

New 1200 V SiC MOSFET Intelligent Power Module

Miran Baek¹, Minsub Lee¹, Soohyuk Han¹, Junbae Lee¹, Daewoong Chung¹

¹ Infineon Technologies Korea, Korea

Miran Baek, Miran.Baek@Infineon.com

Abstract

This paper presents the new and smallest 1200 V silicon carbide (SiC) intelligent power module (IPM) for variable-speed drive applications such as active harmonic filters for HVAC (heating, ventilation and air conditioning) and high-performance motor drives. This IPM has integrated six SiC MOSFETs and optimized a single 6-channel silicon-on-insulator (SOI) gate driver in a transfer-molded type dual-in-line package (DIP) with a direct-bond-copper (DBC) substrate. This paper provides an overall description of electrical characteristics, package and thermal performance.

1 Introduction

Reducing power consumption is globally a major challenge for the environment, which is why inverters are being used increasingly for a wide range of applications. The high efficiency of inverters is an important goal. Especially in applications where high current and high power are required, usually silicon (Si) IGBTs are used because IGBTs have lower saturation voltage than MOSFETs at high current. However, IGBTs are still limited in terms of increased loss due to tail currents during turn-off and for high-speed switching applications.

This paper introduces the worldwide first 1200 V rated SiC MOSFET IPM, the IM828-XCC of the CIPOS™ Maxi IPM family. The SiC MOSFET device is a wide bandgap device that can achieve low $R_{DS(ON)}$ with high breakdown voltage. It does not have tail current because it is a majority carrier device [1]. It can be used in applications such as high PWM carrier frequency.

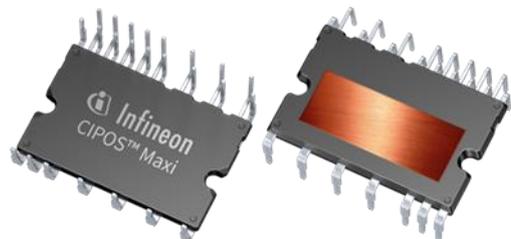
This SiC MOSFET IPM is easy to use because the embedded SOI gate driver IC is optimized to reduce switching oscillation. In addition, maximum 8 kW operating power can be achieved in a compact package owing to the use of a DBC substrate with high thermal conductivity.

This paper describes the features of internal components as well as electrical characteristics, package structure and thermal performance.

2 Overview and circuit configuration

Package outlines of the CIPOS™ Maxi IPM family are shown in Fig. 1[2]. This package is optimized for 1200 V rated IPM. Also it is composed an internal PCB for gate driver IC and a DBC for high thermal conductivity. Figure 2 shows an internal block diagram of a SiC MOSFET IPM. It is composed of six 1200 V rated 45 mΩ SiC MOSFETs in a three-phase inverter structure, together with a single 6-channel SOI gate driver IC and thermistor. Especially this gate driver IC with its integrated bootstrap circuit and other protection functions paves the way for minimization.

Fig. 1: Package outline overview of IM828-XCC (Size: 36 mm x 22.7 mm x 3.1 mm)



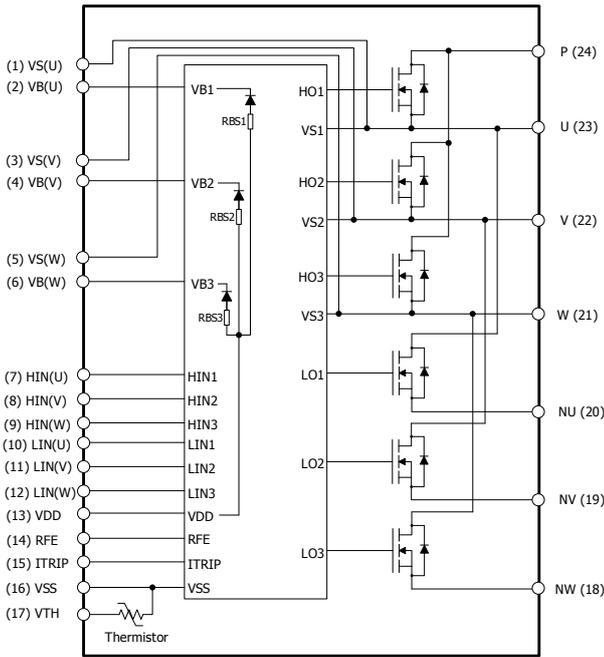


Fig. 2: Block diagram of IM828-XCC

3 Electrical characteristics

3.1 Static characteristics of CoolSiC™ MOSFET

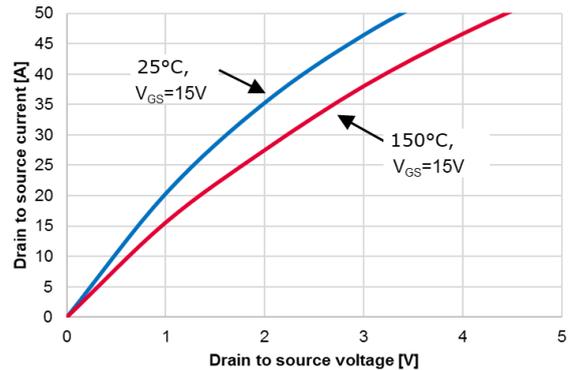
Infineon Technologies have launched the 1200 V rated SiC trench MOSFET, which is called CoolSiC™ MOSFET. Figure 3 (a) shows the static voltage-to-current characteristics of the 45 mΩ CoolSiC™ MOSFET at a gate-to-source voltage (V_{GS}) of 15 V [3]. The breakthrough electric field strength of the SiC is 10 times higher than that of Si; a high breakdown voltage can be achieved within a thin drift range. The $R_{DS(ON)}$ of this SiC MOSFET is typically 45 mΩ at the drain current of 20 A, V_{GS} of 15V and room temperature. Like as Si MOSFETs, the SiC MOSFET also has a parasitic body diode. The body diode of the SiC MOSFET can be used as freewheeling diode. However, since SiC has a wide bandgap of three electronvolt (eV) higher than Si, the body diode has a high forward voltage (V_F). Figure 3 (b) shows the forward voltage characteristics of the body diode. When a channel is generated between the gate and the source of the MOSFET, the V_F of the body diode is greatly reduced [4]. Therefore turning on the MOSFET during the body diode conducting operation (synchronous rectification) can reduce conduction losses. In particular, in the case of inverter drives, the V_F of body-diode is

not a critical problem since the gate voltage of the switching device is often turned on after deadtime.

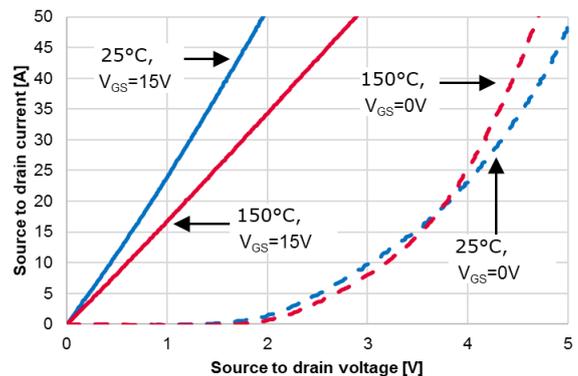
The short circuit capability is guaranteed up to 3 μs under junction temperature of 150°C, DC link voltage of 800 V and bias supply voltage of 15 V.

3.2 Switching characteristics

Figure 4 shows the turn-on switching waveforms of IM828-XCC, which is the CIPOS™ Maxi SiC MOSFET IPM, and the conventional 50 A rated Si-IGBT based IPM. The SiC device has significantly lower reverse-recovery losses than that of the Si device [5]. Also the SiC MOSFET does not generate tail current at turn-off as compared with the Si IGBT as shown in Fig. 5. Thus it can reduce switching losses, and enables high switching-frequency operation. Furthermore, switching oscillation during turn-on and turn-off was minimized due to the optimized design of the gate driver. These characteristics provide enhanced protection against EMI (electromagnetic interference).

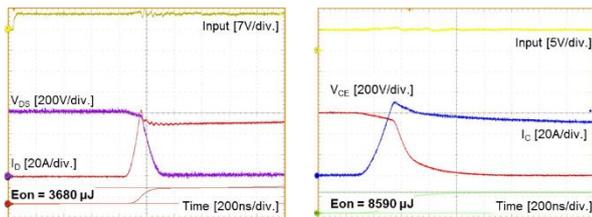


(a) Output characteristics of SiC MOSFET



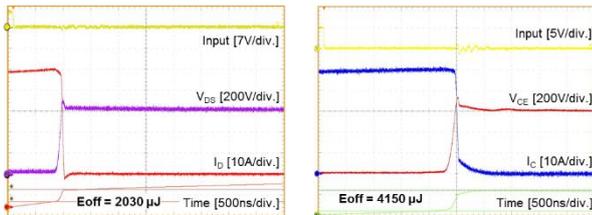
(b) Forward voltage characteristics of the body diode

Fig. 3: Static characteristics of CoolSiC™ MOSFET



Conditions : DC-link voltage= 600 V, bias supply voltage= 15 V, junction temperature= 150°C, drain current or collector current = 50 A

Fig. 4: Turn-on waveform of 50 A (left: IM828-XCC, right: conventional 50 A Si-IGBT based IPM)



Conditions : DC-link voltage= 600 V, bias supply voltage= 15 V, junction temperature= 150°C, drain current or collector current = 50 A

Fig. 5: Turn-off waveform of 50 A (left: IM828-XCC, right: conventional 50 A Si-IGBT based IPM)

3.3 Gate driver IC

The single 6-channel gate driver IC of IM828-XCC can drive SiC MOSFETs by applying the same gate supply as a Si-based IPM without negative bias. In addition, this driver IC has been optimized to reduce parasitic oscillation during the switching operation, which is a chronic problem of the SiC MOSFET. This is applied not only to the inverter drive of relatively low-frequency switching, but also to high-frequency switching of several ten kHz.

This driver IC is a SOI structure which has better integration, reliability and performance for the 1200 V rated IPM. It prevents leakage or latch-up current between adjacent devices structurally. Also it prevents the latch-up effect in case of high dv/dt switching and surge under high temperature [6]. This gate driver IC has an internal dead time of minimum 300 ns to prevent a shoot-through. Also, all outputs of this driver are shut down when a fault occurs, i.e. under voltage or overcurrent protection mode. The RFE pin has an “enable” function and a fault-clear time. The built-in fault clear time has a minimum of 160 μs and can be easily controlled via the RC network of an external pull-up resistor and capacitor such as in Fig. 6. In addition, it provides an integrated bootstrap circuit.

Sink and source currents are optimized independently for high-side and low-side SiC

MOSFET driving without any malfunction such as shoot-through current by the CdV/dt effect or dead time.

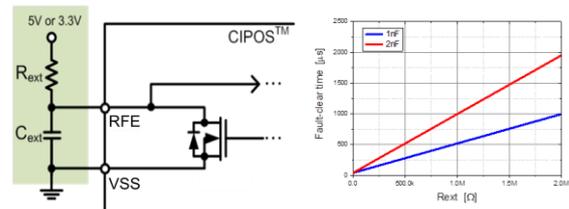


Fig. 6: Adjustable fault-clear time

4 Package

IM828-XCC is designed in the DIP 36X23D package, which is the compact package size (36 mm x 22.7 mm x 3.1 mm) without any dummy pins by optimized internal PCB and DBC structures as shown in Fig 1. A gate driver IC and thermistor are placed on an internal PCB. The six 1200 V rated SiC MOSFETs are placed on the DBC for an effective thermal dissipation. The CIPOS™ Maxi IPM has an independent V_{TH} pin and is connected to the thermistor inside the package, which offers a temperature-monitoring function. In addition, it is designed with transfer-molding technology encapsulation, and meets all international industrial standards such as insulation distance for clearance and creepage. Figure 7 depicts the insulation distance of pin-to-pin and pin-to-DBC.

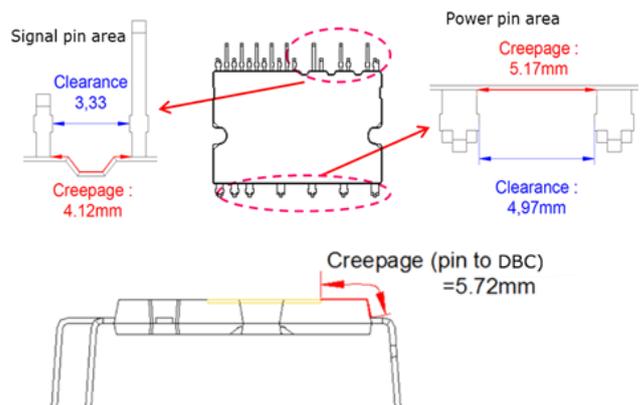


Fig. 7: Clearance and creepage distance

5 Performance

IM828-XCC offers enhanced operating conditions compared to the existing Si-based IPMs such as narrow dead time, shortest input pulse width and high PWM carrier frequency.

Recommend minimum dead time is 0.5 μs and minimum pulse width is 1 μs . PWM carrier frequency is allowed up to 50 kHz under conditions of $V_{DD}=15\text{ V}$.

5.1 Simulation

Figure 8 shows the simulation results of both the IM828-XCC and the conventional 50 A Si-IGBT-based IPM. The switching losses of IM828-XCC are significantly lower than those of the Si-IGBT-based IPM as shown in Fig. 8 (a). Therefore the higher the switching speed, the better the performance of the IM828-XCC. Especially when the switching frequency is 30 kHz, the efficiency of the Si-IGBT based IPM is below 94%, but that of the IM828-XCC is 98%, as shown in Fig. 8 (b).

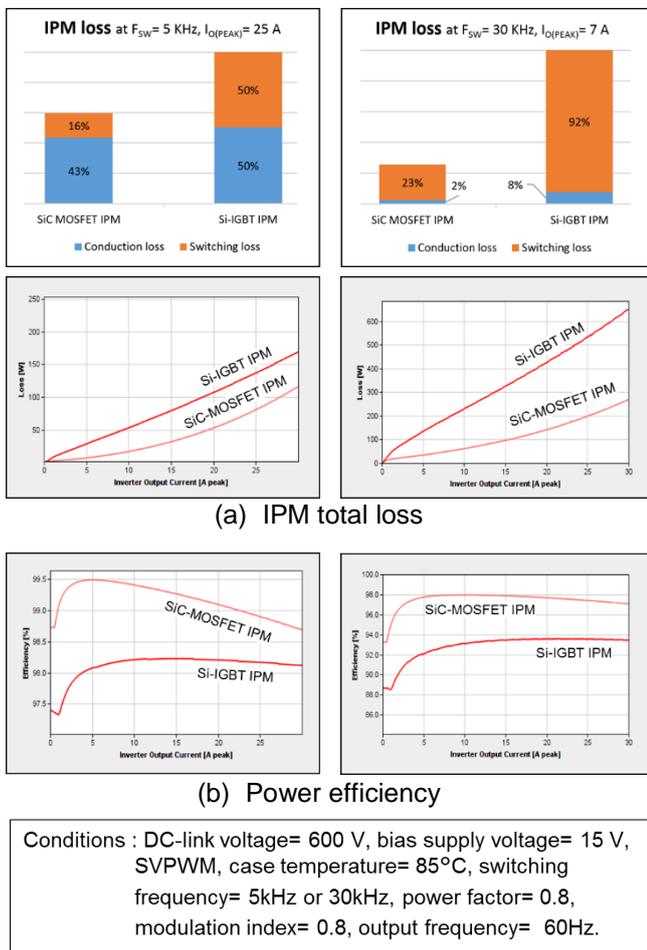


Fig. 8: The performance simulation results of both IM828-XCC and conventional 50 A rated Si-IGBT based IPM (left: 5 kHz, right: 30 kHz)

5.2 Thermal performance

Figure 9 shows an application test board of the SiC MOSFET IPM and a heatsink condition for

comparing the thermal performance during the driving of a three-phase inverter system. The case temperature of IM828-XCC was measured as in Fig. 10. The points in Fig. 10 represent the hottest points in a module. In order to confirm the thermal performance according to switching frequency, two tests were performed. Case 1 is $F_{SW}=5\text{ kHz}$, $I_{O(PEAK)}=25\text{ A}$ and $MI=0.58$. And Case 2 is $F_{SW}=30\text{ kHz}$, $I_{O(PEAK)}=7\text{ A}$ and $MI=0.64$. Figure 11 shows the operating waveforms and the thermal performance comparison results of both the evaluation case 1 and case 2. Although the package area of the IM828-XCC is one-third of the 50 A Si IGBT IPM, the SiC MOSFET IPM shows much better performance, as shown in Fig. 11 (b). The ΔT_{C-A} (case-to-air temperature) results for SiC MOSFET IPM and Si IGBT IPM in case 1 are 28.3°C and 41.6°C respectively. Especially at the higher switching frequency of 30 kHz, ΔT_{C-A} of Si IGBT IPM, 65.5°C, is 4 times higher than that of the SiC MOSFET IPM, 15.7°C. The results show that the IM828-XCC has faster switching speed and much lower losses compared with the Si-IGBT-based IPM.

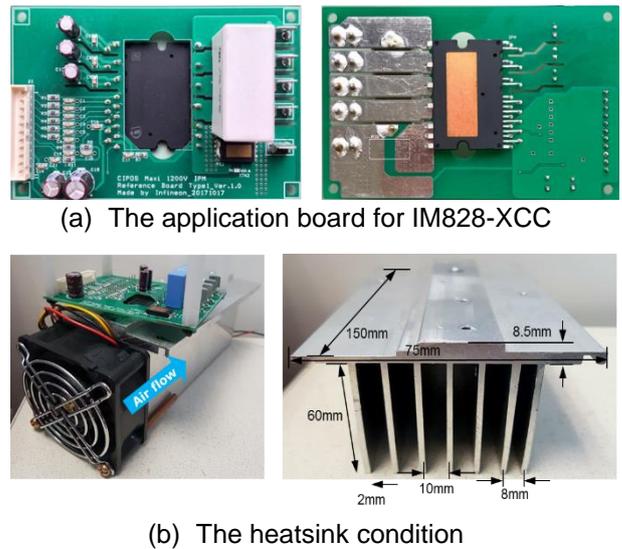


Fig. 9: The test board and heatsink

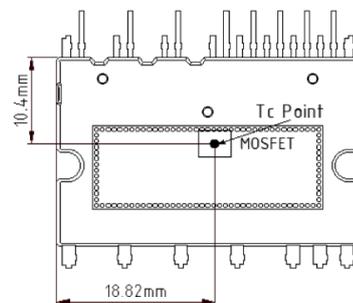
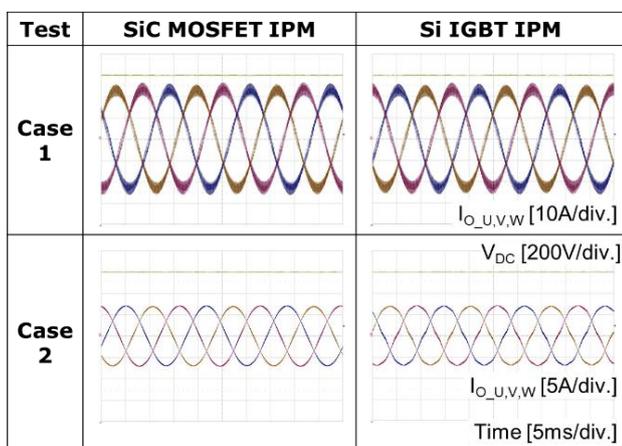


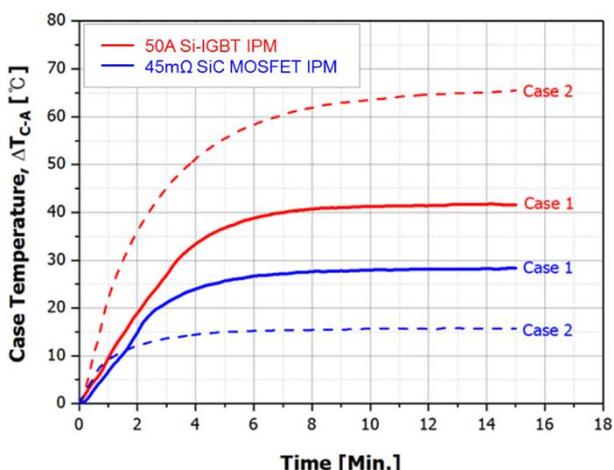
Fig. 10: The point to measure T_c of IM828-XCC

6 Conclusion

In this paper, an overall description of the new CIPOS™ Maxi IPM, IM828-XCC, was presented. It is the world’s first 1200 V rated SiC MOSFET IPM, which has integrated six 45 mΩ CoolSiC™ MOSFETs and a single 6-channel gate driver IC into the optimized small package. This SiC MOSFET IPM has effectively reduced IPM loss, and also has improved power efficiency as compared to an existing Si-based IPM. The IM828-XCC is the best solution that can be applied not only to general motor drive applications, but also to high-switching frequency applications such as active harmonic filters.



(a) Inverter operating waveforms



(b) Thermal performance comparison results

Test condition: $V_{DC} = 600\text{ V}$, $V_{DD} = 15\text{ V}$, $PF = 0.99$, SVPWM

- Case 1 : $F_{SW} = 5\text{ kHz}$, $I_o = 25\text{ A}_{PEAK}$, $MI = 0.58$
- Case 2 : $F_{SW} = 30\text{ kHz}$, $I_o = 7\text{ A}_{PEAK}$, $MI = 0.64$

Fig. 11: The application test results

7 References:

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