Built-in BSD-Function 600V High Voltage Integrated Circuit "M81777FP"

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1. Introduction

In recent years, there has been a growing global trend toward environmental protection such as carbon neutrality and the Sustainable Development Goals (SDGs). Power semiconductors are key parts for saving energy and raising efficiency and thus reducing environmental impact. Amid these circumstances, the use of inverters in motor drive systems for home appliances and industrial equipment has been expanding steadily. Also, there is growing demand for driver ICs that use inverter systems to drive power semiconductors. To increase the capacity of the inverter while reducing its size, the drive systems also need to contribute to downsizing and fewer parts.

As technologies for driver ICs such as our high-voltage integrated circuits (HVICs), we developed our proprietary divided RESURF structure (first generation) in 1997 and commercialized 1,200-V HVICs. In 2008, we developed and commercialized the second-generation divided RESURF structure with higher withstand voltage and larger malfunction tolerance for the 600-V class by fine-pattern forming an N+ buried layer on the first-generation divided RESURF structure.[1] In addition, we applied our proprietary field plate technology to this second-generation divided RESURF structure to increase the withstand voltage to 1,200 V and have been working to commercialize it.[2] The divided RESURF structure is applied to laterally double-diffused metal-oxide-semi-conductor field-effect-transistors (LDMOSFETs). LDMOSFETs are used to convert the voltage to a level to drive high-side circuits; this is called high-voltage level shift in HVICs. Applying the divided RESURF structure increases the withstand voltage and malfunction tolerance while remarkably reducing the area that the LDMOSFETs occupies on a chip. This makes it possible to enhance the drive performance of the driver IC per chip area (larger capacity and higher voltage) and to include protection circuits and power circuits, which used to be configured with external components, thus downsizing and reducing the number of parts and greatly enhancing the system performance.

This paper outlines the built-in BSD-function 600-V high voltage half-bridge driver M81777FP developed this time along with its key technologies, performance and quality. This M81777FP half-bridge driver has a built-in diode function for bootstrap circuits.

2. Built-in BSD-Function 600-V High Voltage Half-bridge Driver M81777FP

2.1 Product outline of M81777FP

Figure 1 shows a functional block diagram of the built-in BSD-function 600-V high voltage half-bridge driver M81777FP. Its functions are listed below.

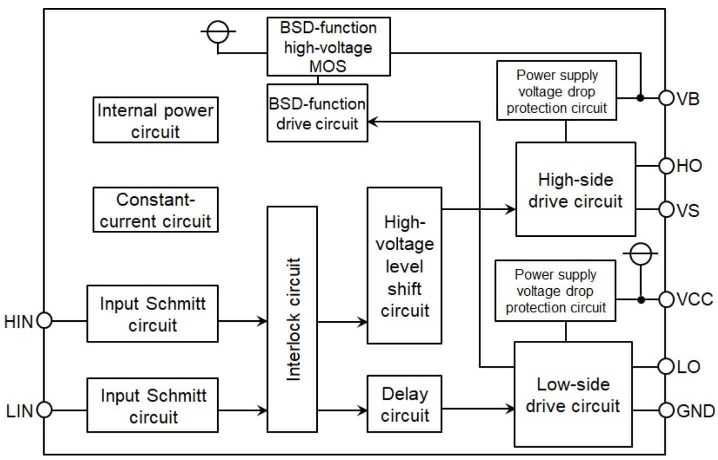


Fig. 1 Functional block diagram of M81777FP

*Power Device Works

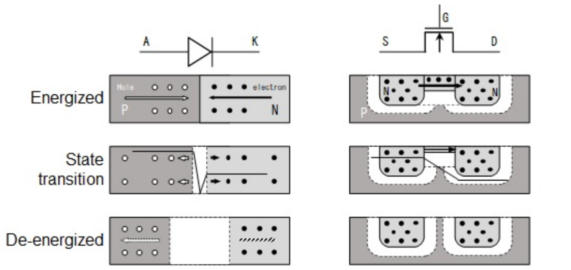


Fig. 2 Comparison of conductive state between diode and MOSFET

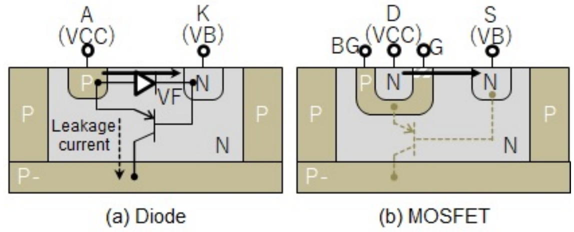


Fig. 3 Cross section of diode and MOSFET

(1) Half-bridge drive
(2) 600-V high-voltage built-in BSD-function
(3) Interface supporting 3.3- and 5.0-V logic input
(4) Input interlock (to prevent the output turning on simultaneously)
(5) 600-V high-voltage level shift circuit
(6) Output current performance (+200 mA/−350 mA)
(7) Power supply voltage drop protection circuits (UV: VCC/VBS)

To make it easy to replace the conventional basic models M81736FP and M81776FP, the M81777FP was designed with compatible pin locations and various properties other than the BSD function.(3)

2.2 Built-in diode function for bootstrap circuits

2.2.1 Use of high-voltage MOSFETs for the BSD function

On the M81777FP, the diode function necessary for bootstrap circuits is realized by operating the high-voltage MOSFETs in ICs as an alternative means. Details of the technologies that allow MOSFETs to be used for charging operation are described below along with their advantages.

(1) Suppression of recovery currents and leakage currents when energized

Figure 2 illustrates the movement of carriers in a diode and MOSFET when energized. For a diode, there are two types of carriers that generate currents: holes, and electrons, so it is a bipolar device. When the state changes from energized to de-energized, the carriers travel in the opposite direction until a depletion layer forms. The movement of carriers in this transition region results in recovery currents and surges. On the other hand, for a MOSFET, there is only one type of carrier that generates currents, so it is a unipolar device. When the state changes from energized to de-energized, no new depletion layer area is formed and whether a current is generated is determined only by the presence or absence of a channel. Accordingly, although recovery currents are problems in diodes, no such currents are generated in MOSFETs.

One advantage of charging operation by MOSFETs is that leakage currents during charge can also be suppressed. Figure 3 illustrates cross sections of a diode and MOSFET. In the diode configuration, when it is biased from the P to N direction, forward voltage VF is generated due to the PN junction. Because the IC is in a junction isolation structure, parasitic PNP Tr occurs with the substrate (P-) as a collector. As the charging current is larger, more base current for this parasitic PNP Tr is secured and the leakage current toward the substrate increases. This current loss makes it difficult to secure product quality because it sometimes causes a latchup phenomenon or other problems. On the other hand, in a MOSFET, the charging current flows from the drain (N) to the source (N) and so no forward voltage VF due to the PN junction is generated. Although parasitic PNP Tr exists in this configuration, if the bias between the MOSFET back gate and source is appropriately treated, no leakage current toward the substrate occurs. Accordingly, the MOSFET configuration is more advantageous for ensuring product quality than the diode configuration.

(2) Gate drive of BSD-function MOSs

Diodes function in a passive way whereby the bias condition of the terminals uniquely determines the state (energization and non-energization). On the other hand, MOSFETs are active elements for which the bias condition of each terminal determines energization, non-energization, amplification, and attenuation. To use MOSFETs for charging operation, the bias of the terminals-gate drive signals in particular-needs to be appropriately applied. Figure 4 shows a simplified circuit structure of a conventional bootstrap circuit consisting of external elements and that where a MOSFET inside an IC is used for charging operation.

In a bootstrap circuit, a diode and resistance are connected between the primary power source (VCC) and secondary power source (VB) and the secondary reference potential (VS) determines whether charging is performed. In the conventional structure, because a diode is connected, when potential VS decreases, charging is performed; and when it increases, the diode is reverse-biased and de-energized in due course.

On the other hand, because MOSFETs are active elements as described above, MOSFET gate drive signals need to be appropriately given to use them for this charging operation.

Figure 5 shows an inverter circuit of half-bridge drive. Whether charging is performed is determined based on potential VS (reference potential). Accordingly, the signal to determine potential VS needs to be synchronized with the BSD-function MOS gate drive signal. Potential VS is the potential at the point at which an output node of the inverter (load) is connected. In a bootstrap circuit, charging operation is performed when potential VS is low (GND level) and this is determined when the N-side transistor of the inverter is in the ON state. Consequently, when the LO output is high, the gate drive synchronization signal is given to perform charging operation and when the LO output is low, charging operation is not performed because potential VS is uncertain or high (level of the power source of the load).

(3) Securing the charging voltage of the secondary power source

The use of synchronization signals described in the previous section to drive the BSD-function MOS gate enables bootstrap charging operation. However, to charge the secondary power source such that its voltage is at the same level as that of the primary power source, the BSD-function MOS needs to be biased in a triode region. As shown in Fig. 4, which is a simplified circuit diagram of the BSD function of a high-voltage MOSFET, a boosted voltage is applied to the MOSFET gate by the charge pump circuit consisting of a diode, capacitance, and buffer circuit. Due to this, the BSD-function MOS operates as a triode and the secondary power source can be charged such that the voltage becomes the same level as that of the primary power source. Figure 6 shows the gate voltage of the BSD-function MOS for each boosting method. In the simplified circuit diagram shown in Fig. 4, boosting operation is performed once per synchronization signal and so the boosted gate potential decreases over time. For the M81777FP, in addition to the structure where boosted voltage is applied to the BSD-function MOS gate, our proprietary circuit structure is used. In the structure, while a synchronization signal is given, the boosted voltage to the gate can be retained. In this booster circuit configuration, the gate potential is kept excited by the boosting operation, which enables stable charging operation.

In addition, in the simplified circuit structure, the potential of the gate voltage is the same as that of VCC and the voltage between the MOSFET gate and source is 0 V when the BSD-function MOS is in the OFF state. Meanwhile, for the M81777FP, 0 V is given as the gate potential to make the OFF state “strong”. This bias method secures a large tolerance to momentary interruption of the primary power source and a malfunction when switching noise occurs on the inverter.

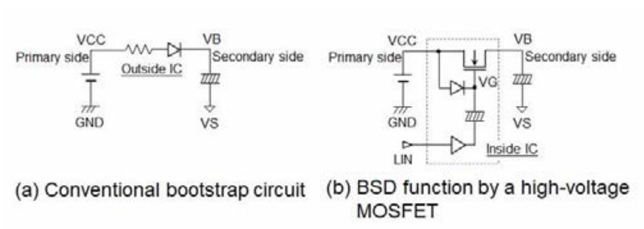


Fig. 4 Simplified circuit structure of each method for charging

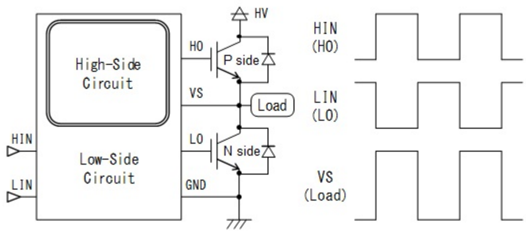
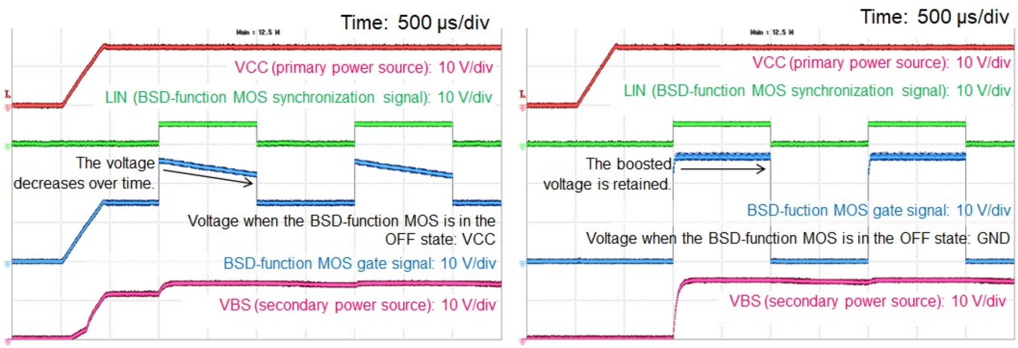


Fig. 5 Inverter circuit of half-bridge drive



(a) Charging operation by the BSD-function MOS of the simplified circuit

(b) Charging operation by the BSD-function MOS of the M81777FP

Fig. 6 Charging function of each method for boosting using BSD-function MOS

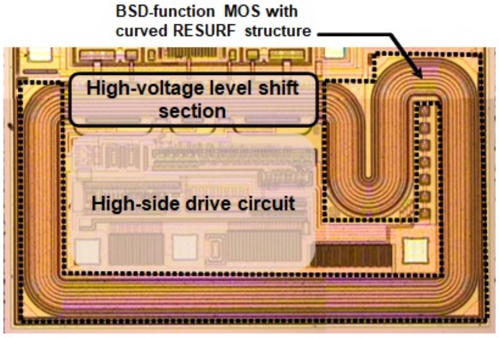


Fig. 7 BSD-function MOS layout of M81777FP

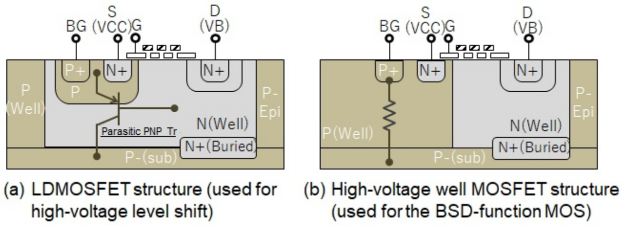


Fig. 8 Cross section of high voltage MOSFET

2.2.2 Current limiting resistance by the on-resistance of the BSD-function MOS

In addition to diodes and capacitors, another element necessary for bootstrap charging is current limiting resistance to suppress surge currents during charging. For the M81777FP, current limiting resistance is realized by the on-resistance of the BSD-function MOS. Figure 7 illustrates the layout of the M81777FP BSD-function MOS. For HVICs, LDMOSFETs are independently arranged by the divided RESURF structure for high-voltage level shift and a BSD-function MOS is provided in a different area. Because the on-resistance of the MOSFET is used as current limiting resistance, the W width of the MOS needs to be adjusted to set a resistance value. If the RESURF structure is extended to secure the W width, a dead space is formed in the high-side drive circuit area. To solve this problem, we have developed a new curved RESURF structure for the M81777FP and this makes it possible to set a current limiting resistance value while minimizing the dead space. For the M81777FP, the current limiting resistance value is adjusted to be 100Ω.

2.2.3 High-voltage MOSFET structure used for BSD-function MOSs

As high-voltage MOSFET structures, there are LDMOSFETs for high-voltage level shift as described in the previous section. For BSD-function MOSs, our newly-developed proprietary high-voltage well MOSFET structure was adopted to secure malfunction tolerance. Figure 8 illustrates the cross-sectional structure of a conventional LDMOSFET and the high-voltage well MOSFET developed this time. One difference between the high-voltage well MOSFET and LDMOSFET is that the new type of MOSFET involves deep P-well diffusion where the MOS back gate is in contact with the substrate (P-).

When an LDMOSFET used for high-voltage level shift is applied as a BSD-function MOS, the back gate and source of the MOS need to be independent and the current input from the back gate to the drain needs to be suppressed. As shown in Fig. 8, in the LDMOSFET structure, there is parasitic PNP Tr between the back gate, drain, and substrate. Generally, parasitic PNP Tr is biased in an OFF state and so does not cause malfunctions. However, during initial charging of the secondary power source (VB) or by a VS negative potential surge that occurs in freewheel diode flowback mode during inverter switching, this parasitic PNP Tr may be active. Accordingly, there were problems with securing malfunction tolerance, including an increase in leakage currents and the occurrence of latchup. For the high-voltage well MOSFET developed this time, as shown in Fig. 8, the back gate is in contact with the substrate and so there is no parasitic PNP Tr which can cause malfunctions. Thanks to this, the M81777FP has large malfunction tolerance to noise during initial charging and VS negative potential surges.

3. Conclusion

We have developed the built-in BSD-function 600-V half-bridge driver M81777FP in which the high-voltage MOSFETs in ICs provide the diode function necessary for bootstrap circuits. This will help reduce the number of parts in inverter drive systems.

References

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