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(54) **Title:** REVERSE POWER FEED (RPF) POWER SUPPLY UNIT (PSU) AND ASSOCIATED METHOD OF USE

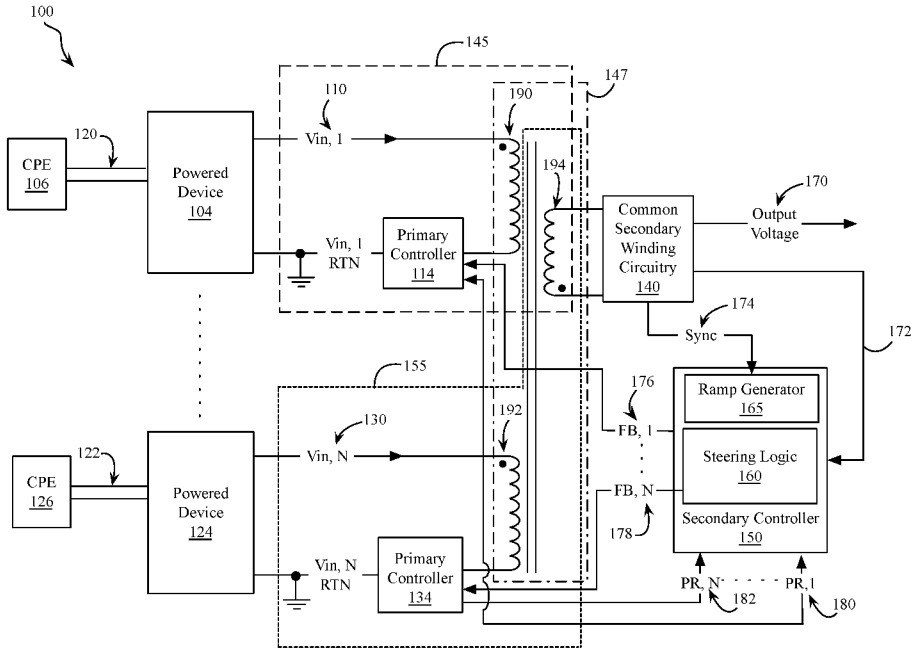


FIG. 1

(57) **Abstract:** A reverse power feeding (RPF) power supply unit (PSU) for remote network distribution point unit (DPU) that is reverse powered from multiple customer premise equipments (CPUs). A plurality of power converters, each having a different primary winding and sharing a common secondary winding of a transformer at the PSU, wherein only one of the power converters is operated at a time to provide a desired output voltage.

[Continued on next page]

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REVERSE POWER FEED (RPF) POWER SUPPLY UNIT (PSU) AND ASSOCIATED METHOD OF USE

TECHNICAL FIELD

[0001] The invention relates generally to the field of reverse power feeding and particularly to a power supply unit that is reverse power fed from customer premises equipment.

BACKGROUND OF THE INVENTION

[0002] Various communication standards, including digital subscriber line (xDSL), very-high-bit-rate digital subscriber line 2 (VDSL2), G.hn, and G.fast, have been developed to provide high-speed data transmission from a service provider (e.g., a central office) to a customer premise over existing twisted-pair copper wiring conventionally used for landline telephone service. Additionally, service providers have increased data bandwidth by installing fiber optic cabling between the central office and a distribution point (DPU) located closer to the customer premise. A particular DPU may interface with a bundle of twisted pairs to service a relatively small number of customer premise connections. This approach shortens the length of the copper pair between the CO interface at the DPU and the customer, thereby allowing increased data rates. As such, the DPU provides telephony and/or data to one or more customer premises equipment (CPE).

[0003] One difficulty arising from an optical connection between the central office and the DPU lies in the challenge of providing a source of power for the DPU. Since the DPU is

positioned at a remote location from the central office, a local power supply for the DPU is often unavailable or expensive to install.

[0004] Power for a DPU may be provided by a reverse power feeding (RPF) power supply unit (PSU), wherein power is supplied to the DPU from the PSU by converting power received from the various CPEs for which telephony and/or data services are provided by the DPU. A standard for reverse power feeding is provided by ETSI and the Broadband World Forum. In accordance with the standards, a PSU in the DPU may combine power contributions from multiple CPEs to power a main distribution unit (MDU) that handles the voice and data communications. In this arrangement, the CPEs provide the power to the remote DPUs over the twisted-pair copper wiring by performing power conversion at the PSU of the DPU.

[0005] While solutions currently exist that allow the DPU to draw its power from the customer premises equipment using the copper lines, the currently known PSUs for powering the DPU are bulky and expensive. Known PSUs utilize up to 16 independent converters, each power converted associated with a particular CPE, each one requiring its own power transformer, power switch and pulse width modulation (PWM) logic, in addition to a large number of analog components and optocouplers to draw power from the copper lines and to provide fair power sharing between the CPEs, while also insuring full galvanic isolation between the converters.

[0006] Accordingly, what is needed in the art is an improved power supply unit (PSU) for a distribution point unit (DPU) implementing reverse power feeding (RPF) which is smaller and more cost effective than the PSUs currently known in the art.

SUMMARY OF THE INVENTION

[0007] In accordance with various embodiments of the present invention, an improved reverse power feeding (RPF) power supply unit (PSU) is provided. The PSU may be located in a remote network distribution point unit (DPU) node and is reverse powered by multiple customer premise equipment (CPE) devices.

[0008] In one embodiment, the present invention provides a reverse power feed (RPF) power supply unit (PSU) which includes a plurality of power converters. The PSU includes at least one transformer comprising a plurality of primary windings and one secondary winding that is shared by the plurality of power converters. Each of the plurality of power converters of the PSU of the present invention includes, the secondary winding, one of the primary windings of the at least one transformer, a primary controller coupled to the one primary winding, a power port coupled to the one primary winding, the power port to provide an input voltage to be converted to an output voltage at the shared secondary winding and a secondary controller coupled to each of the plurality of power converters, the secondary controller for activating one of the power converters having an input voltage present at its power port when an input voltage is present at the power port of two or more of the plurality of power converters sharing the common secondary winding.

[0009] In one embodiment, the PSU of the present invention further includes a delay circuitry and an observer circuitry for preventing more than one of the power converters having an input voltage at its power port from being simultaneously activated.

[0010] In another embodiment, the secondary controller comprises steering logic for providing a feedback signal to each of the power converters having an input voltage present at its

power port to implement a time division multiplexing (TDM) scheme to activate each of the independent power converters for a substantially equivalent period of time.

[0011] In an additional embodiment, the present invention provides a method for operating a reverse power feed (RPF) power supply unit (PSU) which includes, activating only one of a plurality of power converters of the PSU having an input voltage present at its power port when an input voltage is present at a power port of two or more of the plurality of independent power converters, wherein only one of the power converters is activated at a time. In this embodiment, the PSU include at least one transformer having a plurality of primary windings and one secondary winding and each of the plurality of independent power converters of the PSU comprises the one secondary winding, one of the plurality of primary windings coupled to the power port and a primary controller coupled to the primary winding. The method further includes, converting the input voltage at the primary winding of the activated power converter to an output voltage at the shared secondary winding.

[0012] Accordingly, the present invention provides and improved power supply unit (PSU) for a distribution point unit (DPU) implementing reverse power feeding (RPF) which is smaller and more cost effective than the PSUs currently known in the art.

BRIEF DESCRIPTION OF THE DRAWINGS

[0013] The accompanying drawings, which are incorporated in and form a part of this specification, illustrate various embodiments and, together with the Description of Embodiments, serve to explain principles discussed below. The drawings referred to in

this brief description should not be understood as being drawn to scale unless specifically noted.

[0014] FIG. 1 is a block diagram illustrating a reverse power feeding (RPF) power supply unit (PSU), in accordance with an embodiment of the present invention.

[0015] FIG. 2 is a block diagram illustrating a primary controller of the RPF PSU, in accordance with an embodiment of the present invention.

[0016] FIG. 3 is a block diagram illustrating a secondary controller of the RPF PSU, in accordance with an embodiment of the present invention.

[0017] FIG. 4A is a diagram illustrating a time division multiplexing (TDM) scheme for the delay circuitry of the power converters, in accordance with an embodiment of the present invention.

[0018] FIG. 4B is a diagram illustrating the behavior of the observer circuitry of the power converters, in accordance with an embodiment of the present invention.

[0019] FIG. 5 is a flow diagram illustrating a method operating a reverse power feeding (RPF) power supply unit (PSU), in accordance with an embodiment of the present invention.

[0020] **DETAILED DESCRIPTION OF THE INVENTION**

[0021] Reference will now be made in detail to various embodiments, examples of which are illustrated in the accompanying drawings. While various embodiments are discussed herein, it will be understood that they are not intended to be limiting. On the contrary, the presented embodiments are intended to cover alternatives, modifications, and equivalents, which may be included within the spirit and scope of the various embodiments as defined by the appended claims. Furthermore, in this Detailed

Description of the Invention, numerous specific details are set forth in order to provide a thorough understanding. However, embodiments may be practiced without one or more of these specific details. In other instances, well known methods, procedures, components, and circuits have not been described in detail as not to unnecessarily obscure aspects of the described embodiments.

[0022] It will be understood that, although the terms first, second, third, etc., may be used herein to describe various elements, components, regions, layers, and/or sections, these elements, components, regions, layers, and/or sections should not be limited by these terms. These terms are only used to distinguish one element, component, region, layer, or section from another region, layer, or section. Thus, a first element, component, region, layer, or section discussed below could be termed a second element, component, region, layer, or section without departing from the teachings of the present invention.

[0023] Unless otherwise defined, all terms (including technical and scientific terms) used herein have the same meaning as commonly understood by one of ordinary skill in the art to which the present invention belongs. It will be further understood that terms, such as those defined in commonly used dictionaries, should be interpreted as having a meaning that is consistent with their meaning in the context of the relevant art and will not be interpreted in an idealized or overly formal sense unless expressly so defined herein.

[0024] In accordance with various embodiments of the present invention, an improved reverse power feed (RPF) power supply unit (PSU), having a reduced size and a smaller number of required components, is provided. In general, the PSU of the present invention allows a number of independent converters to share a common magnetic core. Due to the limited size of the magnetic core, precautions are preferably implemented to guarantee that not

more than one of the independent converters is operational at the same time. Additionally, if more than one of the independent converters has an input voltage present at its power port, the power between the active power ports should be equally shared. In a particular embodiment, the PSU of the present invention can be used to power a distribution point unit (DPU) over twisted-pair copper wire.

[0025] In accordance with standard RPF requirements, the reverse power fed PSU is required to service up to 16 input power ports provided by copper twisted pairs. The number of active power ports powering the DPU using the reverse power fed PSU may be any number between 1 and 16. Each power port may have a voltage between 32V and 60V, as a function of the loop length, and all the power lines are galvanically isolated from each other, as well as from the secondary side of the transformer. The secondary side of the converter needs to provide a well-regulated 12V output, up to 20W. The PSU is required to become active when at least one of the input power ports is connected to a voltage source and when more than one input power port is connected to the PSU, the power from the connected power ports must be substantially equally shared, within a sharing accuracy of +/-3%. The above requirements have been based on the present standards, it being understood that the embodiments herein are not fixed to the present standards, and may be easily adapted by one skilled in the art to future standards which may have different requirements.

[0026] FIG. 1 illustrates a reverse power feeding power supply unit (PSU) **100** in accordance with an embodiment of the present invention. The PSU **100** comprises at least one transformer **147** and a plurality of power converters for converting a voltage received over twisted pair wiring to a desired output voltage. In particular, FIG. 1 illustrates a first

power converter **145** and a second power converter **155**. However, as shown any number of power converters (1 to N) are within the scope of the present invention. The transformer **147** comprises a plurality of primary windings **190**, **192** and a single secondary winding **194**. As such, each of the power converters **145**, **155** includes one of the primary windings of the transformer **147** and the plurality of power converters **145**, **155** share the secondary winding **194** of the transformer **147**. In particular, the first power converter **145** includes a first primary winding **190** of the transformer **147** and the second power converter **155** includes a second primary winding **192** of the transformer **147** and both the first power converter **145** and the second power converter **155** share the secondary winding **194** of the transformer **147**.

[0027] In FIG. 1, the first power converter **145** includes a shared secondary winding **194**, first primary winding **190**, a primary controller **114** coupled to the first primary winding **190** and an independent power port **110** coupled to the first primary winding **190**. In accordance with reverse power feeding (RPF) standards, a powered device **104** receives a voltage over a twisted pair **120** from a customer premise device (CPE) **106**. A DC voltage is then established across the first primary winding **190** of the first power converter **145** by the powered device **104** at input port **110**, denoted Vin, 1, the potential across input port **110** defined between Vin, 1 and Vin, 1 RTN.

[0028] A second power converter **155** includes the shared secondary winding **194**, second primary winding **192**, a primary controller **134** coupled to the second primary winding **192** and an independent power port **130** coupled to the second primary winding **192**. A powered device **124** receives a voltage over a twisted pair **122** from a customer premise device (CPE) **126**. A DC voltage is then established across the second primary winding

192 of the second power converter **155** by the powered device **124** at input port **130,** denoted Vin, N, the potential across input port **130** defined between Vin, N and Vin, N RTN.

[0029] As such, as illustrated in FIG. 1, the secondary winding **194** is shared between the first power converter **145** and the second power converter **155**. Additionally, a secondary controller **150** operates to activate a single one of the power converters **145**, **155** to transfer power from the primary winding of the one activated power converter to the shared secondary winding **194**, thereby converting an input voltage at the respective power port **110**, **130** of one of the power converters **145**, **155** to an output voltage **170** at the shared secondary winding **194**.

[0030] As such, in the PSU **100** of the present invention, a number of power converters **145**, **155** having primary windings **190**, **192** share a common secondary winding **194**, wherein the transformer **147** includes the primary windings **190**, **192** and the shared secondary winding **194**. Additionally, each of the power converters **145**, **155** is configured to provide the maximum full power required to maintain the output voltage **170** and since the core is limited in size to the maximum full power required at the output, only a single one of the power converters **145**, **155** is operated at one point in time, allowing for a significant reduction in the total magnetic material usage required for the transformer.

[0031] While FIG. 1 illustrates only two power converters **145**, **155**, the PSU **100** of the present invention may include a significantly larger number of power converters to provide reverse power fed power supply unit (PSU). In a particular embodiment, up to 16 power converters may be included to accommodate up to 16 input power ports over the copper twisted pairs following the present RPF standard. As such, the number of active power

converters powering the DPU can be any number between 1 and 16. In one exemplary embodiment, the secondary winding **194** may provide a well-regulated 12V (up to 20W) output voltage **170** from the various input voltages of the power converters **145**, **155**.

[0032] While the number of power converters can be up to a maximum of 16, due to the difficulties in the practical realization of a transformer having a single magnetic core with 16 primary windings and 1 secondary winding, the number of primary windings of the transformer can be limited to 4 or 8 primary windings. Additionally, in many practical applications the equipment itself may be sized for only 4 or 8 input power ports. However, this limitation does not alter the general concept of the invention because one skilled in the art will recognize that the inventive concepts can equally be applied in the case of 2 or 4 transformers.

[0033] For example, the PSU **100** may include a transformer having two magnetic cores. To accommodate 16 power converters, in this embodiment, each of the magnetic cores will have eight primary windings and one secondary winding. The respective secondary windings **194** wound on each of the magnetic cores are coupled in parallel with each other to guarantee that only one of the 16 power converters is operating at a single point in time. For example, assuming a first magnetic core and a second magnetic are present in the transformer, when a first power converter of the eight power converters associated with the first magnetic core is operating, an AC voltage will be induced on the secondary winding of the first magnetic core. The same AC voltage will also be present on the secondary winding of the second magnetic core and, by magnetic induction, AC voltages will be induced on the eight primary windings of the second magnetic core, as well as to all the other seven primary windings of the first magnetic core. From a physical

perspective, the secondary winding of the second magnetic core will act as a primary winding, while the primary windings of the second magnetic core will act as secondary windings, due to the bidirectional characteristics of the magnetic transformer. As such, the observer circuits of the power converters coupled to the primary windings of the second magnetic core will continue to observe that there is another converter running, although it is running on the first magnetic core. Accordingly, in the case of multiple magnetic cores, the configuration of the present invention guarantees that only one of the power converters is operating at one time by enabling each of power converters to observe that there is another converter running, regardless of the whether or not the converter that is running is on the same magnetic core as the power converter that is observing or on a different magnetic core.

[0034] As shown in FIG. 1, the first power converter **145** includes a first primary winding **190** that receives an input voltage at an independent power port **110** to establish a voltage across the first primary winding **190** that is controlled by the respective primary controller **114**. The primary controller **114** additionally provides a power present signal **180**, denoted PR, 1, to the secondary controller **150** to notify the secondary controller **150** that the first power converter **145** has a voltage present at the independent power port **110**. The primary controller **114** additionally receives a feedback signal **176**, denoted FB, 1, from the secondary controller **150** to activate the first power converter **145** and to couple electrical energy from the first primary winding **190** to the common secondary winding **194**, thereby converting the voltage across the first primary winding **190** to the output voltage **170** at the common secondary winding **194**.

[0035] Second power converter **155** includes a second primary winding **192** that receives an input voltage at independent input power port **130** to establish a voltage across the second primary winding **192** that is controlled by the primary controller **134**. The primary controller **134** additionally provides a power present signal **182**, denoted PR, N, to the secondary controller **150** to notify the secondary controller **150** that the second power converter **155** has a voltage present at the input power port **130**. The primary controller **134** additionally receives a feedback signal **178**, denoted FB, N, from the secondary controller **150** to activate the second power converter **155** and to couple electrical energy from the second primary winding **192** to the common secondary winding **194**, thereby converting the voltage across the second primary winding **192** to the output voltage **170** at the common secondary winding **194**.

[0036] The secondary controller **150** includes steering logic **160** for generating the feedback signals **176**, **178** to the power converters **145**, **155** and a ramp generator **165** to receive sync signal **174** from a common secondary winding circuitry **140** to synchronize switching of the power converters **145**, **155**. An output signal **172** is additionally provided to the secondary controller **150** by the common secondary winding circuitry **140** to regulate the output voltage **170**, which output signal may be a scaled representation of output voltage **170**.

[0037] FIG. 2 illustrates an exemplary embodiment of the primary controller **134** of second power converter **155** in more detail, it being understood that the same description may be applied equally to any of the primary controllers. In this exemplary embodiment, the primary controller **134** includes delay circuitry **205** receiving an input from the independent power port **130** and providing an output to a 2-input OR gate **260** and

observer circuitry **210** providing inputs to the 2-input OR gate **260**, the OR gate **260** having an output coupled to a 3-input OR gate **225**. The functions of delay circuitry **205** and observer circuitry **210** will be described further below. The 3-input OR gate **225** further receives a feedback signal **178** from the steering logic **160** of the secondary controller **150** at a second input and an output of a comparator **220** at a third input. The comparator **220** compares a feedback signal from a transistor **235**, developed across a resistor **245** coupled from the source of transistor **235** to ground, to a reference voltage **250**. A first end of primary winding **192**, denoted with a dot, is connected to the respective power port input voltage **130**, exhibiting respective input voltage Vin, N, and a second end of primary winding **192** is connected to an input of observer circuitry **210** and to the drain of transistor **235**. A local oscillator **240** in combination with a latching circuit **230** results in a fixed switching frequency operation of the second power converter **155**. In the illustrated power converter, the maximum peak current through primary winding **192** is defined by the reference voltage **250**. The reference voltage **250** combined with the value Rsense of resistor **245**, the number of turns on the primary winding **192**, the number of turns on the secondary winding **194**, in addition to the properties of the magnetic core, define the amount of power transferred from the primary winding **192** to the secondary winding **194**, per cycle. The primary controller **134** additionally includes an optocoupler **255** for providing the power present signal **182** to the secondary controller **150** when a voltage is present at the independent power port **130** of the second power converter **155**.

[0038] In FIG. 2, the second power converter **155** is a flyback converter that operates at a fixed switching frequency. However, this is not intended to be limiting and any other fixed or

variable frequency power converter topology is within the scope of the present invention. Additionally, the illustrated second power converter **155** is shown to operate with peak current mode control. In the case of a peak current controlled flyback topology, the peak current is limited to a maximum value and the fixed switching frequency operation automatically allows the power converter to provide a fixed amount of power to the secondary side. The illustrated power converter design takes advantage of the intrinsic characteristics of the flyback topology. However, different embodiments using various converter topologies are within the scope of the present invention.

[0039] While the primary controller **134** topology of the second power converter **155** of the power supply unit **100** has been described in detail, the circuitry for all of the primary controllers for each of the power converters of the power supply unit are identical. It follows that the primary controller **114** of the first power converter **145** is identical to the primary controller **134** of the second power converter **155**.

[0040] Since each of the power converters are sized to provide the maximum amount of power required at the common secondary winding, it follows that the number of primary turns on the primary winding, the sense resistor and the peak reference voltage are equal for all the power converters.

[0041] FIG. 3 illustrates common secondary winding circuitry **140** and the secondary controller **150** in additional detail. As shown, the secondary winding circuitry **140** includes a diode **309**, an output capacitor **311** and a feedback resistor divider. The feedback resistor divider includes a first resistor **310** and a second resistor **315**, to provide an output signal **172** to a first input of an error amplifier **330** of the secondary controller **150**. An output reference voltage **171** provides the second input to the error amplifier **330**. The secondary

controller **150** further includes ramp generator **165** that receives a sync signal **174** from the common secondary winding circuitry **140** and steering logic **160** that receives power present signals **180**, **182** from each of the power converters and provides feedback signals **176**, **178** to each of the power converters through respective opto-couplers **340**, **342**. The ramp generator **165** is synchronized, at every switching cycle, with the power converter that is currently operating using the sync signal **174**.

[0042] The secondary controller **150** utilizes a time division multiplexing (TDM) scheme to share the power conversion among each of the power converters, where each of the power converters is operated for a fixed % of time and two power converters do not operate at the same time to avoid magnetic core saturation. The TDM scheme is managed by the steering logic **160** of the secondary controller **150**.

[0043] The steering logic **160** of the secondary controller **150** receives power present logic signals **180**, **182**, denoted PR, 1, PR, N, respectively, from the optocouplers **255** at each of the power converters **145**, **155**. The steering logic **160** uses the power present logic signals **180**, **182** to determine how many and which input power ports are active at a certain time. The steering logic **160** then enables and transfers the digital feedback signals **176**, **178**, denoted FB, 1, FB, N, respectively, to the primary converters **145**, **155** associated with the active input power ports via the optocouplers **340, 342**. As such, feedback signals **176**, **178** needed to regulate the output voltage **170** are not transferred in analog form but are advantageously instead transferred as a logic signal via the optocouplers **340, 342**. The feedback logic signal performs two functions, it enables the respective primary converter at each switching cycle, wherein if the digital feedback signal **176**, **178** is HIGH (inverted logic), the associated independent power converter

will remain OFF because the power switch of the independent power converter is kept always OFF responsive to a HIGH input on the Reset input of latch circuit **230** through gate **225**. In this embodiment, the latch circuit **230** is a reset dominant latch circuit, and when both the set and reset inputs are low, the reset input will dominate, resulting in the output being low. Additionally, when an independent power converter is activated, the digital feedback signal **176**, **178** ends the power switch ON time at every switching cycle, thereby modulating the peak current, hence the energy stored in the magnetic core and the resulting power transferred to the secondary side, thereby regulating the output voltage **170** against variations in the input line voltage and output load.

[0044] To properly provide regulation, it is preferable that the ramp generator **165** in the secondary controller **150** be synchronized with the primary converter **145**, **155** which is active at any given time. With reference again to FIG. 2, each primary converter **155** has its own local oscillator **240**. All of the oscillators in each of the primary converters are preferably arranged to operate at approximately the same frequency, but do not need to be synchronized with each other. Moreover, a range of a few % in the relative frequencies of the oscillators is acceptable. Additionally, the ramp generator **165** in the secondary controller **150** preferably operates at a frequency similar to that of the primary controllers **114**, **134**, but any variation with respect to the local oscillators is absorbed by the fact that, at every switching cycle, the ramp generator **165** is re-synchronized with the primary converter that is active at any given time. Synchronization is accomplished by means of the voltage on the common secondary winding **194**, wherein every time the power switch on the primary winding **192** turns ON, the voltage at the sync signal **174** changes sign (becomes negative). Once the ramp output by ramp generator **165** and the primary

controller are synchronized, comparator **325** compares the error voltage output from the error amplifier **330** with the synchronized ramp output from the ramp generator **165** and the output **178** of the comparator **325** is steered to transistor **235** of the primary controller **134** via the optocoupler **340**, as feedback signal **178** FB, N to the OR gate **225** and the latch **230** to modulate the transistor **235** ON time, which was initiated by the local oscillator **240**, thus defining the transistor duty cycle of that switching period and allowing regulation of the energy transferred by the primary to the secondary winding which, in turn, provides the regulation of the output voltage **170**.

[0045] The steering logic **160** is effective in activating each of the primary converters **145**, **155** of the PSU **100** for a specified period of time, according to the TDM scheme previously described. The steering logic **160** checks how many input ports are present at any given time and, assuming that a number "M" of input ports are present, the steering logic **160** activates the relevant power converters in sequence for a time which is equal to a predetermined total time/M. The predetermined total time is arbitrary, as long as it is much higher than the switching period. As such, the accuracy of the power sharing between different input ports is only a function of a timing accuracy, which may be very high and is dependent only upon the resolution of a timer (not shown) included in the steering logic **160**.

[0046] FIG. 4A provides an exemplary illustration of the TDM scheme that is managed by the steering logic **160** of the secondary controller **150**. In this exemplary embodiment, two power converters are being sequenced, however this is not intended to be limiting and any number of power converters could be sequenced using the TDM scheme. In this exemplary illustration, the upper power converter is first turned-ON **405** and has an input

power port providing 36V. The output voltage **410** is increasing from 0V to the regulated 10V. After 5msec, at **415**, the upper converter **405** is turned-OFF by the steering logic **160**, here represented by a simple pulse voltage **420**, while the lower power converter, whose input power port provides 60 V, is turned-ON **425**. Provided that the switch between the two power converters is fast (i.e. occurring in a few switching cycles), there is no significant drop of the output voltage **410**, which is sustained by output capacitors.

[0047] As long as the secondary controller **150** is supplied by some voltage, the secondary controller can control the activation of the power converters. However, when the PSU **100** is activated for the first time, the secondary controller **150** is not supplied by a voltage and therefore cannot provide any useful signal. Under this condition, any number of input power ports may be connected at the same time and in an unknown sequence. The obvious risk is that, if more than one power port becomes active before the secondary controller **150** is powered-up, the relevant power converters will activate simultaneously, thereby saturating the transformer's core. This undesirable condition is resolved by means of observing the voltage across each of the primary windings **192**, **194**.

[0048] Referring again to FIG. 2, the observer circuitry **210** of the primary controller **134** keeps the primary converter **155** in reset, i.e. by asserting a signal to the Reset input of latch circuit **230** via gates **260**, **225**, as long as a switching voltage is detected across transistor **235** the voltage across the primary winding **192** is already switching during the fixed delay time provided by delay circuit **205**. The combination of these two conditions ensures that each of the power converters senses the presence of any other power converter. In one embodiment, the observer circuitry **210** may include a comparator, or a comparator with a flip-flop circuit. Accordingly, as soon as a first converter receives

its input power **130**, it remains in a waiting state for the fixed delay time provided by the respective delay circuitry **205** and observes the voltage on its primary winding **192**. If the voltage on the primary winding **192** is switching, that indicates that another second converter is currently active, and the power being transferred to secondary winding **194** by the other converter is being reflected to the primary winding **192** and as a result. For example, when the converter **155** wakes-up in response to a voltage present at the independent power port **130**, the observer circuitry **210** observes the voltage on the drain of the transistor **235**. If the drain voltage is LOW, it means that another transistor, in another converter, is operating and forcing the drain to be LOW in response to the magnetic coupling between the primary windings. However, if the observer circuitry **210** observes a HIGH voltage on the drain of the transistor **235**, that does not guarantee that another converter is not operating, it could simply be currently in an OFF state. So, when the drain voltage is HIGH, the observer circuitry **210** waits and observes during the delay time to see if the drain voltage is actually switching from LOW to HIGH and then to LOW again, thereby confirming that there is another converter currently running. Because a condition where more than one, or all, input voltages appear simultaneously on the power converters may occur, it is sufficient to provide the converters with delay times which are different from each other. The fixed delay time is provided by the delay circuitry **205**, and each instance of delay circuitry **205** is set to a respective value. Once the secondary controller **150** is active, it will reset the observer circuitry **210** using signal **178** at each of the primary controllers and take control of the operation of the PSU system.

[0049] FIG. 4B provides an exemplary illustration of the operation of the observer circuitry **210**. In FIG. 4B, an upper power converter and a lower power converter are attempting to start

at the same time. In this exemplary embodiment, the upper power converter has an input power port providing 36V and is turned-ON first, providing the PWM signal from the upper power converter **455**. In response to the upper power converter turning ON, the output voltage **460** is increasing from 0V to the regulated 10V. In this embodiment, it is assumed that the lower power converter has a relative delay of 1msec with respect to the upper power converter. The observer circuitry **210** observes the associated primary winding (**190**, **192**) during the 1msec delay time. As illustrated, because the upper converter is running, the lower converter will stay OFF as shown by the 0V PWM provided by the lower power converter **450**, even after the 1msec delay time **470** has elapsed. The output of the delay of the lower power converter provides the enable signal **465** to the lower power converter after 1msec, however because the upper power converter in ON when the enable signal 465 is initiated, the lower converter will stay OFF.

[0050] With reference to FIG. 5 the operation of the reverse power feeding (RPF) power supply unit (PSU) may begin at a first step **505** by receiving an input voltage at an input power port of one or more of a plurality of power converters. Referring to FIG. 1, an input voltage from a powered device **124** may be received at an independent power port **130** of a power converter **155** of the PSU **100**.

[0051] A next step **510** may include, operating a delay circuitry and an observer circuitry to prevent more than one of the power converters having an input voltage at its power port from being simultaneously activated by the secondary controller. Referring to FIG. 2, the delay circuitry **205** and the observer circuitry **210** of the power converter **155** are used to

prevent more than one of the power converters **145**, **155** from being simultaneously activated.

[0052] A next step **515** may include, providing a power present signal from each primary controller of the power converter when the power converter has an input voltage at its independent power port to notify the secondary controller which of the power converters of the plurality of power converters have an input voltage at its independent power port. Referring to FIG. 2, a power present signal **182** is provided by an optocoupler **255** of the primary controller **134** of the power converter **155** to the secondary controller **150** when an input voltage is present at its independent power port **130**.

[0053] A next step **520** may include, activating a single one of a plurality of power converters having an input voltage present at its power port at a time when an input voltage is present at an independent power port of two or more of the plurality of power converters. Referring to FIG. 1, the secondary controller **150** activates one a single one of the plurality of power converters **145**, **155** at a time in response to the power present signals **180**, **182**.

[0054] A final step **525** may include, converting the input voltage at the primary winding of the activated power converter to an output voltage at the shared secondary winding. Referring to FIG. 1, the input voltage **130** at the primary winding **192** of the activated power converter **155** is converted to an output voltage **170** at the common secondary winding **194**.

[0055] In one embodiment, portions of the reverse power feeding (RPF) power supply unit (PSU) may be implemented in an integrated circuit as a single semiconductor die. Alternatively, the integrated circuit may include multiple semiconductor die that are

electrically coupled together such as, for example, a multi-chip module that is packaged in a single integrated circuit package.

[0056] In various embodiments, portions of the system of the present invention may be implemented in a Field Programmable Gate Array (FPGA) or Application Specific Integrated Circuit (ASIC). As would be appreciated by one skilled in the art, various functions of circuit elements may also be implemented as processing steps in a software program. Such software may be employed in, for example, a digital signal processor, a network processor, a microcontroller or general-purpose computer.

[0057] Unless specifically stated otherwise as apparent from the discussion, it is appreciated that throughout the description, discussions utilizing terms such as “receiving”, “determining”, “generating”, “limiting”, “sending”, “counting”, “classifying”, or the like, can refer to the action and processes of a computer system, or similar electronic computing device, that manipulates and transforms data represented as physical (electronic) quantities within the computer system’s registers and memories into other data similarly represented as physical quantities within the computer system memories or registers or other such information storage, transmission, or display devices.

[0058] The present invention may be embodied on various computing platforms that perform actions responsive to software-based instructions. The following provides an antecedent basis for the information technology that may be utilized to enable the invention.

[0059] The method of the present invention may be stored on a computer readable medium which may be a computer readable signal medium or a computer readable storage medium. A computer readable storage medium may be, for example, but not limited to, an electronic, magnetic, optical, electromagnetic, infrared, or semiconductor system,

apparatus, or device, or any suitable combination of the foregoing. More specific examples (a non-exhaustive list) of the computer readable storage medium would include the following: an electrical connection having one or more wires, a portable computer diskette, a hard disk, a random access memory (RAM), a read-only memory (ROM), an erasable programmable read-only memory (EPROM or Flash memory), an optical fiber, a portable compact disc read-only memory (CD-ROM), an optical storage device, a magnetic storage device, or any suitable combination of the foregoing. In the context of this document, a computer readable storage medium may be any non-transitory, tangible medium that can contain, or store a program for use by or in connection with an instruction execution system, apparatus, or device.

[0060] A computer readable signal medium may include a propagated data signal with computer readable program code embodied therein, for example, in baseband or as part of a carrier wave. Such a propagated signal may take any of a variety of forms, including, but not limited to, electro-magnetic, optical, or any suitable combination thereof. A computer readable signal medium may be any computer readable medium that is not a computer readable storage medium and that can communicate, propagate, or transport a program for use by or in connection with an instruction execution system, apparatus, or device. However, as indicated above, due to circuit statutory subject matter restrictions, claims to this invention as a software product are those embodied in a non-transitory software medium such as a computer hard drive, flash-RAM, optical disk or the like.

[0061] Program code embodied on a computer readable medium may be transmitted using any appropriate medium, including but not limited to wireless, wire-line, optical fiber cable, radio frequency, etc., or any suitable combination of the foregoing. Computer program

code for carrying out operations for aspects of the present invention may be written in any combination of one or more programming languages, including an object-oriented programming language such as Java, C#, C++, Visual Basic or the like and conventional procedural programming languages, such as the "C" programming language or similar programming languages.

[0062] Aspects of the present invention are described below with reference to flowchart illustrations and/or block diagrams of methods, apparatus (systems) and computer program products according to embodiments of the invention. It will be understood that each block of the flowchart illustrations and/or block diagrams, and combinations of blocks in the flowchart illustrations and/or block diagrams, can be implemented by computer program instructions. These computer program instructions may be provided to a processor of a general-purpose computer, special purpose computer, or other programmable data processing apparatus to produce a machine, such that the instructions, which execute via the processor of the computer or other programmable data processing apparatus, create means for implementing the functions/acts specified in the flowchart and/or block diagram block or blocks.

[0063] These computer program instructions may also be stored in a computer readable medium that can direct a computer, other programmable data processing apparatus, or other devices to function in a particular manner, such that the instructions stored in the computer readable medium produce an article of manufacture including instructions which implement the function/act specified in the flowchart and/or block diagram block or blocks.

[0064] The computer program instructions may also be loaded onto a computer, other programmable data processing apparatus, or other devices to cause a series of operational steps to be performed on the computer, other programmable apparatus or other devices to produce a computer implemented process such that the instructions which execute on the computer or other programmable apparatus provide processes for implementing the functions/acts specified in the flowchart and/or block diagram block or blocks.

[0065] Further, for purposes of discussing and understanding the embodiments of the invention, it is to be understood that various terms are used by those knowledgeable in the art to describe techniques and approaches. Furthermore, in the description, for purposes of explanation, numerous specific details are set forth in order to provide a thorough understanding of the present invention. It will be evident, however, to one of ordinary skill in the art that the present invention may be practiced without these specific details. In some instances, well-known structures and devices are shown in block diagram form, rather than in detail, in order to avoid obscuring the present invention. These embodiments are described in sufficient detail to enable those of ordinary skill in the art to practice the invention, and it is to be understood that other embodiments may be utilized and that logical, mechanical, electrical, and other changes may be made without departing from the scope of the present invention.

CLAIMS

What we claim is:

1. A reverse power feed (RPF) power supply unit (PSU), the PSU comprising:

   at least one transformer comprising a plurality of primary windings and one secondary winding;

   a plurality of power converters sharing the secondary winding of the at least one transformer, wherein each of the plurality of power converters comprises;

      a unique one of the plurality of primary windings of the at least one transformer;

      a primary controller coupled to the unique one primary winding;

      an independent power port coupled to the unique one primary winding, the independent power port to provide an input voltage to be converted to an output voltage at the secondary winding of the at least one transformer; and

   a secondary controller coupled to each of the plurality of power converters, the secondary controller for activating only one of the power converters having an input voltage present at its independent power port at a time when an input voltage is present at the independent power port of two or more of the plurality of power converters sharing the secondary winding.

2. The PSU of claim 1, wherein each of the plurality of power converters has a peak current controlled flyback converter topology.

3. The PSU of claim 1, wherein each of the plurality of power converters are configured to provide a maximum power required at the shared secondary winding.

4. The PSU of claim 1, wherein each of the plurality of power converters further comprises a local oscillator and wherein each of the local oscillators has a substantially equivalent frequency.

5. The PSU of claim 1, wherein the primary controller of each of the plurality of power converters further comprises a delay circuitry and an observer circuitry, the delay circuitry and the observer circuitry for preventing more than one of the power converters having an input voltage at its independent power port from being simultaneously activated.

6. The PSU of claim 1, wherein each of the power converters further comprises a primary optocoupler coupled to the independent power port, the primary optocoupler to provide a power present signal to the secondary controller when the power converter has an input voltage at its independent power port.

7. The PSU of claim 1, wherein the secondary controller comprises steering logic for providing a feedback signal to each of the power converters having an input voltage present at its independent power port, the feedback signal implements a time division multiplexing (TDM) scheme to activate each of the power converters for a substantially equivalent period of time.

8. The PSU of claim 7, wherein the feedback signal is provided to each of the plurality of power converters by a secondary optocoupler.

9. The PSU of claim 7, wherein the secondary controller further comprises:

a comparator;

an error amplifier having an output coupled to a first input of the comparator, wherein the error amplifier receives an input from a common secondary winding circuitry coupled to the common secondary winding; and

a ramp generator having an output coupled to a second input of the comparator, wherein the ramp generator receives a sync signal from the common secondary winding circuitry and wherein an output of the comparator is coupled to the steering logic to synchronize the secondary controller with a local oscillator of the one power converter that is activated.

10. The PSU of claim 1, wherein the input voltage is provided by one or more customer premise equipment (CPE).

11. A reverse power feed (RPF) power supply unit (PSU) in a Distribution Point Unit (DPU), the PSU comprising:

at least one transformer comprising a plurality of primary windings and one secondary winding;

a plurality of power converters sharing the secondary winding of the at least one transformer, wherein each of the plurality of power converters comprises;

one primary winding of the plurality of primary windings of the at least one transformer;

a primary controller coupled to one primary winding;

an independent power port coupled to the one primary winding, the independent power port to provide an input voltage, the input voltage to be converted to an output voltage at the secondary winding of the at least one transformer; and

a secondary controller coupled to each of the plurality of power converters, the secondary controller for activating one at a time of the power converters having an input voltage present at its power port when an input voltage is present at the power port of two or more of the plurality of power converters sharing the secondary winding.

12. A method of operating a reverse power feed (RPF) power supply unit (PSU) comprising at least one transformer comprising a plurality of primary windings and one secondary winding and a plurality of power converters sharing the secondary winding of the at least one transformer, the method comprising:

activating one of the plurality of power converters having an input voltage present at its independent power port when an input voltage is present at an independent power port of two or more of the plurality of power converters, wherein only one of the plurality of power converters is activated at a time and wherein each of the plurality of power converters of the PSU comprises;

one primary winding of the plurality of primary windings of the at least one transformer and

a primary controller coupled to the one primary winding; and

converting the input voltage at the primary winding of the activated power converter to an output voltage at the secondary winding.

13. The method of claim 12, wherein each of the plurality of power converters has a peak current controlled flyback converter topology.

14. The method of claim 12, wherein each of the plurality of power converters are configured to provide a maximum power required at the shared secondary winding.

15. The method of claim 12, wherein each of the plurality of power converters further comprises a local oscillator.

16. The method of claim 12 further comprising, operating a delay circuitry and an observer circuitry to prevent more than one of the power converters having an input voltage at its power port from being simultaneously activated by the secondary controller.

17. The method of claim 16 further comprising, prior to activating one of a plurality of power converters of the PSU, providing a power present signal from the primary controller to the secondary controller when the power converter has an input voltage at its power port to notify the secondary controller which of the power converters of the plurality of power converters have an input voltage at its power port.

18. The method of claim 12, wherein activating one of a plurality of power converters of the PSU further comprises:

providing a feedback signal to each of the power converters having an input voltage present at its power port; and

implementing a time division multiplexing (TDM) scheme to activate each of the power converters for a substantially equivalent period of time using the digital feedback signal.

19. The method of claim 12 further comprising, synchronizing the secondary controller with a local oscillator of the one power converter that is activated by the secondary controller.

20. The method of claim 1, wherein the input voltage is provided by one or more customer premise equipment (CPE).

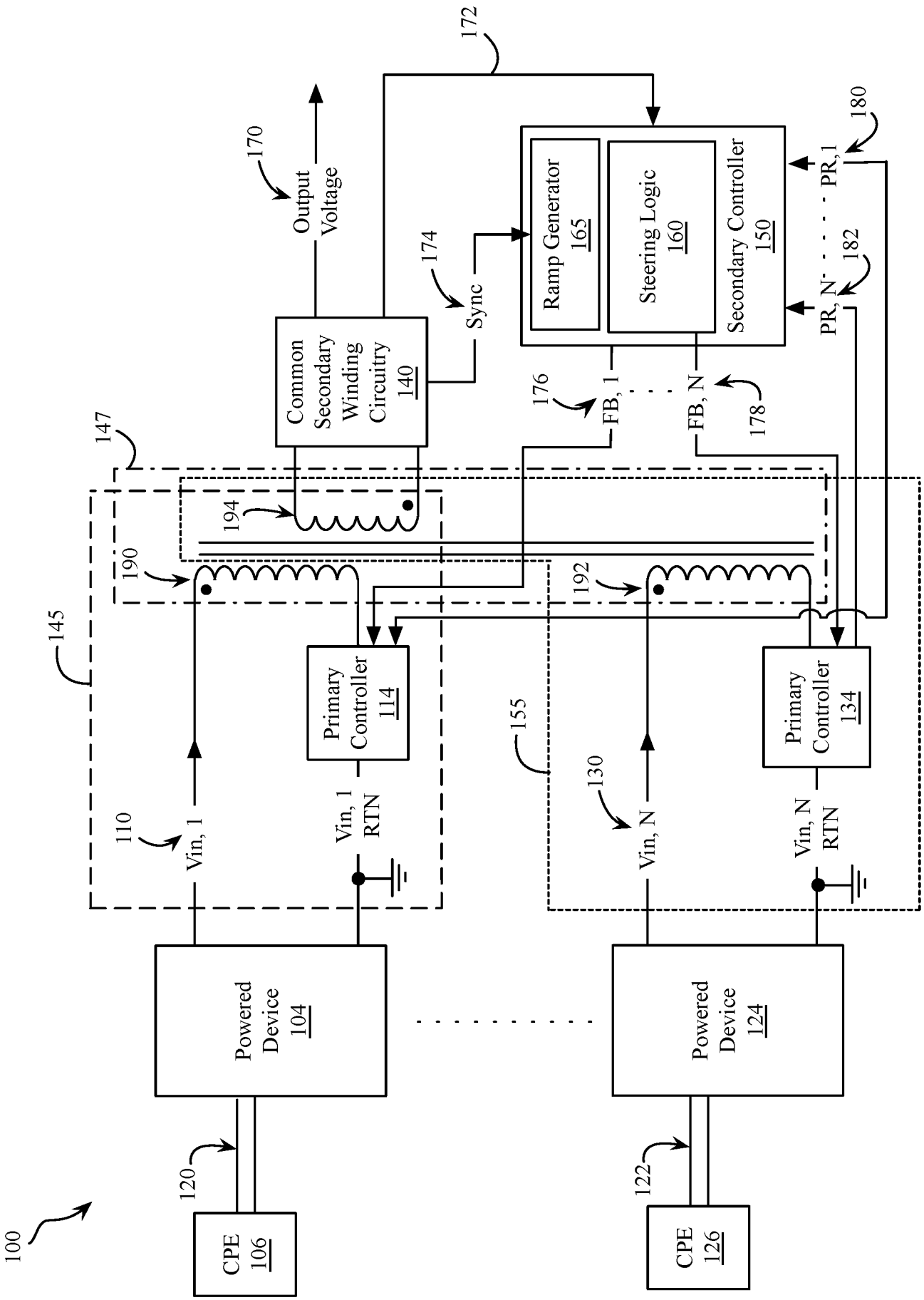

100
CPE 106
120
Powered Device 104
110
Vin, 1
Vin, 1 RTN
Primary Controller 114
145
147
190
194
Common Secondary Winding Circuitry 140
Output Voltage
170
172
174
Sync
Ramp Generator 165
Steering Logic 160
Secondary Controller 150
176
FB, 1
178
FB, N
180
PR, 1
182
PR, N
192
155
130
Vin, N
Vin, N RTN
Primary Controller 134
Powered Device 124
122
CPE 126

FIG. 1

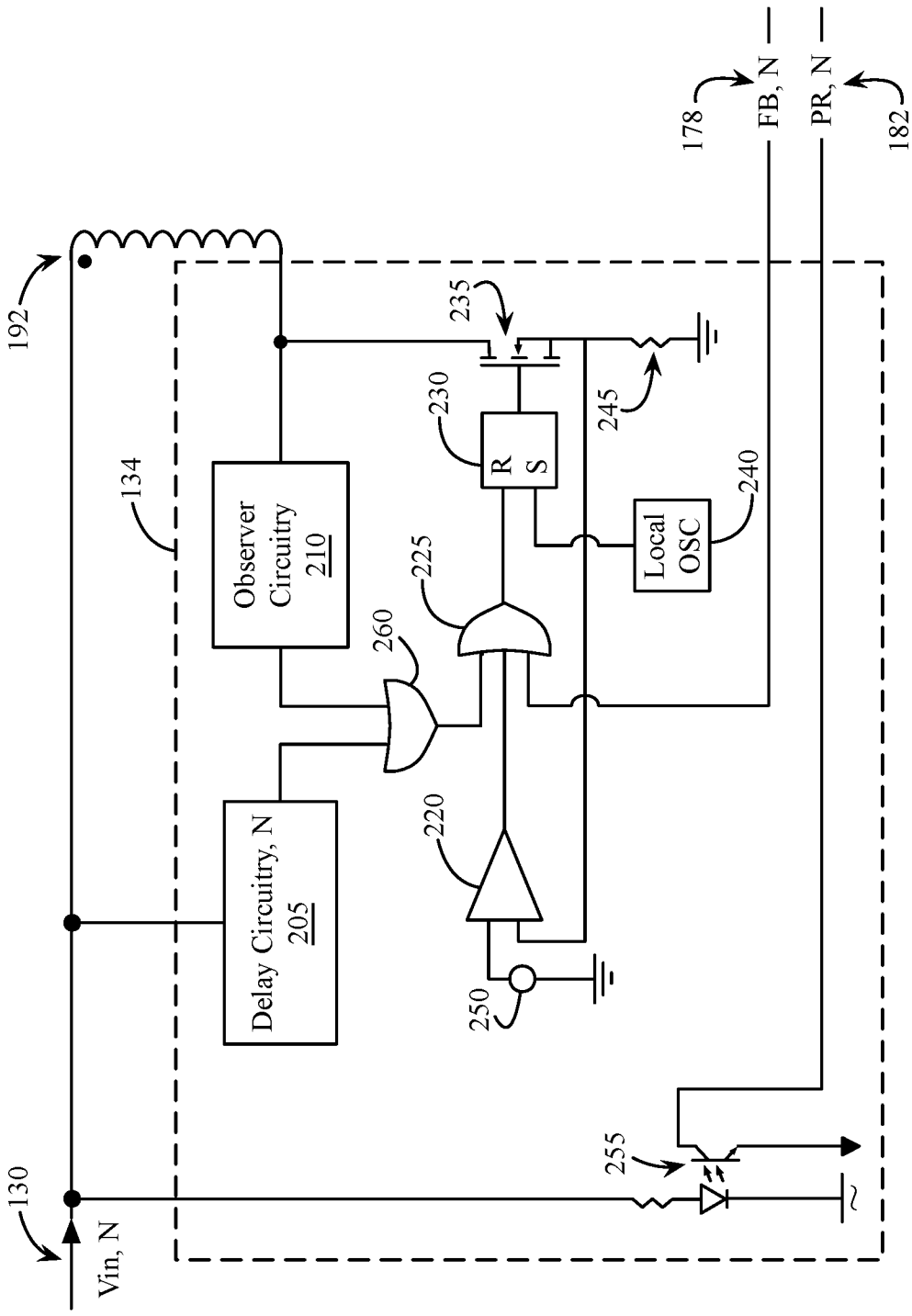

178
FB, N
PR, N
182
192
235
230
245
R
S
240
Local OSC
134
Observer Circuitry 210
225
260
220
Delay Circuitry, N 205
250
255
130
Vin, N

FIG. 2

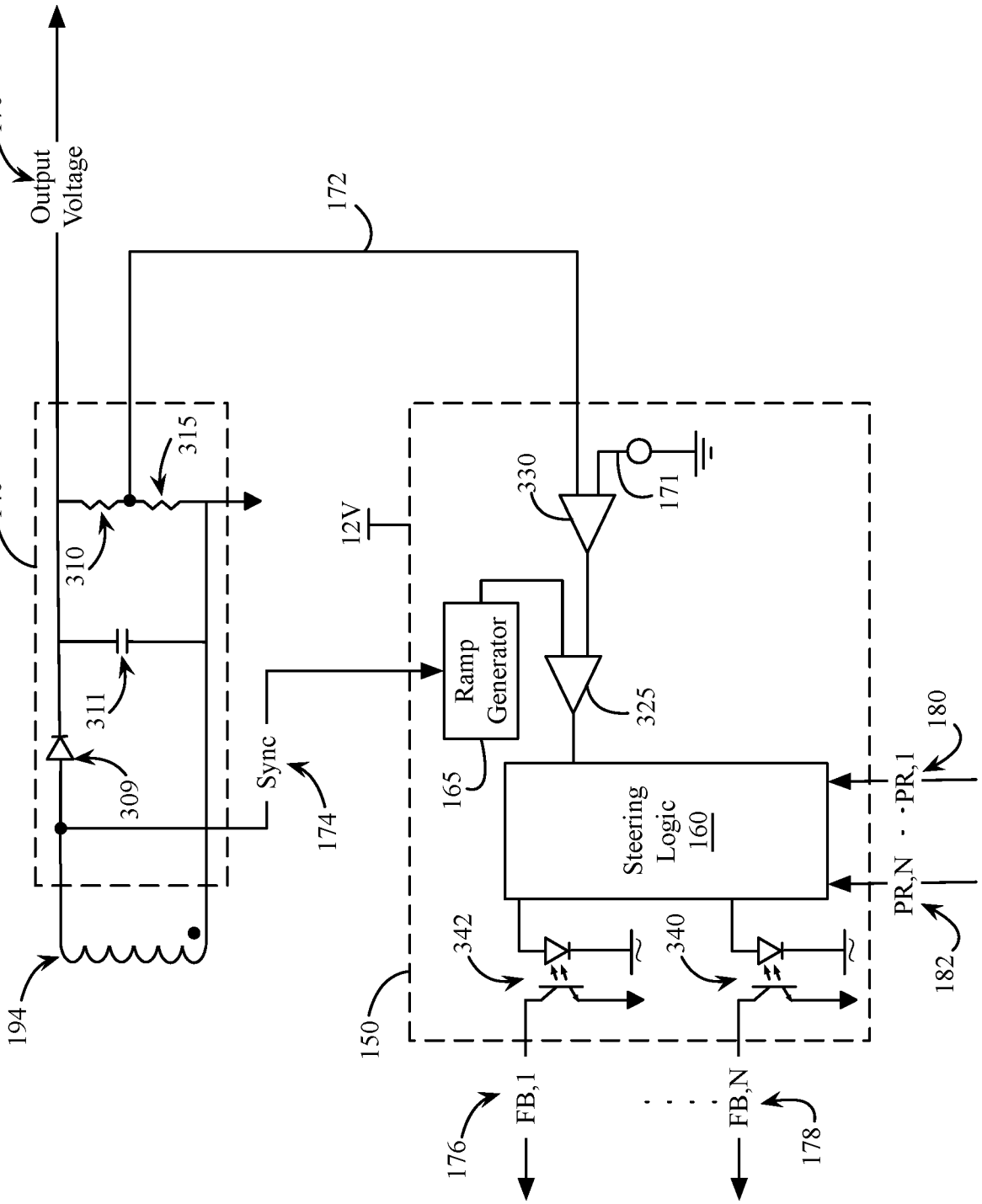

170
Output Voltage
172
140
315
310
311
309
194
Sync
174
12V
330
171
Ramp Generator
165
325
Steering Logic 160
180
PR,1
PR,N
182
342
340
150
176
FB,1
FB,N
178

FIG. 3

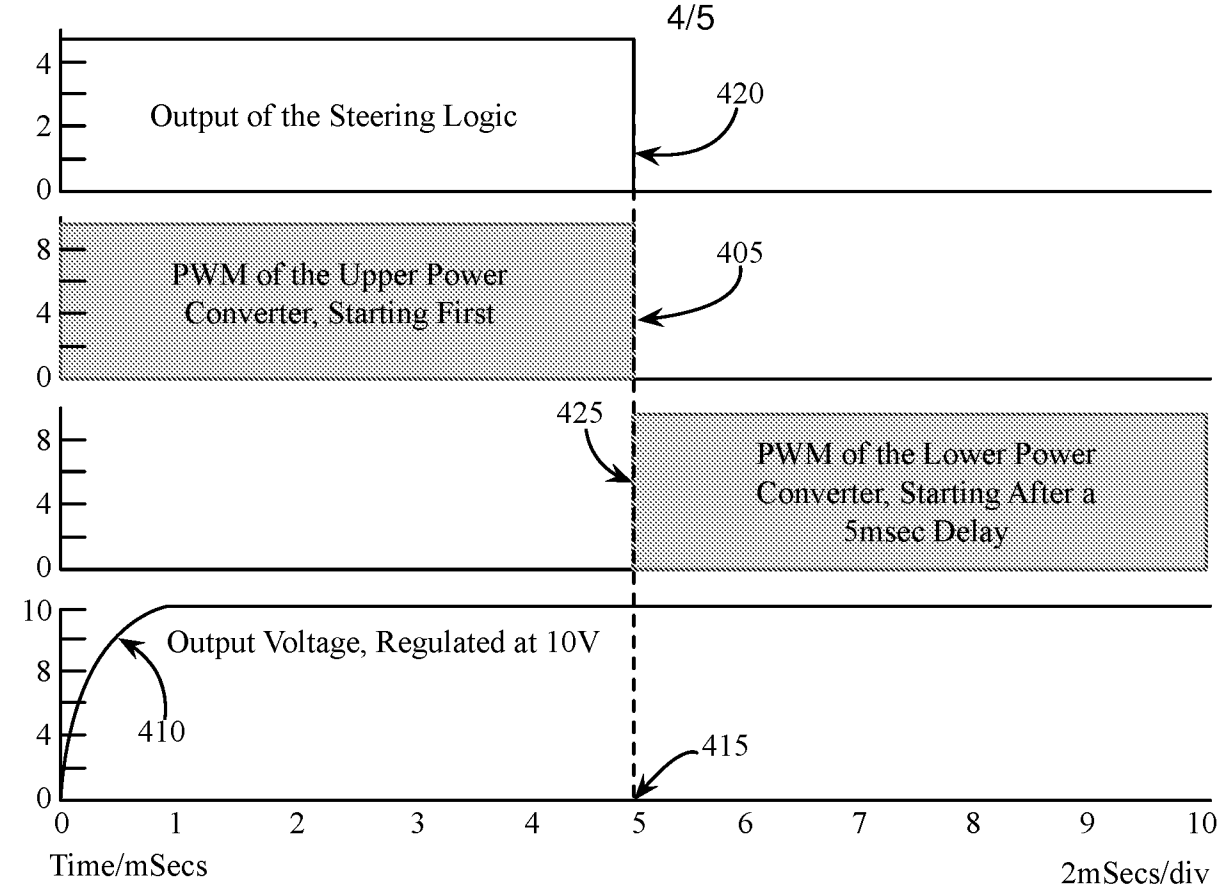

Output of the Steering Logic
420
PWM of the Upper Power Converter, Starting First
405
425
PWM of the Lower Power Converter, Starting After a 5msec Delay
Output Voltage, Regulated at 10V
410
415
Time/mSecs
2mSecs/div

FIG. 4A

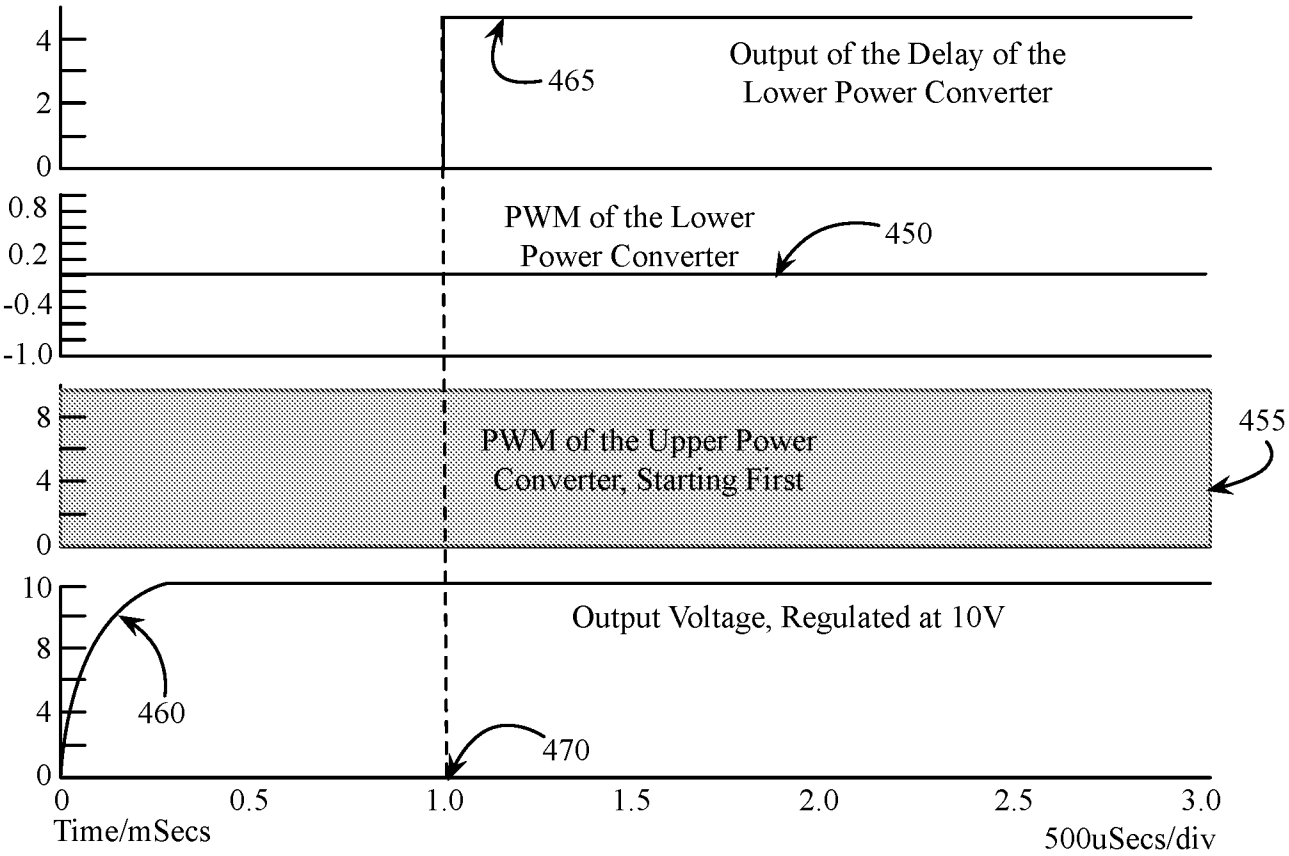

465
Output of the Delay of the Lower Power Converter
PWM of the Lower Power Converter
450
PWM of the Upper Power Converter, Starting First
455
Output Voltage, Regulated at 10V
460
470
Time/mSecs
500uSecs/div

FIG. 4B

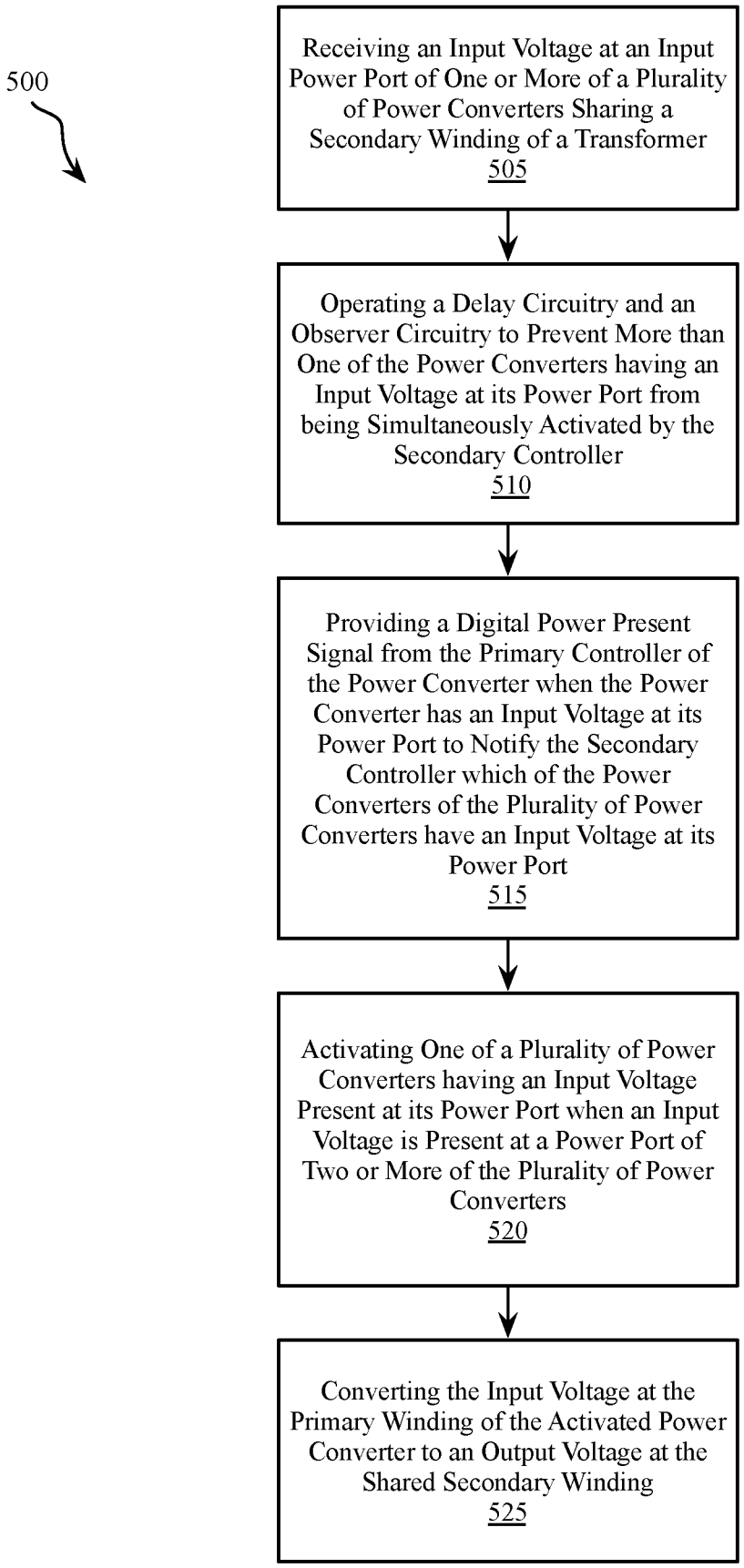

500
Receiving an Input Voltage at an Input Power Port of One or More of a Plurality of Power Converters Sharing a Secondary Winding of a Transformer
505
Operating a Delay Circuitry and an Observer Circuitry to Prevent More than One of the Power Converters having an Input Voltage at its Power Port from being Simultaneously Activated by the Secondary Controller
510
Providing a Digital Power Present Signal from the Primary Controller of the Power Converter when the Power Converter has an Input Voltage at its Power Port to Notify the Secondary Controller which of the Power Converters of the Plurality of Power Converters have an Input Voltage at its Power Port
515
Activating One of a Plurality of Power Converters having an Input Voltage Present at its Power Port when an Input Voltage is Present at a Power Port of Two or More of the Plurality of Power Converters
520
Converting the Input Voltage at the Primary Winding of the Activated Power Converter to an Output Voltage at the Shared Secondary Winding
525

FIG. 5

INTERNATIONAL SEARCH REPORT

International application No
PCT/US2019/044829

A. CLASSIFICATION OF SUBJECT MATTER
INV. H04M19/08
ADD.

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)
H04M H04B H04L

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)
EPO-Internal, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 7 187 563 B1 (BOBREK PAVLO [US]) 6 March 2007 (2007-03-06) column 2, line 53 - column 6, line 36; figures 1-4	1-20

A	US 2016/309045 A1 (PEKER ARKADIY [US] ET AL) 20 October 2016 (2016-10-20) paragraph [0047] - paragraph [0049]; figure 4	1-20

A	US 6 577 882 B1 (ROOS STURE [SE]) 10 June 2003 (2003-06-10) column 3, line 16 - column 4, line 31; figures 1,2	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

"E" earlier application or patent 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	Date of mailing of the international search report
6 January 2020	14/01/2020

Name and mailing address of the ISA/	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Fax: (+31-70) 340-3016	Sorrentino, Andrea

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No
PCT/US2019/044829

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		US 7187563 B1	06-03-2007
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		WO 2016170530 A1	27-10-2016
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		DE 60026340 T2	19-10-2006
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		US 6577882 B1	10-06-2003
		WO 0122716 A1	29-03-2001