(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) World Intellectual Property Organization
International Bureau

(43) International Publication Date
20 September 2018 (20.09.2018)

WIPO | PCT

(10) International Publication Number
WO 2018/166912 A1

(51) International Patent Classification:
H03K 17/082 (2006.01) *H03K 17/691* (2006.01)

(21) International Application Number:
PCT/EP2018/055909

(22) International Filing Date:
09 March 2018 (09.03.2018)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:
17161130.4 15 March 2017 (15.03.2017) EP

(71) Applicant: **WÜRTH ELEKTRONIK EISOS GMBH & CO. KG** [DE/DE]; Max-Eyth-Str. 1, 74638 Waldenburg (DE).

(72) Inventors: **SHOUSHA, Mahmoud**; Am Lichtfeld 9, 85386 Eching (DE). **HAUG, Martin**; Ehrwalder Strasse 78, 81377 München (DE).

(74) Agent: **RAU, SCHNECK & HÜBNER PATENTANWÄLTE RECHTSANWÄLTE PARTGMBB**; Königstrasse 2, 90402 Nürnberg (DE).

(81) Designated States *(unless otherwise indicated, for every kind of national protection available)*: AE, AG, AL, AM, AO, AT, AU, AZ, BA, BB, BG, BH, BN, BR, BW, BY, BZ, CA, CH, CL, CN, CO, CR, CU, CZ, DE, DJ, DK, DM, DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IR, IS, JO, JP, KE, KG, KH, KN, KP, KR, KW, KZ, LA, LC, LK, LR, LS, LU, LY, MA, MD, ME, MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PA, PE, PG, PH, PL, PT, QA, RO, RS, RU, RW, SA, SC, SD, SE, SG, SK, SL, SM, ST, SV, SY, TH, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, ZA, ZM, ZW.

(84) Designated States *(unless otherwise indicated, for every kind of regional protection available)*: ARIPO (BW, GH, GM, KE, LR, LS, MW, MZ, NA, RW, SD, SL, ST, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, RU, TJ, TM), European (AL, AT, BE, BG, CH, CY, CZ, DE, DK,

(54) **Title:** POWER SWITCHING DEVICE AND METHOD TO OPERATE SAID POWER SWITCHING DEVICE

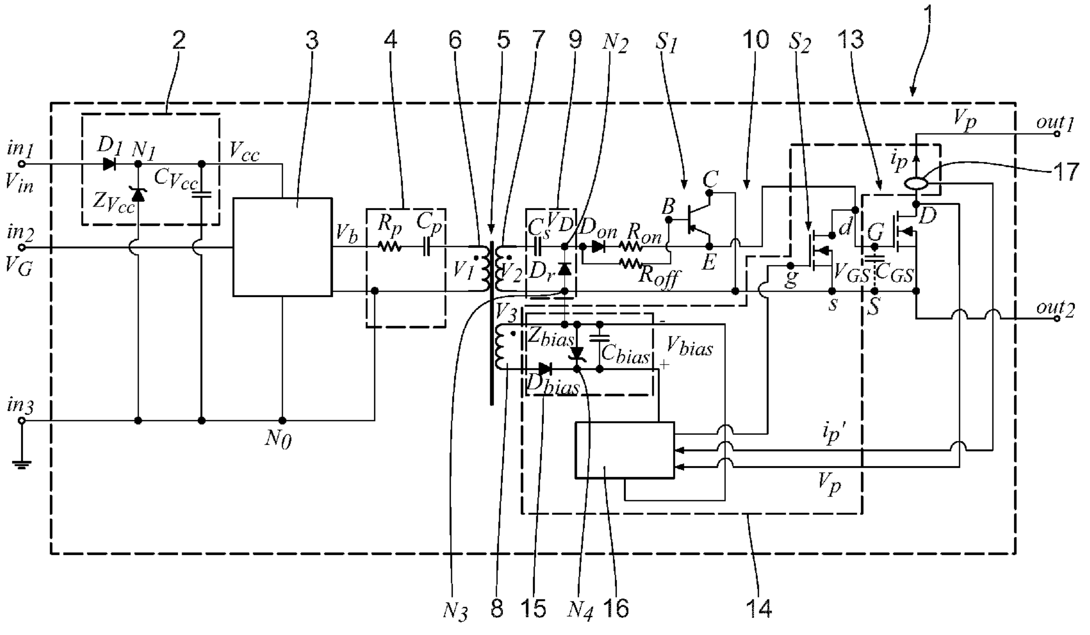


Fig. 1

(57) **Abstract:** A power switching device (1) comprises a buffer circuit (3), a filter circuit (4), a transformer (5), a restoration circuit (9), a conditioning circuit (10) and a power switch (13). The buffer circuit (3) provides a unipolar buffer output voltage (V_b) dependent on an input voltage (V_{in}) and a control voltage (V_G). The filter circuit (4) blocks a direct component of the buffer output voltage (V_b) which is added on the secondary side of the transformer (5) by the restoration circuit (9). The power switch (16) is controlled by a unipolar conditioning voltage (V_D) provided by the restoration circuit (9) to the conditioning circuit (10). The power switching device (1) acts as a plug and play module and can be used and operated in a flexible and easy manner.

WO 2018/166912 A1

[Continued on next page]

EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU, LV, MC, MK, MT, NL, NO, PL, PT, RO, RS, SE, SI, SK, SM, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, KM, ML, MR, NE, SN, TD, TG).

Declarations under Rule 4.17:
— *of inventorship (Rule 4.17(iv))*

Published:
— *with international search report (Art. 21(3))*

Power switching device and method to operate said power switching device

The present application claims priority of European patent application EP 17 161 130.4 the content of which is incorporated herein by reference.

The invention relates to a power switching device and a method to operate said power switching device.

US 4 461 966 A (corresponds to DE 30 45 771 A1) discloses a circuit for controlling at least one power FET. A unipolar input voltage is applied from a controller to input terminals. The input voltage is differentiated. The resulting bipolar voltage appears due to a transformer as an output voltage at the secondary side of the transformer. The positive pulse of the output voltage arrives at the gate electrode through a diode and charges up the input capacitance of the FET. In this way the FET is switched on. Simultaneously a capacitor is charged up through a Zener diode. Due to the following negative pulse the Zener diode breaks down and the capacitor is discharges such that a transistor connected in parallel to the input capacitance is opened. As a result the input capacitance is discharged and the FET is blocked. The known circuit has the disadvantages that the level of the driving voltage of the FET is dependent on the duty cycle of the input voltage and that the controller has to provide the required power to operate the circuit.

It is an object of the present invention to provide a power switching device which can be used and operated in a flexible and easy manner. In particular, it is an object of the invention to provide a power switching device which is configured as plug and play module and can easily be installed.

This object is achieved by a power switching device comprising the features of claim 1. The inventive power switching device integrates a buffer circuit, a filter circuit, a transformer, a restoration circuit, a conditioning circuit and a power switch to act as a plug and play module which can operate in various applications without worrying about the way the power switching device is connected to a controller and/or to a power stage. An input voltage from a power stage is applied by means of the first input terminal to the buffer circuit. Accordingly a control voltage from a controller is applied via a second input terminal to the buffer circuit. The controller may provide a positive unipolar control voltage or a negative unipolar control voltage or an alternating control voltage. Hence, the power switching device can be operated with a standard available controller, in particular with a simple controller which provides a unipolar control voltage. Preferably, the power switching device comprises a third input terminal. The third input terminal provides a reference node. The third input terminal is in particular connected with a common ground of the power stage and the controller. The buffer circuit provides the buffer output voltage which depends on the input voltage and the control voltage. The buffer output voltage corresponds to the control voltage and is unipolar or bipolar. Due to the buffer circuit the controller is not affected by the required power because the required power is provided by the power stage. Preferably, the buffer circuit is connected with the third input terminal. The filter circuit is designed to block a direct component of the buffer output voltage and to provide an alternating primary side voltage. Input terminals of the filter circuit are connected to output terminals of the buffer circuit. The filter circuit acts as low-cut filter. Preferably, the filter circuit interacts with the primary side winding of the transformer. Dependent on the transformation ratio the alternating primary side voltage is transformed into an alternating secondary side voltage by the transformer. Furthermore, due to the transformer the secondary side is isolated from the primary side. The restoration circuit is arranged at the secondary side. By means of the restoration circuit the control voltage is reconstructed on the secondary side of the transformer without affecting its duty cycle or frequency. The restoration circuit is designed such that the blocked direct component is at least partially added to the alternating secondary side voltage in order to provide a unipolar conditioning voltage. By adding the blocked direct component a level of the driving voltage of the power switch is independent from the duty cycle of the control voltage. The duty cycle is the ratio of a pulse duration and a switching period. Therefore, the duty cycle is also called duty ratio. The conditioning voltage has two voltage levels. Dependent on the voltage level the conditioning circuit controls a driving current. For example, at a first voltage level the driving current charges an internal capacitance of the power switch, whereas at a second voltage level the driving current discharges the internal capacitance of the power switch. The internal capacitance of the power switch provides a driving voltage such that the power switch is switched on and switched off. For example, the charged internal capacitance provides a first level of the driving voltage such that the power switch is switched on and the discharged internal capacitance provides a second level of the driving voltage such that the power switch is switched off. Preferably, the power switch is a MOSFET, in particular a n-channel MOSFET. In this case the internal capacitance is a gate-source-capacitance and the driving voltage is a gate-source-voltage. Alternatively, the power switch is a bipolar junction transistor (BJT) or an insulated gate bipolar transistor (IGBT). In case of a bipolar junction transistor the driving voltage is a base-emitter signal, in particular a base-emitter voltage. The output terminals are connected to the power switch. For example, the output terminals are connected to drain and source of the MOSFET or to emitter and collector of the bipolar junction transistor.

A power switching device according to claim 2 ensures a flexible and easy use and operation. To act as a low-cut filter the filter circuit comprises a filter capacitor and a filter resistor. Preferably, the filter capacitor and the filter resistor are connected in series and interact with the primary side winding of the transformer. The filter circuit enables to block the direct component of the buffer output voltage in an easy and reliable manner.

A power switching device according to claim 3 ensures a flexible and easy use and operation. The filter capacitor and the primary side winding build a filter of second order. Preferably, a filter resistor is connected in series to the series connection of the filter capacitor and the primary side winding. The series connection enables to block the direct component of the buffer output voltage.

A power switching device according to claim 4 ensures a flexible and easy use and operation. By means of the restoration capacitor a direct component is added to the alternating secondary side voltage. Due to this added direct component the output voltage of the restoration circuit or the conditioning voltage becomes unipolar. By the unipolar conditional voltage the level of the driving voltage is independent of the duty cycle of the control voltage.

A power switching device according to claim 5 ensures a flexible and easy use and operation. Preferably, the blocking element is connected in parallel to a series connection of the secondary side winding and a restoration capacitor. For example, the blocking element is a diode. Preferably, a series connection of the restoration capacitor and the secondary side winding is connected to a node N_2 and a node N_3. The restoration capacitor is connected to the node N_2, whereas the secondary side winding is connected to the node N_3. A diode is connected to the node N_2 and the node N_3. The diode is connected such that a flow direction of the diode is directed from the node N_3 to the node N_2. The diode allows a current flow from the node N_3 to the node N_2. The blocking element enables a unipolar conditioning voltage at the output of the restoration circuit. Additionally, due to the blocking function the blocking element reduces the driving losses.

A power switching device according to claim 6 ensures a flexible and easy use and operation. By means of the buffer circuit the required power is provided without affecting the controller. Preferably, the buffer circuit is at least one of a Schmitt trigger or a totem pole pair.

A power switching device according to claim 7 ensures a flexible and easy use and operation. The voltage stabilization circuit ensures an essentially constant output voltage which is applied to the buffer circuit. Hence, the power switching device can be operated independent from the quality of the input voltage. For example, the voltage stabilization circuit is based on a Zener diode. Preferably, the voltage stabilization circuit comprises a regulator, for example a low-drop out regulator (LDO regulator).

A power switching device according to claim 8 enables an easy operation. The switch-on-circuit serves to switch on the power switch, whereas the switch-off-circuit serves to switch-off the power switch. The switch-on-circuit works at a first voltage level of the conditioning voltage, whereas the switch-off-circuit works at a second voltage level of the conditioning voltage.

A power switching device according to claim 9 ensures an easy operation. When the conditioning voltage has a first voltage level, the blocking element allows a flow of a driving current such that the power switch is switched on. Preferably, the blocking element is a diode. The blocking element of the switch-on-circuit and the blocking element of the filter circuit are preferably operated in common. If both blocking elements are designed as diodes, these diodes have the same flow direction. Preferably, the blocking element is connected in series to a resistor. Preferably, a series connection of a diode and a resistor is connected to a node N_2 and to the power switch, in particular to a gate terminal of a MOSFET. Preferably, the flow direction of the diode is directed from the node N_2 to the power switch. For example, the power switch is a MOSFET and the driving signal is a driving current through the blocking element such that an internal capacitance of the MOSFET, namely a gate-source-capacitance is charged by the driving current. The gate-source-capacitance provides a driving voltage which switches on the power switch. In particular, the first voltage level is not equal to zero.

A power switching device according to claim 10 ensures an easy operation. When the conditioning voltage has a second voltage level the control switch has a switching state such that the power switch is switched off. Preferably, the control switch is a bipolar junction transistor. For example, the control switch is switched on when the second voltage level is zero and the driving current discharges an internal capacitance of the power switch such that the power switch is switched off. Preferably, the switch-off-circuit comprises exactly one control switch, which is in particular a bipolar junction transistor. Preferably, the bipolar junction transistor is a PNP bipolar junction transistor. Preferably, a collector terminal of the control switch is connected to a source terminal of the power switch, whereas an emitter terminal of the control switch is connected to a gate terminal of the power switch. Preferably, a bias terminal of the control switch is connected to a resistor which is connected to a node N_2. Preferably, the source terminal of the power switch and the collector terminal of the control switch are connected to a node N_3.

A power switching device according to claim 11 ensures an easy operation. Dependent on the voltage level the conditioning circuit controls the driving current and charges or discharges the internal capacitance of the power switch in order to switch on or switch off the power switch. Since the conditioning circuit uses the internal capacitance of the power switch no external capacitor is necessary to provide the driving voltage.

A power switching device according to claim 12 ensures an easy operation. Since the internal capacitance is comparatively small switching on and switching off of the power switch happens quickly by charging or discharging the internal capacitance. Therefore, the power switching device enables a high switching frequency.

A power switching device according to claim 13 ensures a flexible and easy use and operation. The protection circuit comprises at least one measuring element to measure at least one of a current and voltage of the power switch. Dependent on the current and/or voltage of the power switch the protection circuit detects whether the power switch is currently operated in a predefined undesired operation area. The protection circuit provides at least one of the protection features over current protection, short circuit protection and over temperature protection. Furthermore, voltage and current measurements can be used to calculate switching losses and to compare it to worst case conditions in order to detect excessive power losses and/or to provide over voltage protection.

A power switching device according to claim 14 ensures a flexible and easy use and operation. The protection switch switches off the power switch when an operation in an undesired operation area is detected. Preferably, the protection switch is connected in parallel to an internal capacitance of the power switch such that the internal capacitance is discharged and the power switch is switched off when the protection switch is switched on. Preferably, the protection switch is a MOSFET.

A power switching device according to claim 15 ensures a flexible and easy use and operation. When the protection switch is switched on the internal capacitance is discharged and the power switch is switched off. Preferably, the protection switch is designed as n-channel MOSFET. Preferably, a drain terminal of the protection switch is connected to a gate terminal of the power switch and a source terminal of the protection switch is connected to a source terminal of the power switch. Preferably, a control unit is connected to a gate terminal of the protection switch and provides a protection signal to the gate terminal.

A power switching device according to claim 16 ensures a flexible and easy use and operation. The protection circuit provides at least one of a power switch current and a power switch voltage to the control unit. Dependent on the power switch current and/or the power switch voltage the control unit compares an operation point of the power switch with at least one predefined undesired operation area. The control unit provides a protection signal when the operation point is within the at least one undesired operation area. The protection signal may be used as a warning signal and/or to switch off the power switch. For example, the control unit is designed as an IC, a microcontroller or a FPGA.

A power switching device according to claim 17 ensures a flexible and easy use and operation. An additional secondary side supply winding is coupled to the already existing transformer such that a supply voltage is provided to power up the protection circuit. The transformation ratio of the supply winding defines the required supply voltage. The protection circuit may comprise a stabilization circuit to stabilize the supply voltage and to provide an essentially constant input voltage to the control unit. The stabilization circuit comprises a diode, a Zener diode and a capacitor. The diode and the secondary side supply winding are connected in series such that the diode is connected to a node N_4 and the secondary side supply winding is connected to a node N_3. A flow direction of the diode is directed to the node N_4. The Zener diode and the capacitor are connected in parallel to the node N_3 and the node N_4. The anode of the Zener diode is connected to the node N_3 and the cathode of the Zener diode is connected to the node N_4.

Furthermore, it is an object of the present invention to provide a flexible and easy method to operate a power switching device.

This object is achieved by a method to operate a power switching device comprising the steps of claim 18. The advantages of the method according to the invention correspond to the advantages of the power switching device according to the invention already described before.

Further features, advantages and details of the invention will be apparent from the following description of an embodiment which refers to the accompanying drawings.

Fig. 1 shows a schematic diagram of a power switching device,

Fig. 2 shows a schematic diagram of a conditioning circuit of the power switching device in Fig. 1,

Fig. 3 shows a time diagram of a conditioning voltage with a first voltage level and a second voltage level at the input of the conditioning circuit,

Fig. 4 shows an equivalent circuit of the conditioning circuit when the first voltage level is applied to the conditioning circuit, and

Fig. 5 shows an equivalent circuit of the conditioning circuit when the second voltage level is applied to the conditioning circuit.

Fig. 1 shows a power switching device 1 which is designed as a plug and play module. The power switching device 1 comprises three input terminals in_1, in_2 and in_3 and two output terminals out_1 and out_2. An input voltage V_{in} from a power stage (not shown) is applied to the first input terminal in_1. A unipolar control voltage V_G from a controller (not shown) is applied to the second input terminal in_2. The control voltage V_G is preferably a PWM signal. A common ground of the power stage and the controller is applied to the third input terminal in_3.

The power switching device 1 comprises a voltage stabilization circuit 2 which is connected upstream of a buffer circuit 3 to the first input terminal in_1. The voltage stabilization circuit 2 comprises a diode D_1, a Zener diode Z_{Vcc} and a capacitor C_{Vcc}. The diode D_1 is connected to the first input terminal in_1 and a first node N_1. A parallel connection of the Zener diode Z_{Vcc} and the capacitor C_{Vcc} is connected to the first node N_1 and a reference node N_0. The reference node N_0 is connected to the third input terminal in_3.

The first node N_1 is connected to the buffer circuit 3 such that the voltage stabilization circuit 2 provides a stabilized input voltage V_{cc} to the buffer circuit 3. The second input terminal in_2 is connected to the buffer circuit 3 such that the buffer circuit 3 provides a unipolar buffer output voltage V_b dependent on the stabilized input voltage V_{cc} and the control voltage V_G. The buffer circuit 3 comprises at least one of a voltage amplifier and a current amplifier. For example, the buffer circuit 3 is designed as Schmitt trigger or a totem pole pair. The buffer circuit 3 is connected to the reference node N_0. Due to the buffer circuit 3 the required power is provided by the power stage and the controller is not affected by the required power.

The buffer circuit 3 is connected to a filter circuit 4. The filter circuit 4 serves to block a direct component V_{DC} of the buffer output voltage V_b and to provide an alternating primary side voltage V_1. The filter circuit 4 comprises a filter resistor R_p and a filter capacitor C_p which are connected in series. The series connection of the filter resistor R_p and the filter capacitor C_p is connected to the buffer circuit 3 and a transformer 5. The series connection of the filter resistor R_p and the filter capacitor C_p is connected in series to a primary winding 6 of the transformer 5. The primary side winding 6 is further connected to the reference node N_0. Due to the series connection of the filter resistor R_p, the filter capacitor C_p and the primary side winding 6 the filter circuit 4 acts as low-cut filter.

At the secondary side the transformer 5 comprises a secondary side winding 7 and a secondary side supply winding 8. The primary side winding 6 and the secondary side winding 7 define a first transformation ratio. The alternating primary side voltage V_1 is transformed to the secondary side such that the transformer 5 provides an alternating secondary side voltage V_2 dependent on the first transformation ratio. The transformer 5 isolates the primary side from the secondary side.

A restoration circuit 9 is connected to the secondary side winding 7. The restoration circuit 9 adds the blocked direct component V_{DC} to the secondary side voltage V_2 and provides a unipolar conditioning voltage V_D which is the input voltage of a conditioning circuit 10. The restoration circuit 9 comprises a restoration capacitor C_S and a blocking element D_r. The restoration capacitor C_S is connected in series to the secondary side winding 7. The series connection of the restoration capacitor C_S and the secondary side winding 7 is connected to a second node N_2 and a third node N_3. The blocking element D_r is connected to the second node N_2 and the third node N_3 such that it is connected in parallel to the series connection of the restoration capacitor C_S and the secondary side winding 7. The blocking element D_r is designed as diode. The conditioning voltage V_D is the voltage across the blocking element D_r.

The conditioning circuit 10 comprises a switch-on-circuit 11 and a switch-off-circuit 12. The switch-on-circuit 11 switches on a power switch 13 when the conditioning voltage V_D has a first voltage level V_{D1}, whereas the switch-off-circuit 12 switches off the power switch 13 when the conditioning voltage V_D has a second voltage level V_{D2}.

The conditioning voltage V_D is shown in Fig. 3, wherein t denotes time. The conditioning voltage V_D is due to the added direct component V_{DC} unipolar and corresponds essentially to the control voltage V_G. Within a switching period T_S the conditioning voltage V_D has the first voltage level V_{D1} for a time period of $D \cdot T_S$ and the second voltage level V_{D2} for a time period of $(1 - D) \cdot T_S$. D denotes the duty cycle of the power switch 13. The second voltage level V_{D2} is essentially zero. The first voltage level V_{D1} is positive.

The power switch 13 is designed as n-channel MOSFET. A drain terminal D is connected to the first output terminal out_1, whereas a source terminal S is connected to the second output terminal out_2. The power switch 13 comprises a gate-source capacitance C_{GS} between a gate terminal G and the source terminal S.

The switch-on-circuit 11 comprises a blocking element D_{on} and a resistor R_{on}, which are connected in series. The blocking element D_{on} is a diode. The series connection of the blocking element D_{on} and the resistor R_{on} is connected to the second node N_2 and to the gate terminal G. The third node N_3 is connected to the source terminal S. When the conditioning voltage V_D has the first voltage level V_{D1} the switch-on-circuit 11 provides a driving current i which charges the gate-source capacitance C_{GS} and provides a driving voltage V_{GS} that switches on the power switch 13. This is shown in Fig. 4.

The switch-off-circuit 12 comprises a control switch S_1. The control switch S_1 is designed as bipolar junction transistor. Preferably, the bipolar junction transistor is a PNP bipolar junction transistor. A collector terminal C of the control switch S_1 is connected to the source terminal S, whereas an emitter terminal E of the control switch S_1 is connected to the gate terminal G. A bias terminal B of the control switch S_1 is connected to a resistor R_{off} which is connected to the second node N_2. When the conditioning voltage V_D has the second voltage level V_{D2}, namely essentially zero, the switch-on-circuit 11 is blocked by the diode D_{on} and the control switch S_1 is switched on due to the driving voltage V_{GS} and a current via the emitter terminal E and the bias terminal B. The control switch S_1 acts as a short circuit such that the gate-source-capacitance C_{GS} is discharged by a driving current i and the power switch 13 is switched off. The switch-off-circuit 12 is shown in Fig. 5.

Furthermore, the power switching device 1 comprises a protection circuit 14 in order to detect whether the power switch 13 is operated in an undesired operation area. The secondary side supply winding 8 provides a supply voltage V_3 which is used for power supply of the protection circuit 14. The primary side winding 6 and the secondary side supply winding 8 define a second transformation ratio which depends on the required supply voltage V_3. The protection circuit 14 comprises a stabilization circuit 15 which provides a stabilized supply voltage V_{bias}. The stabilized supply voltage V_{bias} is applied to a control unit 16.

The stabilization circuit 15 comprises a diode D_{bias}, a Zener diode Z_{bias} and a capacitor C_{bias}. The diode D_{bias} and the secondary side supply winding 8 are connected in series. The secondary side supply winding 8 is connected to the third node N_3. The diode D_{bias} is connected to a fourth node N_4. The Zener diode Z_{bias} and the capacitor C_{bias} are connected in parallel to the third node N_3 and the fourth node N_4. Hence, the control unit 16 shares the same ground as the power switch 13.

The protection circuit 14 comprises a measuring element 17 to measure a power switch current i_P. The measured power switch current i_P‘ is provided to the control unit 16. Furthermore, a power switch voltage V_P is provided to the control unit 16. The power switch voltage V_P is in particular the drain-source-voltage of the power switch 13. Dependent on the power switch current i_P‘ and/or the power switch voltage V_P the control unit 16 determines whether the power switch 13 is operated within an undesired operation area or not. In case the power switch 13 is operated within an undesired operation area the control unit 16 creates a protection signal p. The protection signal p is in particular a voltage signal.

The protection circuit 15 comprises a protection switch S_2 which serves to switch off the power switch 13 in case that the power switch 13 is operated within an undesired operation area. The protection switch S_2 is connected in parallel to the gate-source-capacitance C_{GS}. The protection switch S_2 provides a short circuit to the gate-source-capacitance C_{GS} in case it is switched on.

The protection switch S_2 is designed as n-channel MOSFET. A drain terminal d of the protection switch S_2 is connected to the gate terminal G, whereas a source terminal s of the protection switch S_2 is connected to the source terminal S. The control unit 16 is connected to a gate-terminal g of the protection switch S_2 and provides the protection signal p to the gate terminal g.

The power switching device 1 acts as a plug and play module and can be used for many applications where the source terminal S of the power switch 13 is connected to a fixed voltage or a floating voltage. The power switching device 1 omits the effort usually needed to design properly driving and conditioning scheme for switches that have floating sources such as switches utilized in isolated topologies, conventional non-isolated topologies with floating source-power devices or topologies with an unconventional way of connecting power devices. The power switching device 1 can be powered up using a power stage even if it is used in isolated topology. Real-life examples of potential applications are isolated topologies such as flyback, flybuck, forward, push-pull, half bridge and full bridge and also, non-isolated topologies which have a high side switch or floating source-switch, such as buck, boost and buck-boost converters. Using the power switching device 1 solves the problem of driving and conditioning since the device 1 or many of them connected in every possible way in a circuit topology, can be easily driven using the same controller that shares the same power stage ground without building dedicated power supply for each switch 13. Furthermore, the power switching device 1 provides different protection features such as over current protection, short circuit protection and over temperature protection.

The power switching device 1 is capable of working regardless of the source connection of the power switch 13 since it uses the transformer 5 to provide an isolated differential gate-source voltage V_{GS} that is positive when it is desired to turn on the power switch 13 or an almost zero voltage when it is desired to turn off the power switch 13. The power switching device 1 can be operated with a bipolar or a unipolar control voltage V_G. Preferably, the controller can only generate a unipolar control voltage V_G, namely a positive or negative voltage, with respect to the ground. Hence, the power switching device 1 needs an isolation or dedicated power supply to provide the required driving voltage V_{GS}. Due to the buffer circuit 3 the required power is provided by the power stage and the controller is not affected by the required power. The voltage stabilization circuit 2 can be designed as low-drop out regulator (LDO). The filter circuit 4 blocks the direct component V_{DC} in the unipolar buffer output voltage V_b such that the resulting alternating primary side voltage V_1 is transformed into the alternating secondary side voltage V_2. The restoration circuit 9 restores the blocked direct component V_{DC} according to the transformation ratio of the transformer 5. Due to the restoration circuit 9 the level of the driving voltage V_{GS} is not dependent on the duty cycle D. The blocking element or diode D_r is used to block the negative part of the secondary side voltage V_2 and to reduce the gate driving losses. The blocking element or diode D_{on} and the resistor R_{on} are used to charge the gate-source capacitance C_{GS} and to turn the power switch 13 on when the control voltage V_G is high, whereas the control switch S_1 (PNP bipolar junction transistor) is used to discharge the gate-source capacitance C_{GS} and to turn off the power switch 13 when the control voltage V_G is low. The power switching device 1 works with a power switch 13 that is designed as MOSFET, bipolar junction transistor or IGBT since all of these power switches 13 require a differential driving signal with respect to its source terminal or emitter terminal.

Additionally, the power switching device 1 provides different protection features. Since the control unit 16 shares the same ground as the power switch 13, the current and voltage information can be fed directly to it. Since the power switch current i_P and the power switch voltage V_P are available, over current protection, short circuit protection and over temperature protection can be provided by calculating undesired operation areas and safe operation areas. Additionally, switch power losses and temperature rise can be calculated and estimated. Furthermore, voltage and current measurements can be used to calculate switching losses and to compare it to worst case conditions in order to detect excessive power losses and/or to provide over voltage protection. When any violation of the safe operation is detected, the control unit 16 produces a protection signal p, namely a high gating pulse to the protection switch S_2 such that the power switch 13 is turned off and hence protected.

Claims

1. Power switching device, comprising
   - a first input terminal (in_1) to apply an input voltage (V_{in}) from a power stage,
   - a second input terminal (in_2) to apply a control voltage (V_G) from a controller,
   - a buffer circuit (3) to provide a buffer output voltage (V_b) dependent on the input voltage (V_{in}) and the control voltage (V_G),
   - a filter circuit (4) to block a direct component (V_{DC}) of the buffer output voltage (V_b) and to provide a primary side voltage (V_1),
   - a transformer (5) to transform the primary side voltage (V_1) into a secondary side voltage (V_2),
   - a restoration circuit (9) to at least partially add the blocked direct component (V_{DC}) to the secondary side voltage (V_2) and to provide a conditioning voltage (V_D),
   - a conditioning circuit (10) to provide a driving signal (i, V_{GS}) dependent on the conditioning voltage (V_D), and
   - a power switch (13) connected to a first output terminal (out_1) and a second output terminal (out_2), which is controlled by the driving signal (i, V_{GS}).

2. Power switching device according to claim 1, **characterized in that** the filter circuit (4) comprises a filter capacitor (C_p) and a filter resistor (R_p), which are in particular connected in series.

3. Power switching device according to claim 1 or 2, **characterized in that**

the filter circuit (4) comprises a filter capacitor (C_p), which is connected in series to a primary side winding (6) of the transformer (5).

4. Power switching device according to at least one of claims 1 to 3,
characterized in that
the restoration circuit (9) comprises a restoration capacitor (C_s), which is connected in series to a secondary side winding (7) of the transformer (5).

5. Power switching device according to at least one of claims 1 to 4,
characterized in that
the restoration circuit (9) comprises a blocking element (D_r), in particular a diode, which is connected in parallel to a secondary side winding (7) of the transformer (5), and in particular to a series connection of the secondary side winding (7) and a restoration capacitor (C_s).

6. Power switching device according to at least one of claims 1 to 5,
characterized in that
the buffer circuit (3) comprises at least one of a voltage amplifier and a current amplifier.

7. Power switching device according to at least one of claims 1 to 6,
characterized in that
a voltage stabilization circuit (2) is connected upstream of the buffer circuit (3) to the first input terminal (in_1).

8. Power switching device according to at least one of claims 1 to 7,
characterized in that

the conditioning circuit (10) comprises a switch-on-circuit (11) and a switch-off-circuit (12).

9. Power switching device according to at least one of claims 1 to 8, **characterized in that** a switch-on-circuit (11) is part of the conditioning circuit (10) and comprises a blocking element (D_{on}), in particular a diode, which allows a flow of a driving current (i) such that the power switch (13) is switched on when the conditioning voltage (V_D) has a first voltage level (V_{D1}).

10. Power switching device according to at least one of claims 1 to 9, **characterized in that** a switch-off-circuit (12) is part of the conditioning circuit (10) and comprises a control switch (S_1), in particular a bipolar junction transistor, which allows a flow of a driving current (i) such that the power switch (13) is switched off when the conditioning voltage (V_D) has a second voltage level (V_{D2}).

11. Power switching device according to at least one of claims 1 to 10, **characterized in that** the conditioning circuit (10) is connected to the power switch (13) such that at a first voltage level (V_{D1}) of the conditioning voltage (V_D) a driving current (i) charges an internal capacitance (C_{GS}) of the power switch (13) and that at a second voltage level (V_{D2}) of the conditioning voltage (V_D) the driving current (i) discharges the internal capacitance (C_{GS}) of the power switch (13).

12. Power switching device according to at least one of claims 1 to 11, **characterized in that** the conditioning circuit (10) is connected to the power switch (13) such that a charged internal capacitance (C_{GS}) of the power switch (13) provides a first level of a driving voltage (V_{GS}) such that the power switch (13) is switched on and the discharged internal capacitance (C_{GS}) provides a second level of the driving voltage (V_{GS}) such that the power switch (13) is switched off.

13. Power switching device according to at least one of claims 1 to 12, **characterized by** a protection circuit (14) to detect an operation of the power switch (13) in an undesired operation area.

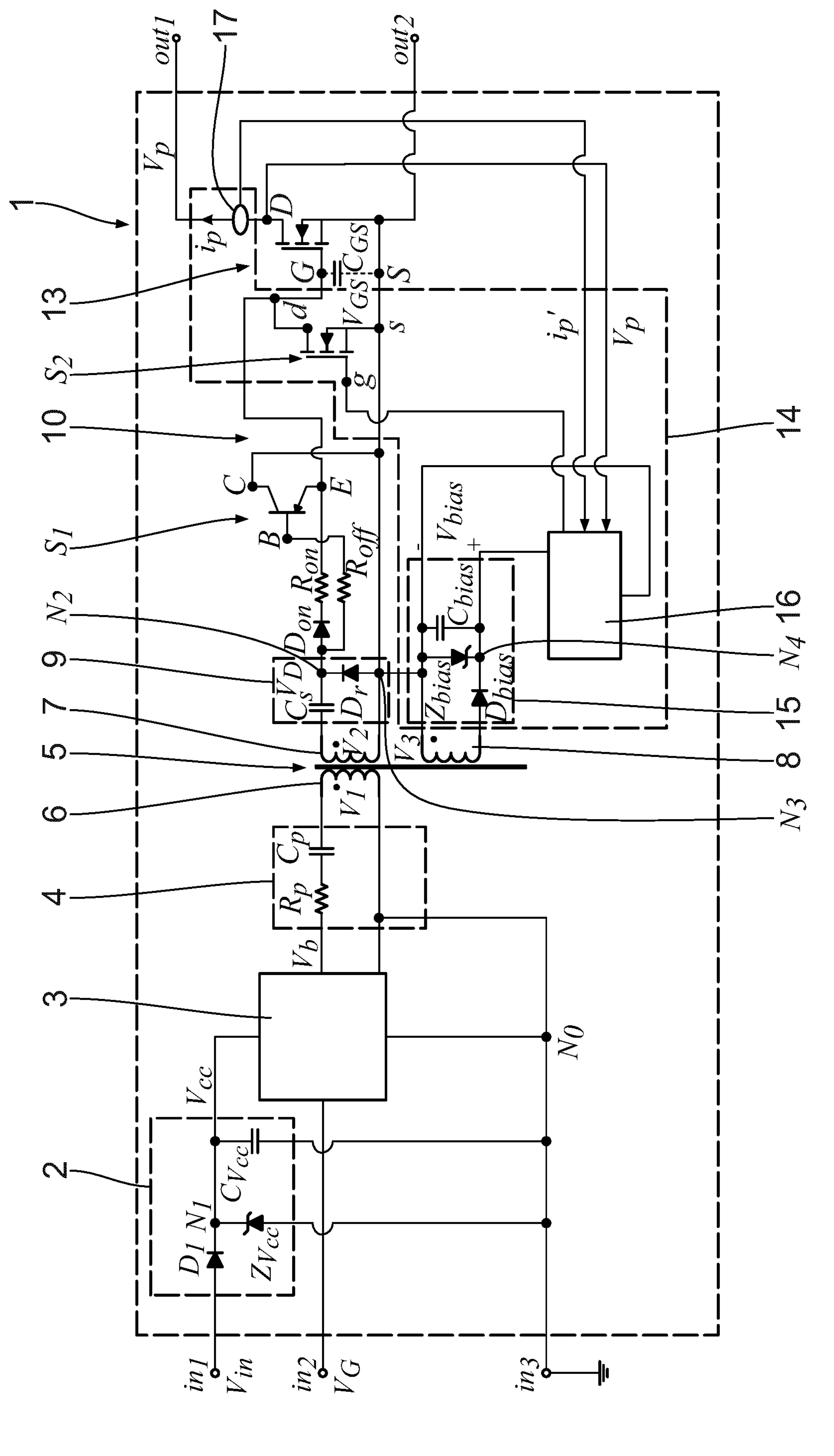
14. Power switching device according to claim 13, **characterized in that** the protection circuit (14) comprises a protection switch (S_2) to switch off the power switch (13) when an operation in an undesired operation area is detected.

15. Power switching device according to claim 14, **characterized in that** the protection switch (S_2) is connected in parallel to an internal capacitance (C_{GS}) of the power switch (13).

16. Power switching device according to at least one of claims 13 to 15, **characterized in that** the protection circuit (14) comprises a control unit (16) to provide a protection signal (p) dependent on at least one of a power switch current (i_P) and a power switch voltage (V_P).

17. Power switching device according to at least one of claims 13 to 16, **characterized in that** the transformer (5) comprises a secondary side supply winding (8) to provide a supply voltage (V_3) to the protection circuit (14).

18. Method to operate a power switching device, comprising the following steps:
   - providing a power switching device (1) according to at least one of claims 1 to 17,
   - applying an input voltage (V_{in}) from a power stage to the first input terminal (in_1),
   - applying a unipolar control voltage (V_G) from a controller to the second input terminal (in_2),
   - providing a unipolar buffer output voltage (V_b) dependent on the input voltage (V_{in}) and the unipolar control voltage (V_G),
   - blocking a direct component (V_{DC}) of the unipolar buffer output voltage (V_b) and providing an alternating primary side voltage (V_1),
   - transforming the alternating primary side voltage (V_1) into an alternating secondary side voltage (V_2),
   - adding at least partially the blocked direct component (V_{DC}) to the alternating secondary side voltage (V_2) and providing a unipolar conditioning voltage (V_D), and
   - controlling the power switch (13) dependent on the unipolar conditioning voltage (V_D).



out1
out2
17
1
13
S2
10
S1
N2
9
7
5
6
4
3
2
14
16
N4
15
8
N3
Vp
ip
D
G
S
CGS
VGS
d
s
g
C
B
E
Ron
Roff
Don
CVD
Cs
Dr
V2
V3
V1
Vbias
Cbias
Zbias
Dbias
ip'
Cp
Rp
Vb
Vcc
N0
CVcc
N1
D1
ZVcc
in1
Vin
in2
VG
in3

Fig. 1

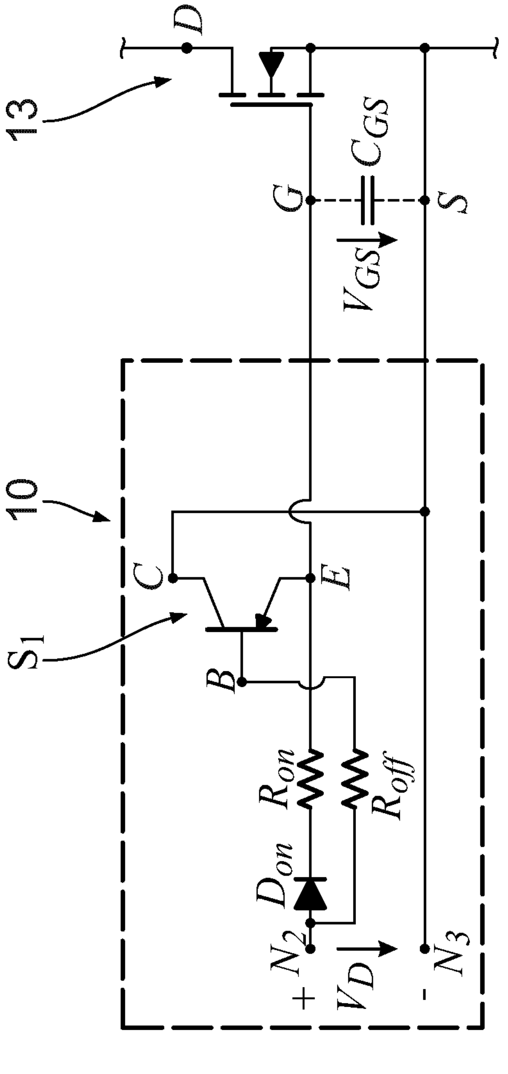

13
10
S1
D
G
S
C
E
B
C_{GS}
V_{GS}
R_{on}
R_{off}
D_{on}
N_2
N_3
V_D
+
-

Fig. 2

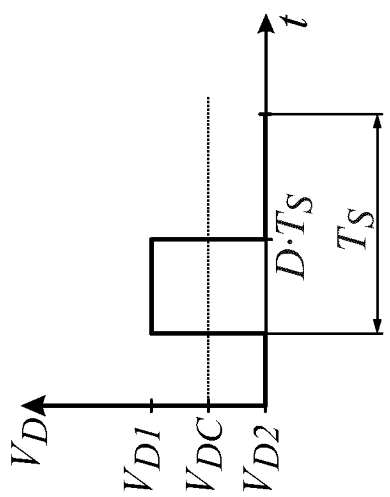

t
V_D
V_{D1}
V_{DC}
V_{D2}
$D{\cdot}T_S$
T_S

Fig. 3

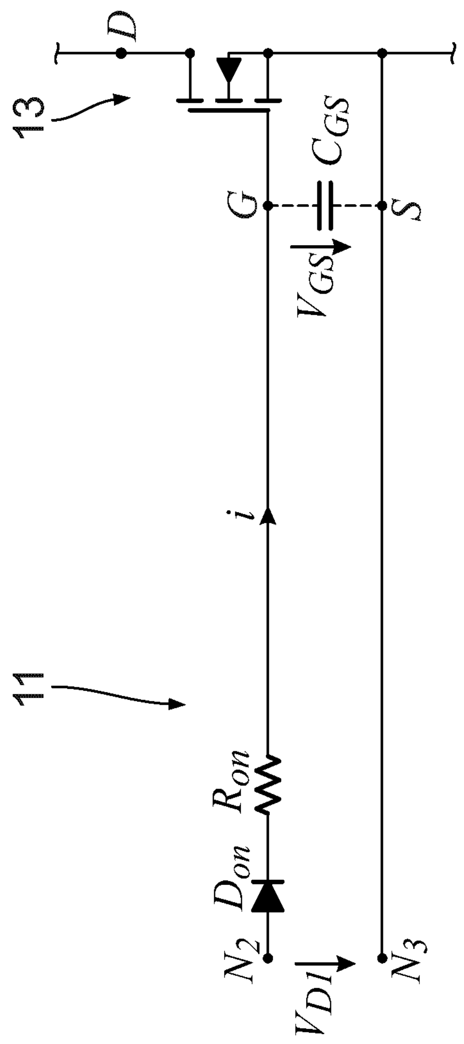

D
13
C_{GS}
G
S
V_{GS}
i
11
R_{on}
D_{on}
N_2
N_3
V_{D1}

Fig. 4

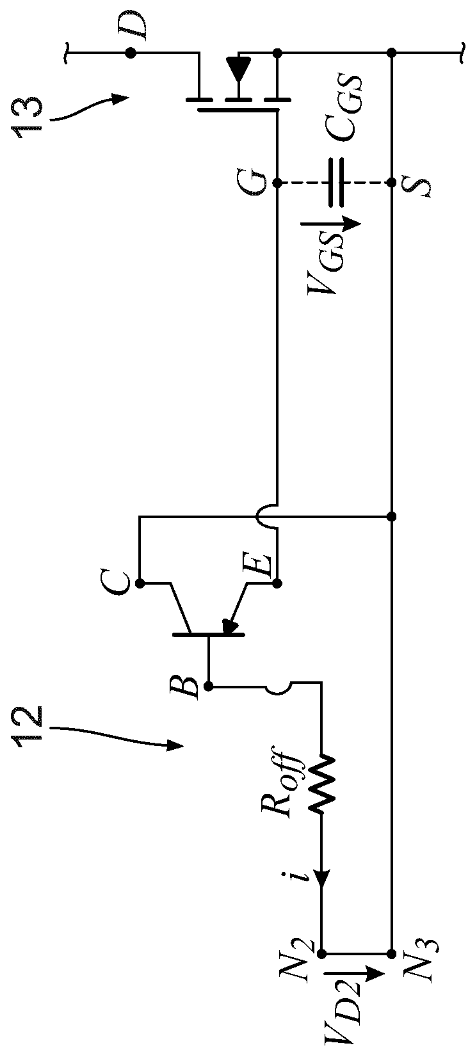

D
13
C_{GS}
G
S
V_{GS}
C
E
B
12
R_{off}
i
N_2
N_3
V_{D2}

Fig. 5

INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2018/055909

A. CLASSIFICATION OF SUBJECT MATTER
INV. H03K17/082 H03K17/691
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)
H03K

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 2014/367563 A1 (ZHONG QISHUI [CN] ET AL) 18 December 2014 (2014-12-18) figure 4 -----	1-18
X	US 2003/164721 A1 (REICHARD JEFFREY A [US]) 4 September 2003 (2003-09-04) figure 2a -----	1-4,6-18
X	US 5 019 719 A (KING RAY [US]) 28 May 1991 (1991-05-28) figure 1 -----	1-18
A	DE 103 12 704 A1 (CONTI TEMIC MICROELECTRONIC [DE]) 30 September 2004 (2004-09-30) paragraph [0024]; figure 1 -----	13-17
	-/--	

[X] Further documents are listed in the continuation of Box C.

[X] 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
7 May 2018	17/05/2018

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	Loiseau, Ludovic

1

International application No
PCT/EP2018/055909

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 2009/147544 A1 (MELANSON JOHN L [US]) 11 June 2009 (2009-06-11) figure 1A	17
A	WO 2015/016891 A1 (SCHNEIDER ELECTRIC SOLAR INVERTERS USA INC [US]) 5 February 2015 (2015-02-05) figure 2	9-12

1

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No
PCT/EP2018/055909

Patent document cited in search report		Publication date	Patent family member(s)			Publication date
US 2014367563	A1	18-12-2014	CN	104022676	A	03-09-2014
			US	2014367563	A1	18-12-2014
			US	2016054265	A1	25-02-2016
US 2003164721	A1	04-09-2003	NONE			
US 5019719	A	28-05-1991	NONE			
DE 10312704	A1	30-09-2004	DE	10312704	A1	30-09-2004
			WO	2004084409	A1	30-09-2004
US 2009147544	A1	11-06-2009	NONE			
WO 2015016891	A1	05-02-2015	CN	105493398	A	13-04-2016
			EP	3028379	A1	08-06-2016
			US	2016191053	A1	30-06-2016
			WO	2015016891	A1	05-02-2015