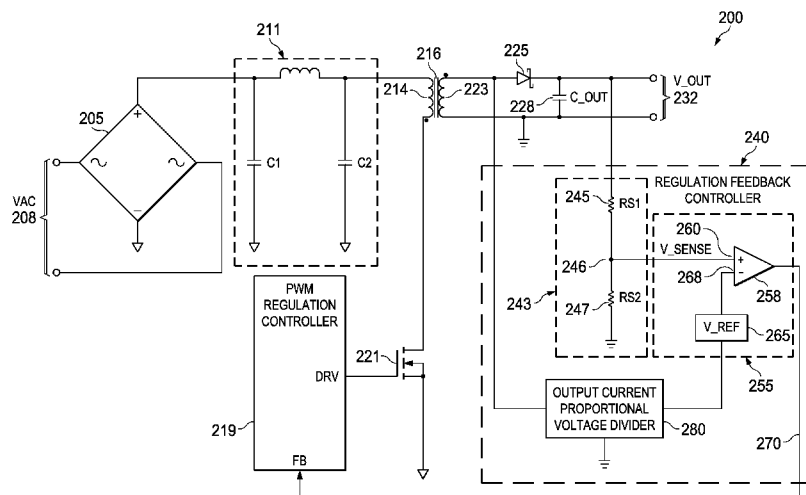


FIG. 2

(57) Abstract: In described examples, a voltage converter (200) generates an output voltage (V_OUT). A sense circuit (243) generates a sense signal (V_SENSE) proportional to the output voltage (V_OUT). A regulation feedback controller (255) determines a difference between the sense signal (V_SENSE) and a reference voltage (V_REF), and generates a negative feedback control signal that causes a pulse width modulation ("PWM") regulation controller (219) to drive the output voltage (V_OUT) closer to a set-point determined by the reference voltage (V_REF). A voltage divider (280) is coupled to a secondary winding (223) of a flyback transformer (216) to increase the reference voltage (V_REF) in proportion to a magnitude of current flow at the output of the converter (200) and to increase the set-point to compensate for a voltage drop between the converter (200) and a device powered by the converter (200).

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VOLTAGE CONVERTER COMPENSATION APPARATUS AND METHODS

[0001] This relates in general to electronic circuitry, and in particular to voltage converter compensation apparatus and methods.

BACKGROUND

[0002] Electrical power sources and the devices powered by them are generally connected by cables, which provide for current flow between the power source and the device to be powered. Modern electronic circuits are usually direct current (“DC”) powered, and the DC power supply often includes voltage regulation circuitry to provide for stable supply voltage level(s). For reasons of convenience and for ease of regulatory approval, small alternating current (“AC”)-to-DC power supplies (“converters”) that reside at the wall power outlet (“wall converters”) have become increasingly popular over the past few decades. The terms “converter,” “voltage converter,” “power converter” and “adapter” are synonymous as used herein. The principles illustrated by examples herein may apply equally to AC/DC converters and DC/DC converters.

[0003] FIG. 1 is a block diagram of a conventional power converter 110 and a device 115 powered by the converter 110. The power converter 110 may, but need not be, a wall adapter. The power converter 110 and the powered device 115 are connected by a cable 120. The cable 120 includes two or more conductors (e.g., the conductors 125 and 130). Two or more conductors 125 may be necessary in the case of a multi-voltage power converter. The conductor(s) 125 carry current 135 to the powered device 115, and the conductor 130 carries return current 140.

[0004] A resistance 145 is associated with the conductor 125, and a resistance 150 is associated with the conductor 130. The values of both resistances 145 and 150 are a function of the gauge, length, and composition of the conductors 125 and 130, respectively. Currents 135 and 140 flowing through the resistances 145 and 150, respectively, cause a voltage drop across the cable 120 proportional to the currents 135 and 140. The cable voltage drop results in the input voltage V_{PD} 160 to the powered device 115 being unequal to the regulated output voltage V_{OUT} 165 of the converter 110. The cable voltage drop may be compensated for, if the cable

resistance characteristics and powered device operating currents are known by the designers of the converter 110.

[0005] An increasingly popular type of AC/DC converter supplies a regulated universal serial bus (“USB”) level voltage of 5.0 vdc for charging of mobile phones and other portable electronic devices. Such examples of the powered device 115 employ increasingly faster and more powerful processors, and larger capacity memory devices, resulting in high current draws. The latter high current draws can result in a cable voltage drop that is significant in relation to a USB-level V_{OUT} 165 of 5.0 vdc. This situation can result in a challenge for cable voltage drop compensation at the regulation circuitry of the converter 110.

SUMMARY

[0006] In described examples, a voltage converter generates an output voltage. A sense circuit generates a sense signal proportional to the output voltage. A regulation feedback controller determines a difference between the sense signal and a reference voltage, and generates a negative feedback control signal that causes a pulse width modulation (“PWM”) regulation controller to drive the output voltage closer to a set-point determined by the reference voltage. A voltage divider is coupled to a secondary winding of a flyback transformer to increase the reference voltage in proportion to a magnitude of current flow at the output of the converter and to increase the set-point to compensate for a voltage drop between the converter and a device powered by the converter.

BRIEF DESCRIPTION OF THE DRAWINGS

[0007] FIG. 1 is a block diagram of a conventional power converter and a device powered by the converter.

[0008] FIG. 2 is a schematic diagram of an example voltage converter, including a voltage drop compensation apparatus of example embodiments.

[0009] FIG. 3 is a schematic diagram of an example voltage converter, including a voltage drop compensation apparatus of example embodiments.

[0010] FIG. 4 is a diagram of waveforms associated with an output current proportional voltage divider and averaging circuit portion of a voltage drop compensation apparatus of example embodiments.

[0011] FIG. 5 is a flow diagram of a method of voltage regulation in a flyback voltage converter that includes a voltage drop compensation apparatus of example embodiments.

DETAILED DESCRIPTION OF EXAMPLE EMBODIMENTS

[0012] FIG. 2 is a schematic diagram of an example voltage converter 200, including a voltage drop compensation apparatus 240. The voltage converter 200 is an example of an AC/DC converter. However, embodiments and methods herein apply equally to AC/DC and DC/DC converters. The example voltage converter 200 includes a bridge rectifier 205 and a voltage ripple filtering circuit 211 to supply DC voltage to a primary winding 214 of a flyback transformer 216. A pulse width modulation (“PWM”) regulation controller 219 determines an appropriate conduction duty cycle of a primary winding current control switch 221. Primary winding voltage pulses of variable width induce voltage in a secondary winding 223 of the flyback transformer 216. The secondary winding voltage is rectified by a diode 225, and the resulting DC voltage is filtered by a capacitor 228, resulting in an output voltage V_{OUT} at an output 232 of the converter 200.

[0013] The voltage drop compensation apparatus 240 includes an output voltage sense circuit 243 coupled to the output 232 of the voltage converter 200. The output voltage sense circuit 243 generates an output voltage sense signal that is proportional to the output voltage V_{OUT} generated by the voltage converter 200. In some embodiments, the output voltage sense circuit 243 may include a first voltage sense resistor 245. The first voltage sense resistor 245 may be coupled between the output 232 of the voltage converter 200 and a voltage sense input terminal 260 of a regulation feedback controller 255, such as a differential amplifier 258 and a reference voltage source 265. The output voltage sense circuit 243 may also include a second voltage sense resistor 247 coupled at a node 246 between the voltage sense input 260 of the differential amplifier 258 and a common voltage rail. The common voltage rail is generally a ground rail, but may be a voltage rail other than ground in some embodiments.

[0014] The voltage drop compensation apparatus 240 also includes the regulation feedback controller 255. The feedback controller 255 is coupled to the output voltage sense circuit 243 (e.g., at the node 246). The feedback controller 255 determines a voltage difference between the output voltage sense signal and a reference voltage. The feedback controller 255 generates a negative feedback control signal to send to the PWM regulation controller 219. The negative feedback control signal causes the PWM regulation controller 219 to drive the converter output voltage V_{OUT} closer to a set-point determined by the reference voltage.

[0015] In some embodiments, the regulation feedback controller 255 may include a differential

amplifier 258. In such case, a voltage sense input terminal 260 of the differential amplifier 258 is coupled to the output voltage sense circuit 243. An output terminal of the differential amplifier 258 is coupled to the PWM regulation controller 219. The regulation feedback controller 255 also includes a reference voltage source 265. The reference voltage source 265 is coupled between an output current proportional voltage divider 280 and a reference voltage input terminal 268 of the differential amplifier 258. The reference voltage source 265 supplies the reference voltage.

[0016] The voltage drop compensation apparatus 240 may also include an optocoupler (not shown in FIG. 2). The optocoupler is connected in series with a conductor 270 of the negative feedback control signal to galvanically isolate a primary side of the voltage converter 200 from a secondary side of the voltage converter 200.

[0017] The voltage drop compensation apparatus 240 also includes an output current proportional voltage divider 280. The output current proportional voltage divider 280 is coupled to the secondary winding 223 of the flyback transformer 216. In some embodiments, the output current proportional voltage divider 280 may also be coupled to a common voltage rail including a ground rail. The voltage divider 280 increases the reference voltage at the input terminal 268 in proportion to a magnitude of current flow at the output 232 of the converter 200. This increases the output voltage set-point of the converter 200 to compensate for a voltage drop between the converter 200 and a device powered by the converter 200 (e.g., the powered device 115 of FIG. 1). The voltage drop may occur across a cable connecting the converter 200 and the powered device 115.

[0018] FIG. 3 is a schematic diagram of an example flyback voltage converter 300, including a voltage drop compensation apparatus 340. The example voltage converter 300 includes a bridge rectifier 205, a voltage ripple filtering circuit 211, a primary winding 214 of a flyback transformer 216, a PWM regulation controller 219, a primary winding current control switch 221, a secondary winding 223, a diode 225, a filtering capacitor 228, and an output 232, all as previously described with respect to the voltage converter 200 of FIG. 2.

[0019] The voltage converter 300 also includes a voltage drop compensation apparatus. The voltage drop compensation apparatus includes an output voltage sense circuit 243 to generate an output voltage sense signal proportional to the output voltage V_{OUT} as previously described with respect to the voltage converter 200 of FIG. 2. Some embodiments of the voltage sense

circuit 243 include first and second voltage sense resistors 245 and 247, respectively. The first and second voltage sense resistors 245 and 247 are coupled in series between the output 232 of the voltage converter 300 and a common voltage rail, such as a ground rail. A junction node 246 of the first and second voltage sense resistors 245 and 247 is coupled to a reference input terminal 315 of a regulation device 310. In some embodiments, the regulation device 310 may be a shunt regulator, such as a TL431.

[0020] The regulation device 310 determines a voltage difference between the output voltage sense signal and an internal reference voltage. The regulation device 310 generates a negative feedback control signal that is proportional to the voltage difference. The negative feedback control signal causes the PWM regulation controller 219 to drive the converter output voltage V_{OUT} closer to a set-point determined by the reference voltage. In some embodiments, the voltage drop compensation apparatus also includes an optocoupler. A light-emitting element 330 of the optocoupler is communicatively coupled in series between the regulation device 310 and the output 232 of the voltage converter 300. The optocoupler couples a galvanically isolated version of the negative feedback control signal as light energy to an optical receiver portion 332 of the optocoupler configured at the PWM regulation controller 219.

[0021] The voltage drop compensation apparatus also includes an output current proportional voltage divider and averaging circuit 340. The circuit 340 is coupled to the secondary winding 223 of the flyback transformer 216. The circuit 340 increases the reference voltage in proportion to current flow at the output 232 of the voltage converter 300. This increases the converter output voltage set-point to compensate for a voltage drop between the converter 300 and a device powered by the converter 300 (e.g., the powered device 115 of FIG. 1). The voltage drop may occur across a cable connecting the converter 300 and the powered device 115d.

[0022] FIG. 4 is a diagram of waveforms associated with the circuit 340. Referring also to FIG. 3, a voltage divider portion of the circuit 340 includes a compensation diode 343. The compensation diode 343 is anode-coupled to the secondary winding 223 of the flyback transformer 216. The compensation diode 343 directs current flow in a forward direction from the secondary winding 223.

[0023] The top waveform of FIG. 4 illustrates current pulses 405 traversing the secondary winding 223. The PWM regulation controller 219 determines the peak current 410 and adjusts the duty cycle of the primary (and thus secondary) winding current pulses 405. The duty cycle is

defined as the pulse length 415 divided by the PWM cycle period 435. The middle waveform of FIG. 4 illustrates voltage pulses 420 at a nodal junction 365 of the cathode of the compensation diode 343 and a terminal of a first compensation resistor 345. The pulse length 415 of the cathode voltage pulses 420 corresponds to the pulse length 415 of the secondary current pulses 405. The peak voltage 425 of the cathode voltage pulses 420 is equal to the output voltage V_{OUT} of the converter 300, plus the voltage drop across the rectifying diode 225, minus the voltage drop across the compensation diode 343. The peak voltage 425 is approximately equal to V_{OUT} , because the voltage drops across the two diodes 225 and 343 are approximately equal (but of opposite polarity) and effectively cancel each other in determining the peak voltage 425.

[0024] The voltage divider portion of the circuit 340 also includes the first compensation resistor 345. A first terminal of the first compensation resistor 345 is coupled to a cathode of the compensation diode 343. The voltage divider portion of the circuit 340 further includes a second compensation resistor 348. The second compensation resistor 348 is coupled in series between the first compensation resistor 345 and a common voltage node (e.g., a ground terminal).

[0025] A voltage division node 370 is located at a junction of the first and second compensation resistors 345 and 348, respectively. The voltage division node 370 is coupled to a terminal of a reference voltage source (not shown in FIG. 3) associated with the regulation device 310. In the example case of a shunt regulation device (such as a TL431), the reference voltage source is located internally to the regulation device 310. The voltage generated at the voltage division node 370 is additive to the reference voltage generated by the reference voltage source. Accordingly, the voltage divider portion of the circuit 340 increases the total reference voltage of the regulation device 310 by a magnitude of the voltage generated at the voltage division node 370.

[0026] An averaging circuit portion 355 of the circuit 340 includes a compensation capacitor 358. The compensation capacitor 358 is coupled in parallel with the second compensation resistor 348 to create a resistor-capacitor (“RC”) low-pass filter. The averaging circuit 355 averages a voltage-divided version of the rectangular voltage waveform pulses 420 of FIG. 4 appearing at the node 365. The voltage-divided version of each voltage pulse 420 is averaged over the PWM cycle period 435 to generate a continuous DC offset voltage 430 at the voltage division node.

[0027] FIG. 5 is a flow diagram of a method 500 of voltage regulation in a flyback voltage converter that includes a voltage drop compensation apparatus of example embodiments. Such apparatus implement a negative feedback converter output voltage control loop. The method 500 is associated with a regulation device communicatively coupled to a converter output voltage sense circuit and to a PWM regulation controller portion of the voltage converter. The method 500 includes increasing a reference voltage by a magnitude of a variable compensation offset voltage proportional to a magnitude of current flow at a converter output to generate a compensated reference voltage. Compensating the reference voltage as described increases the converter output voltage set-point. This compensates for a voltage drop in a cable used for coupling the converter to a device powered by the converter.

[0028] The method 500 commences at block 505 with sensing a rectangular voltage waveform at a secondary winding of a flyback transformer associated with the flyback voltage converter. The rectangular voltage waveform has a duty cycle equal to a duty cycle of a waveform of a pulsed current flowing through the secondary winding as determined by the PWM regulation controller. The rectangular voltage waveform also has a peak voltage magnitude that is proportional to the converter output voltage.

[0029] At block 510, the rectangular voltage waveform is averaged over a PWM cycle period to generate a DC offset voltage. At block 515, the DC offset voltage is voltage-divided by a selected ratio to generate the variable compensation offset voltage.

[0030] At block 520, an output voltage sense signal is generated, proportional to an output voltage generated by the voltage converter. At block 525, a difference is determined between a magnitude of the output voltage sense signal and the compensated reference voltage at the regulation device. At block 530, a negative feedback control signal is generated, proportional to the voltage difference.

[0031] At block 535, the negative feedback control signal is received at the PWM regulation controller. At block 540, some versions of the method 500 include driving a light-emitting element associated with an optocoupler configured between the regulation device and the PWM regulation controller using the negative feedback control signal. This galvanically isolates a primary side of the flyback voltage converter from a secondary side of the converter.

[0032] At block 545, the converter output voltage is driven closer to a set-point determined by the compensated reference voltage to decrease a magnitude of the voltage difference. The

method 500 continues indefinitely by looping from block 545 to block 505.

[0033] Apparatus and methods described herein may be useful in applications other than compensating voltage converter output voltage levels for voltage drops across cables connecting a voltage converter to a device to be powered. The apparatus 200 and 300 and the method 500 provide a general understanding of the sequences of various methods and the structures of various embodiments.

[0034] The various embodiments may be incorporated into semiconductor analog and digital circuits for use in receptacle power converters, electronic circuitry used in computers, communication and signal processing circuitry, single-processor or multi-processor modules, single or multiple embedded processors, multi-core processors, data switches, and application-specific modules including multi-layer and multi-chip modules, among others. Such apparatus and systems may further be included as subcomponents within a variety of electronic systems, such as robotics, medical devices (e.g., heart monitor, blood pressure monitor), motor vehicles, televisions, cellular telephones, personal computers (e.g., laptop computers, desktop computers, handheld computers, tablet computers), workstations, radios, video players, audio players (e.g., MP3 (Moving Picture Experts Group, Audio Layer 3) players), set top boxes, household appliances and others.

[0035] Accordingly, structures and methods disclosed herein include a compensation diode and a voltage divider with an averaging circuit to generate an output current-compensated reference voltage that is proportional to regulator output current. The current compensation reference voltage is added to the regulation feedback controller reference voltage, which adjusts the negative feedback signal to the PWM regulation controller in proportion to the converter output current draw. The net effect is to increase the converter output voltage in proportion to the converter output current draw as compensation for the voltage drop in the cable connecting the converter to the powered device. More precisely-regulated voltage levels may be delivered to an input of the powered device.

[0036] Apparatus disclosed herein are applicable to voltage regulation circuits in “flyback” type PWM AC/DC and DC/DC switching voltage converters. Flyback converters include a flyback transformer to receive variable duty cycle current pulses through the primary winding of the transformer. As used herein, the term “flyback converter” includes a voltage converter that adjusts the width and/or duty cycle of pulses conducted through the primary side winding of a

transformer, in order to control the voltage waveform generated at the secondary winding, such that the duty cycle of the voltage waveform at the secondary side winding is proportional to the converter output current.

[0037] A flyback voltage converter may employ primary side regulation or secondary side regulation. As used herein, “primary side” includes circuitry directly or indirectly connected to the transformer primary winding or to an auxiliary winding referenced to the primary winding. “Secondary side” includes circuitry directly or indirectly connected to the transformer secondary winding. In primary side regulation, secondary voltage is sensed with an auxiliary transformer winding and compared to a primary side reference voltage. A resulting difference signal is fed back to a PWM regulation controller to adjust the primary winding drive pulse width and/or duty cycle for voltage regulation purposes. In secondary side regulation, the rectified and filtered converter output voltage is sensed and compared to a secondary side reference voltage. A resulting difference signal is fed back to the PWM regulation controller to adjust the primary winding drive pulse.

[0038] Apparatus disclosed herein are applicable to secondary side regulated flyback voltage converters. Often, secondary side regulation is more precise, because the actual DC output voltage is used for creating the voltage control feedback signal. However, measures of regulator output current are useful to determine actual interconnection cable voltage drop and the corresponding regulated output voltage compensation. Output current may be measured by measuring the voltage drop across a resistor in series with the regulator output. However, such a series resistor adds cost as an external component, consumes power, and generates heat and is undesirable.

[0039] Converter output voltage is sensed across a voltage divider connected between the converter output and ground or other sensing circuit. A regulation device (such as a TL431) or circuit (“regulation feedback controller”) compares the sensed output voltage to a reference voltage. The regulation feedback controller generates a negative feedback control signal representing the difference between the sensed regulator output voltage and the reference voltage. The negative feedback control signal is routed back to the PWM regulation controller to adjust the primary current pulse width and/or duty cycle. The current pulse is adjusted in a direction that causes the magnitude of the sensed output voltage to be driven toward the magnitude of the reference voltage. In some embodiments, the regulation feedback controller

may drive an optocoupler to electrically isolate the primary and secondary side circuitry.

[0040] A compensation diode and a voltage divider with an averaging circuit generate a current compensation reference voltage that is proportional to regulator output current averaged over a PWM cycle. The current compensation reference voltage is added to the regulation feedback controller reference voltage, which adjusts the negative feedback signal to the PWM regulation controller in proportion to the converter output current draw. The net effect is to increase the converter output voltage in proportion to the converter output current draw as compensation for the voltage drop in the cable connecting the converter to the powered device.

[0041] Modifications are possible in the described embodiments, and other embodiments are possible, within the scope of the claims.

CLAIMS

What is claimed is:

1. A voltage drop compensation apparatus associated with voltage regulation in a flyback voltage converter, the apparatus comprising:

an output voltage sense circuit to couple to an output of the voltage converter to generate an output voltage sense signal proportional to an output voltage generated by the voltage converter;

a regulation feedback controller coupled to the output voltage sense circuit to determine a voltage difference between the output voltage sense signal and a reference voltage and to generate a negative feedback control signal to send to a pulse width modulation (“PWM”) regulation controller, the negative feedback control signal being to cause the PWM regulation controller to drive the converter output voltage closer to a set-point determined by the reference voltage; and

an output current proportional voltage divider to couple to a secondary winding of a flyback transformer associated with the voltage converter to increase the reference voltage in proportion to a magnitude of current flow at the output of the converter and to increase the converter output voltage set-point to compensate for a voltage drop between the converter and a device powered by the converter.

2. The apparatus of claim 1, wherein the voltage drop between the converter and the device powered by the converter is a connecting cable voltage drop.

3. The apparatus of claim 1, wherein the regulation feedback controller includes:

a differential amplifier with: a voltage sense input terminal coupled to the output voltage sense circuit; and an output terminal to couple to the PWM regulation controller; and

a reference voltage source coupled between the output current proportional voltage divider and a reference voltage input terminal of the differential amplifier to supply the reference voltage.

4. The apparatus of claim 3, wherein the output voltage sense circuit includes:

a first voltage sense resistor coupled between the output of the voltage converter and the voltage sense input terminal of the differential amplifier; and

a second voltage sense resistor coupled between the voltage sense input of the differential amplifier and a common voltage rail.

5. The apparatus of claim 4, wherein the common voltage rail is a ground rail.
6. The apparatus of claim 1, wherein the output current proportional voltage divider is to couple to a common voltage rail.
7. The apparatus of claim 1, further comprising:
 - an optocoupler coupled in series with a conductor of the negative feedback control signal to galvanically isolate a primary side of the voltage converter from a secondary side of the voltage converter.
8. A voltage drop compensation apparatus associated with voltage regulation in a flyback voltage converter, the apparatus comprising:
 - an output voltage sense circuit to couple to an output of the voltage converter to generate an output voltage sense signal proportional to an output voltage generated by the voltage converter;
 - a regulation device coupled to the output voltage sense circuit to determine a voltage difference between the output voltage sense signal and a reference voltage and to generate a negative feedback control signal proportional to the voltage difference, the negative feedback control signal being to cause a pulse width modulation (“PWM”) regulation controller to drive the converter output voltage closer to a set-point determined by the reference voltage; and
 - an output current proportional voltage divider and averaging circuit to couple to a secondary winding of a flyback transformer associated with the voltage converter to increase the reference voltage in proportion to current flow at the output of the voltage converter, in order to increase the converter output voltage set-point to compensate for a voltage drop in a cable to couple the converter output to a device powered by the converter.
9. The apparatus of claim 8, wherein the regulation device is a TL431 shunt regulator.
10. The apparatus of claim 8, wherein a voltage divider portion of the output current proportional voltage divider and averaging circuit includes:
 - a compensation diode anode-coupled to the secondary winding of the flyback transformer to direct current flow in a forward direction from the secondary winding;
 - a first compensation resistor with a first terminal coupled to a cathode of the compensation diode; and
 - a second compensation resistor coupled in series between the first compensation resistor and a common voltage node, a voltage division node at the junction of the first and second

compensation resistors being coupled to a terminal of a reference voltage source associated with the regulation device, in order to increase the reference voltage by a magnitude of a continuous direct current (“DC”) voltage generated at the voltage division node.

11. The apparatus of claim 10, wherein an averaging circuit portion of the output current proportional voltage divider and averaging circuit includes:

a compensation capacitor coupled in parallel with the second compensation resistor to create a resistor-capacitor (“RC”) low-pass filter, the low-pass filter being to average a voltage-divided version of a series of rectangular voltage pulses appearing at a node between the cathode of the compensation diode and the first terminal of the first compensation resistor, a duration T of each rectangular voltage pulse being equal to a duration T of each of a series of current pulses flowing in the secondary winding as determined by the PWM regulation controller, the averaging circuit being to average the voltage-divided version of each rectangular voltage pulse over a PWM cycle period P to generate the continuous DC voltage at the voltage division node.

12. The apparatus of claim 8, further comprising:

an optocoupler, wherein a light-emitting element of the optocoupler is communicatively coupled in series between the regulation device and the output of the voltage converter to couple a galvanically isolated version of the negative feedback control signal as light energy to an optical receiver portion of the optocoupler configured at the PWM regulation controller.

13. The apparatus of claim 8, wherein the output voltage sense circuit includes:

a first voltage sense resistor coupled between the output of the voltage converter and a reference input terminal of the regulation device; and

a second voltage sense resistor coupled between the reference input terminal of the regulation device and a common voltage rail.

14. A method of voltage regulation in a flyback voltage converter, the method comprising:

at a regulation device communicatively coupled to a converter output voltage sense circuit and to a pulse width modulation (“PWM”) regulation controller portion of the voltage converter to implement a negative feedback converter output voltage control loop, increasing a reference voltage by a magnitude of a variable compensation offset voltage proportional to a magnitude of current flow at a converter output to generate a compensated reference voltage, in order to increase a converter output voltage set-point to compensate for a voltage drop in a cable

used for coupling the converter to a device powered by the converter.

15. The method of claim 14, further comprising:

sensing a rectangular voltage waveform at a secondary winding of a flyback transformer associated with the flyback voltage converter, the rectangular voltage waveform having a duty cycle equal to a duty cycle of a waveform of a current flowing through the secondary winding as determined by the PWM regulation controller and having a peak voltage magnitude proportional to a peak current magnitude of the secondary current waveform.

16. The method of claim 15, further comprising:

averaging the rectangular voltage waveform over a PWM cycle period to generate a direct current ("DC") offset voltage; and

voltage-dividing the DC offset voltage by a selected ratio to generate the variable compensation offset voltage.

17. The method of claim 14, further comprising:

generating an output voltage sense signal proportional to an output voltage generated by the voltage converter.

18. The method of claim 17, further comprising:

at the regulation device, determining a voltage difference between a magnitude of the output voltage sense signal and the compensated reference voltage; and

generating a negative feedback control signal proportional to the voltage difference.

19. The method of claim 18, further comprising:

at the PWM regulation controller, receiving the negative feedback control signal; and driving the converter output voltage closer to a set-point determined by the compensated reference voltage to decrease a magnitude of the voltage difference.

20. The method of claim 19, further comprising:

driving a light-emitting element of an optocoupler configured between the regulation device and the PWM regulation controller using the negative feedback control signal, in order to galvanically isolate a primary side of the flyback voltage converter from a secondary side of the converter.

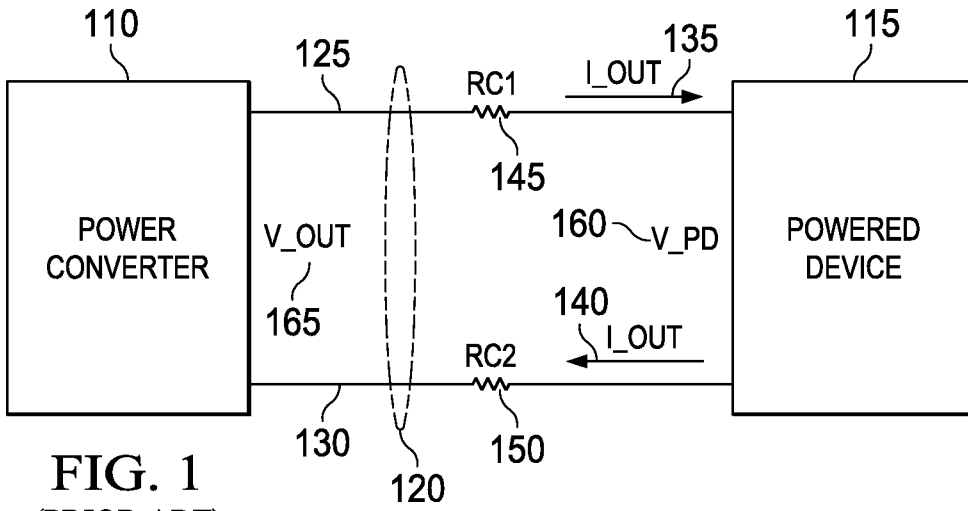


FIG. 1
(PRIOR ART)

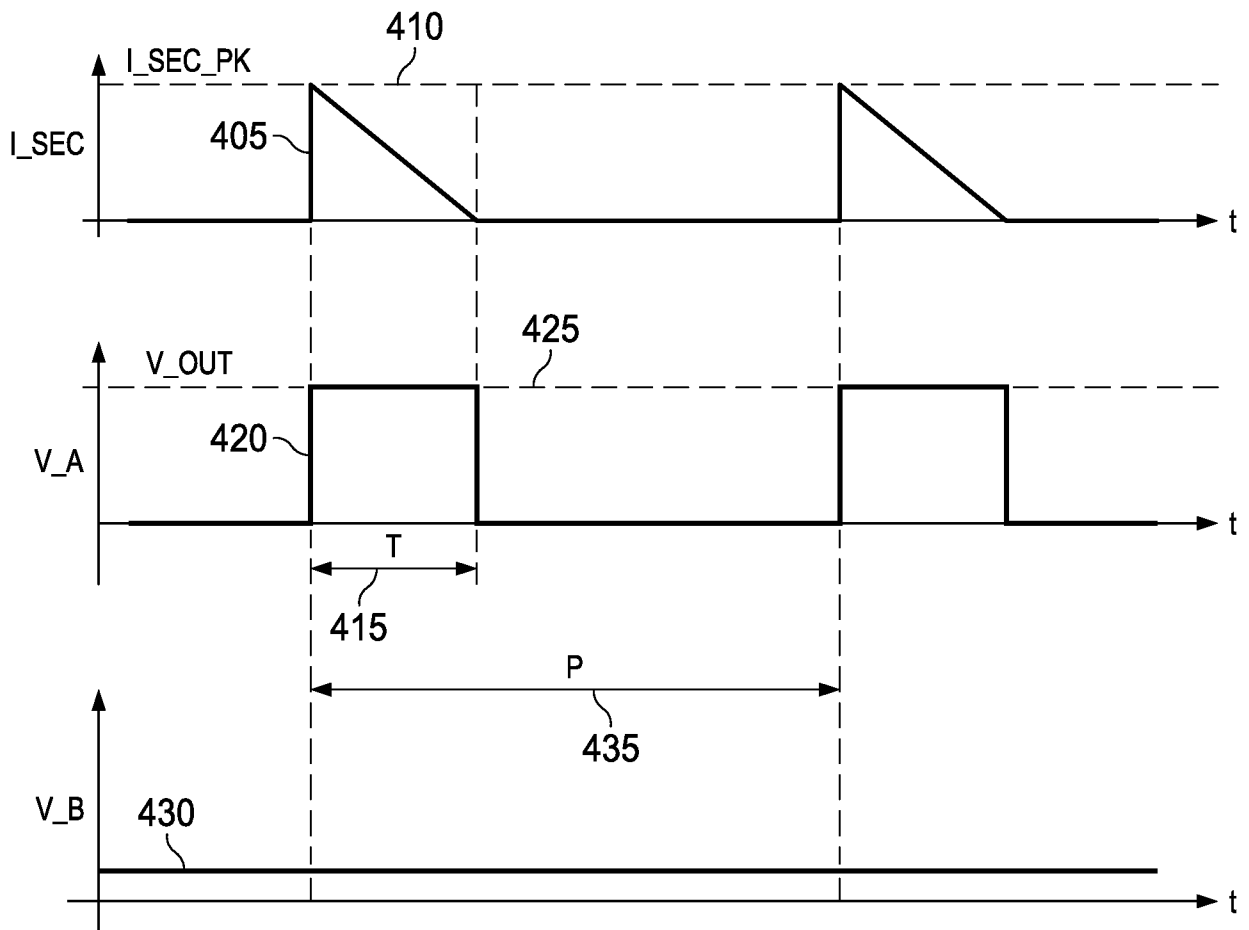


FIG. 4

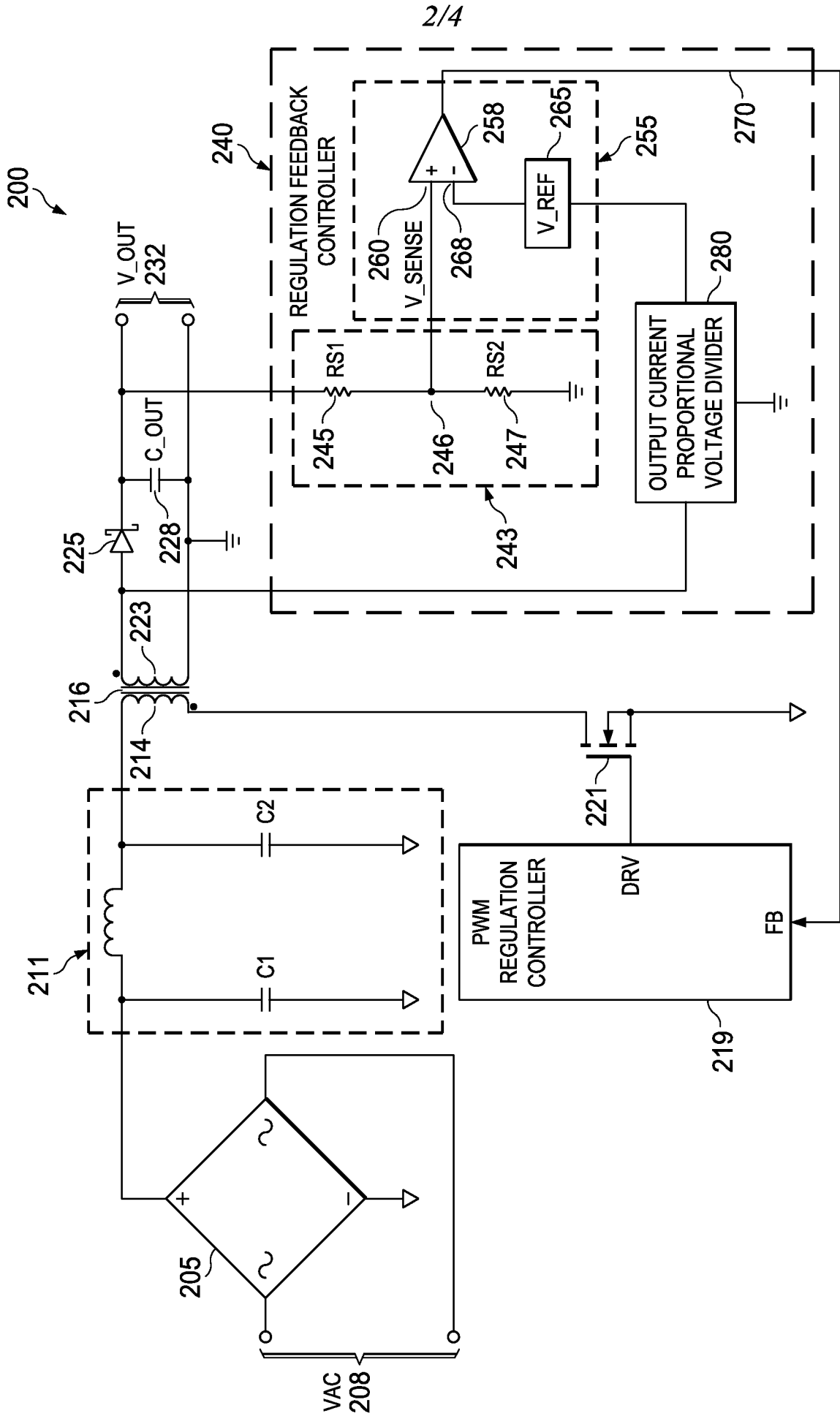


FIG. 2

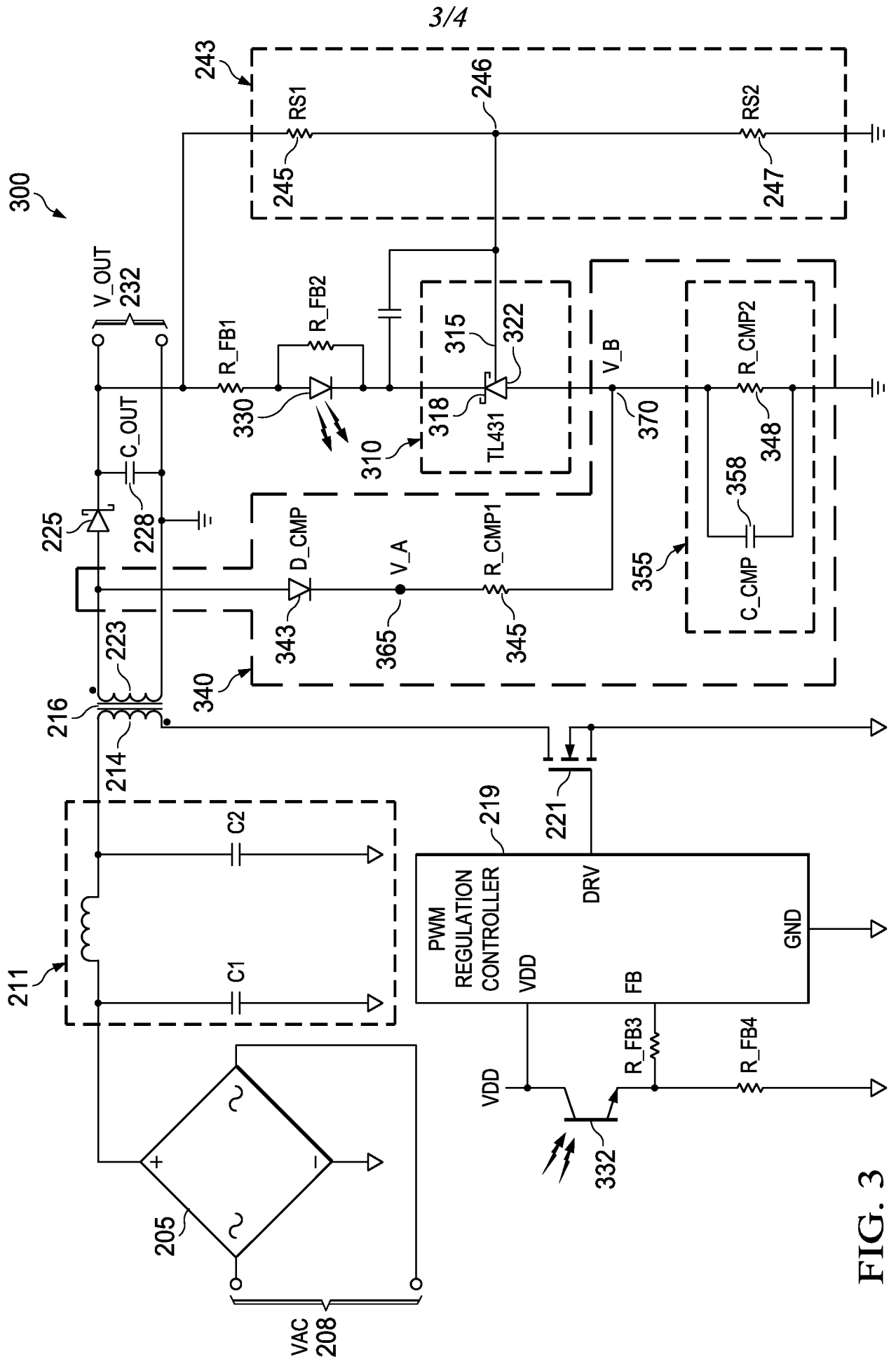


FIG. 3

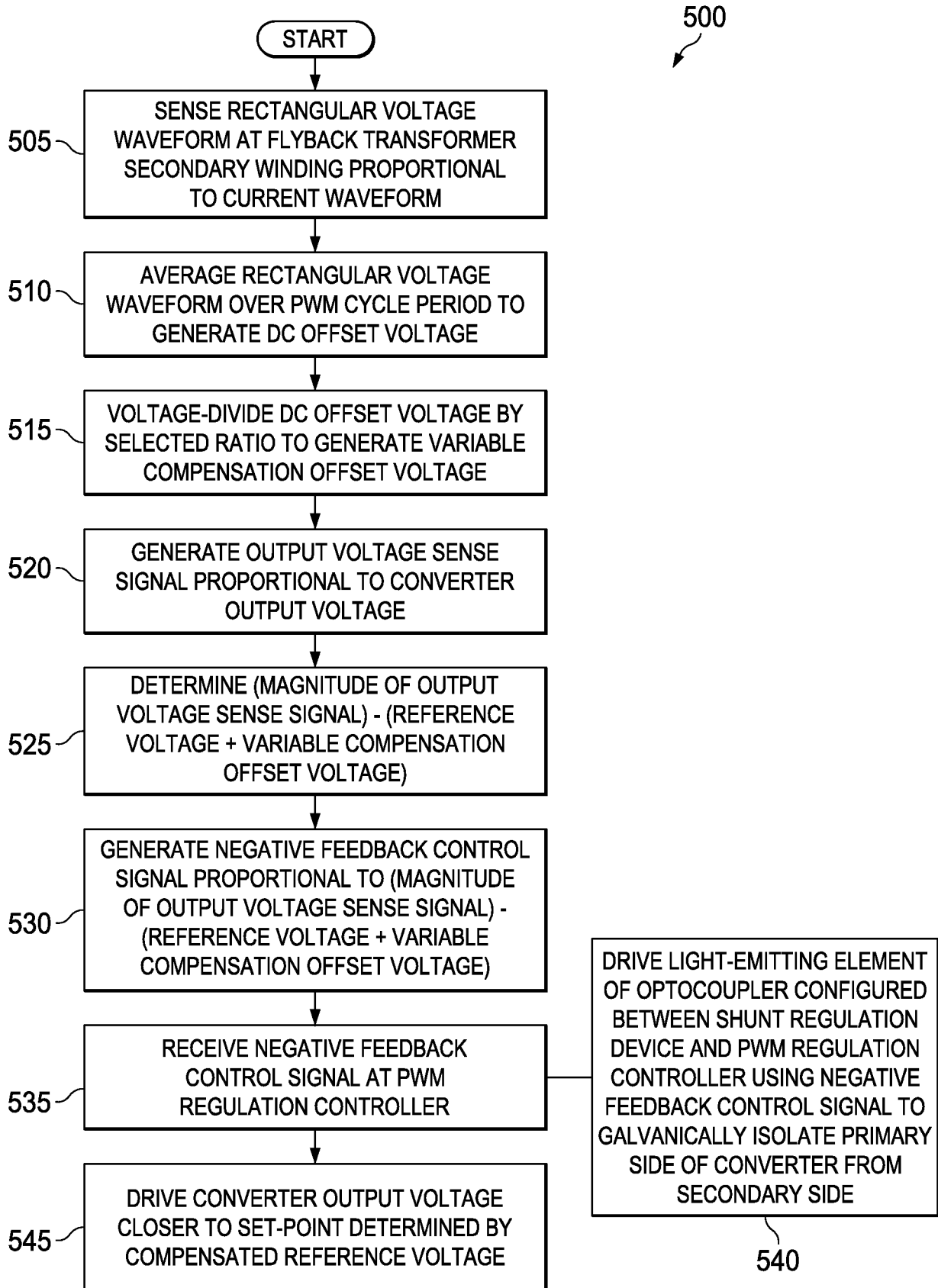


FIG. 5

INTERNATIONAL SEARCH REPORT

International application No.

PCT/US 2014/048661

A. CLASSIFICATION OF SUBJECT MATTER

G05F 1/565 (2006.01)

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)

G05F 1/565, H02M 1/156, 3/335

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, Information Retrieval System of FIPS

C. DOCUMENTS CONSIDERED TO BE RELEVANT

| Category* | Citation of document, with indication, where appropriate, of the relevant passages | Relevant to claim No. |
|-----------|--|---------------------------------|
| Y A | RU 2260833 C1 (OTKRYTOE AKTSIONERNOE OBSHESTVO "RAMENSKOE PRIBOROSTROITELNOE KONSTRUKTORSKOE BYURO" (OAO "RPKB")) 20.09.2005, fig. 1, p. 5, lines 40-41, 45-53, p. 7, lines 5-20 | 1, 2, 6-9, 12-20 3-5, 10, 11 |
| Y | US 2012/0002451 A1 (POWER INTEGRATIONS, INC.) 05.01.2012, fig. 2, [0006], [0033], [0040] | 1, 2, 6-9, 12-20 |
| Y | US 2013/0155724 A1 (POWER INTEGRATIONS, INC.) 20.06.2013, fig. 1, [0025]-[0026] | 1, 2, 6-9, 12-20 |

 Further documents are listed in the continuation of Box C. See patent family annex.

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| * Special categories of cited documents: | "T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention |
| "A" document defining the general state of the art which is not considered to be of particular relevance | "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 |
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| "P" document published prior to the international filing date but later than the priority date claimed | |

Date of the actual completion of the international search

02 December 2014 (02.12.2014)

Date of mailing of the international search report

25 December 2014 (25.12.2014)

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

I. Golovinova

Telephone No. 499-240-25-91