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Press Conference

Tuesday, 10th of May 2016
PCIM Europe, Messezentrum 1, 90471 Nuremberg (Germany)
NCC Ost, Level 1, Room Hongkong

Press release

Mitsubishi Electric to Expand Lineup of T Series IGBT Module Using 7th Generation IGBTs

17 new models for low power loss and highly reliable industrial equipment

IGBT-T NX-Type PressFitPin

IGBT-T NX-Type Solder

IGBT-T std-Type

TOKYO, March 30, 2016 – Mitsubishi Electric Corporation (TOKYO: 6503) announced today that sample shipments of 17 new models of the T series power semiconductor modules featuring seventh-generation insulated-gate bipolar transistors (IGBTs) are scheduled for September 30. The new modules with a voltage rating of 1.7 kV offer low power loss and high reliability, perfectly meeting the demands of companies producing general-purpose inverters, uninterruptible power supplies (UPS), photovoltaics (PV), wind power generation systems, servos, elevators, and other industrial equipment.

Product Features

The lineup is expanded by 17 models with 1.7 kV rating, providing for a wide range of inverter capacity. The new models include 12 NX-type package models (six with solder pin package and six with press-fit pin package) with current ratings ranging from 100 A to 600 A, and five standard-type package models ranging from 75 A to 300 A. The expanded lineup provides for AC 690 V / DC 1000 V PV system inverters, offering a wide range of inverter capacity.

With an improved internal structure, the latest package technology enhances the reliability of the existing standard-type package while keeping compatibility to it. An insulation and copper base integrated in the substrate, along with an improved internal electrode construction, help to increase the thermal cycle life, i.e. the life proven in a stress test of relatively long-term temperature cycling between two case temperatures, and to lower the internal inductance, finally leading to a more reliable equipment performance.

Thanks to 1.7 kV rated seventh-generation CSTBT™ chips with incorporated carrier-store effect, power loss and EMI noise could be reduced.

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Relaxed Field of Cathode (RFC) diode chips incorporating a novel backside diffusion process, with the P layer being partially added on the cathode side and the hole injected during the recovery period to soften the recovery waveform, also contribute to the low power loss and the suppression of a recovery voltage surge.

Package Details

As to the NX-type package, the internal inductance is reduced by 30 percent compared with conventional sixth-generation IGBT modules. Using Solid-Cover- (SLC-) technology, the thermal cycle life could be improved by combining a resin-insulated metal baseplate with direct potting resin, which is a specifically controlled epoxy resin matched to the thermal expansion rate that features improved adhesion. The press-fit pin package model can be fixed to the equipment without soldering, simply by pressing the pins into the PCB board. The resin filling reduces siloxane, a low molecular chemical compound in the silicone resin, and improves the gas barrier effect to meet the market demands.

With regard to the standard-type package, the internal inductance is reduced by 30 percent compared with a conventional sixth-generation IGBT module thanks to an improved internal electrode construction. The Thick-Metal-Substrate- (TMS-) technology removes the solder layer and increases the thermal cycle life. The package can be downsized by decreasing the baseplate area by 24 percent from 80 × 110 mm to 62 × 108 mm, increasing the thickness of the copper pattern and improving the thermal conductivity.

Other Features

The optional PC-TIM module is based on a Phase Change Thermal Interface Material, a high thermal conductivity grease which becomes solid at room temperature and softer with rising temperature. The module uses PC-TIM of optimized thickness, eliminating the need for thermal grease.

Environmental Awareness

The products mentioned in this release are compliant with the Restriction of the Use of Certain Hazardous Substances in Electrical and Electronic Equipment (RoHS) directive 2011/65/EU.

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Press release

Mitsubishi Electric Develops X-Series New Dual HV IGBT Module

More flexibility through standardized package for next-generation high-power semiconductor module

HV100

LV100

TOKYO, April 6, 2016 – Mitsubishi Electric Corporation (TOKYO: 6503) announced today the development of a next-generation power module, called X-Series New Dual HV IGBT module, for traction and electric power applications used in heavy industries. The new module features higher power density and efficiency for inverters, as well as a standardized package that allows for a flexible design of inverter systems.

Samples of the New Dual module's 3.3 kV (LV100) version will be available for shipping from March 2017. The 1.7 kV, 3.3 kV (HV100), 4.5 kV and 6.5 kV versions will follow from 2018 onwards. In the future, the company plans to expand the lineup by a version below 1.7 kV.

The modules will be exhibited at major trade shows including MOTORTECH JAPAN 2016 during TECHNO-FRONTIER 2016 in Japan from April 20 to 22, Power Conversion Intelligent Motion (PCIM) Europe 2016 in Nuremberg, Germany, from May 10 to 12, and PCIM Asia 2016 in Shanghai, China, from June 28 to 30.

High-power modules are key devices for controlling power conversion in electronic systems in a wide range of power classes from several kilowatts up to several megawatts. Until now, modules with a maximum voltage rating of up to 6.5 kV and a maximum current rating of several thousand amperes have been commercially available.

Product Features

The New Dual HV IGBT module will meet the demand for efficient, high power density semiconductor devices, offering a wide range of current and voltage ratings. High energy efficiency and power density in inverters is achieved with the use of seventh-generation IGBTs adopting CSTBT™ and RFC diodes which keep the power loss in inverter systems low.

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Inverter capability is increased by three AC main terminals on the LV100 package which spread and equalize the current density. Maximum performance is reached by an improved package technology and low parasitic inductance.

The common frame size of the two LV100 and HV100 modules supports more diverse inverter configurations and power ratings. Simple, standard 2-in-1 connections allow for an optimal system design as well as for voltage and current ratings ranging from 1.7 kV/900 A to 6.5 kV/225 A, making system configuration scalable and more flexible.

Thanks to the standardized package dimensions of 100 mm × 140 mm × 40 mm, manufacturers of industrial electronics are able to simplify design and secure multiple sources for inverters. Moreover, the new standardized package is compatible with the terminal and attachment locations of Infineon Technologies AG, Germany.

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Tuesday, 10th of May 2016
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Press release

Mitsubishi Electric to Ship Samples of G1 Series IPMs Using 7th Generation IGBTs

Reduced power loss and improved reliability for industrial equipment


G1 A Package


G1 B Package


G1 C Package

TOKYO, April 13, 2016 – Mitsubishi Electric Corporation (TOKYO: 6503) announced the start of sample shipments of its new G1 series intelligent power modules (IPM), high-function modules with a dedicated IC offering self-protection functions, featuring seventh-generation insulated-gate bipolar transistors (IGBTs) and comprising three different packages and 52 models in total, is scheduled for May 2016. Variable frequency inverters are being increasingly used in a wide range of motor control systems to deliver enhanced energy efficiency. In the output stage of these inverters, IPMs are commonly used for switching electric currents at high speeds. There is growing demand for IPMs offering low power loss, high output and small package sizes. The new modules deliver reduced power loss and improved reliability for general-purpose inverters, servo amplifiers, elevators, and other industrial equipment.

The modules are exhibited at major trade shows including MOTOR-TECH JAPAN 2016 during TECHNO-FRONTIER 2016 in Japan from April 20 to 22.

Product Features

A novel package technology downsizes industrial equipment and improves its reliability. The new compact packaging achieved by optimizing the main terminal shape reduces the package size by about 30 percent compared to the previous L1 series product, thereby contributing to the provision of compact, lightweight inverters. Integration of insulation and copper base in the substrate helps to increase the thermal cycle life, i.e. the life proven in stress tests of relatively long-term temperature cycling between two case temperatures. Finally this leads to more reliable equipment performance.

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Thanks to upgraded seventh-generation CSTBT™ chips with incorporated carrier-store effect, power loss and EMI noise could be reduced. Relaxed Field of Cathode (RFC) diode chips incorporating a novel backside diffusion process, with the P layer being partially added on the cathode side and the hole injected during the recovery period to soften the recovery waveform, also contribute to the low power loss and the suppression of a recovery voltage surge.

Two new functions ease the design in the customers' development processes. The new error mode identification process, featuring Over Temperature Protection (OT), Supply Under Voltage-lock Protection (UV) and Short-Circuit Protection (SC), easily identifies the cause of errors. Thanks to the innovative two steps switching speed function, the trade-off between energy losses and noise could also be improved.

Other Features

The optional PC-TIM option is based on a Phase Change Thermal Interface Material, a high thermal conductivity grease, solid at room temperature and adapting with rising temperature. PC-TIM of optimized thickness is used, eliminating the need for thermal grease.

The A package serves for a flexible layout and shape of the main terminal. For the 6-in-1 circuit module, users can select between a straight or L-shaped main terminal layout and between a screw or solder pin version; for the 7-in-1 circuit, they can select between a screw or solder pin version of the straight main terminal layout. The package size is 50 mm × 90 mm.

The B and C package with sizes of 55 mm × 120 mm, respectively 85 mm × 120 mm, have a L-shaped screw version of the main terminal layout, respectively.

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Bodo´s Power Systems®

200A/600V Silicon Carbide Hybrid Intelligent Power Module for Servo-Inverter Applications

In Multi-Axis Servo-Drives several servo amplifiers are operating from a common DC-link power supply. Mechanically those servo amplifiers usually are mounted in a so called "book-shelf-arrangement" in a common mechanical rack. This specific construction principle is providing a limited space at each inverter's backside for cooling the power semiconductors.

By E.Thal, Mitsubishi Electric

With its S1-Series IPM Mitsubishi Electric was providing a dedicated solution for this specific application (module ratings see Table 1). The baseplate width of S1-IPM is only 50mm (see Figure 1), allowing a narrow housing for each servo amplifier and thus a compact size of the whole multi-axis servo rack.

As next step Mitsubishi Electric now is introducing its new Silicon Carbide Chip technology into this proven IPM design. A new 200A/600V 6in1 IPM (type name PMH200CS1D060) was developed by using SiC Schottky Barrier Diodes (SBD). This approach is called "Hybrid SiC" module. For better understanding the used terminology, please refer to Figure 2.

Figure 1: S1-series package outline, Baseplate footprint: 50x120mm

S1-Series IPM	Vces (V)	Ic(A)					
	600	-	50	75	100	150	200
	1200	25	50	75	100	-	-

Table 1:S1-Series line-up

A hybrid SiC module is containing Silicon-based IGBT in combination with SiC-based Schottky barrier diodes. The main benefit of using SiC Schottky barrier diodes as free-wheeling diodes is the drastically reduced switching loss in the diode itself. As shown in Figure 2 this results also in a substantial reduction of IGBT-turn-on loss.

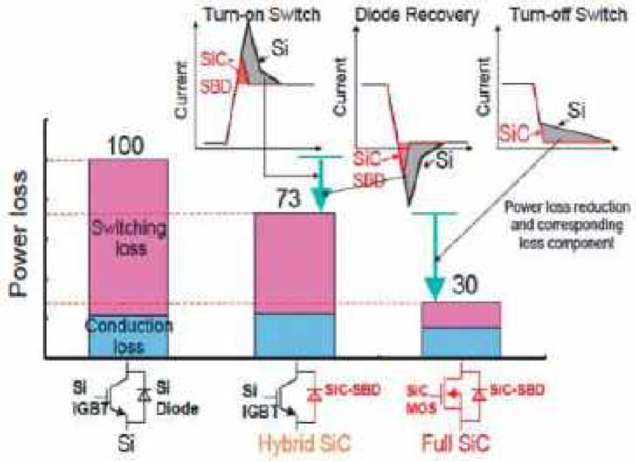

Figure 2: Evolution of SiC technology in power modules

Both effects are very welcome in servo inverter applications which are operating typically at high PWM switching frequencies. This was the motivation and background for developing this new 200A/600V hybrid SiC IPM dedicated for servo inverter applications.

The switching energy characteristics of the new SiC hybrid module PMH200CS1D060 are shown in Figure 3; the switching energy characteristics of its Si-based predecessor type PM200CS1D060 are shown in Figure 4.

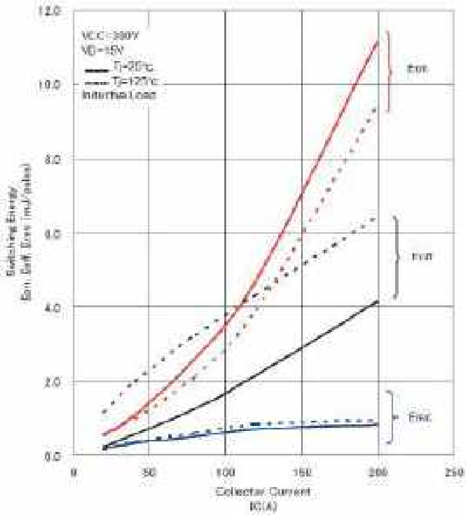

Figure 3: Switching loss of PMH200CS1D060 (Hybrid SiC-Module)

When comparing those characteristic curves (for example at Tj=125°C and rated current 200A) we can find 2 improvements caused by the SiC Schottky barrier diode in PMH200CS1D060:

- FWDi switching loss is reduced from 5mJ to 1mJ
- IGBT turn-on loss Eon is reduced from 11mJ to 9,5mJ
- Carrier life time control of IGBT chip was improved to suit with SiC Schottky barrier diode specification. As a results of improvement, IGBT turn-off loss Eoff was improved from 7.5mJ to 6.5mJ.

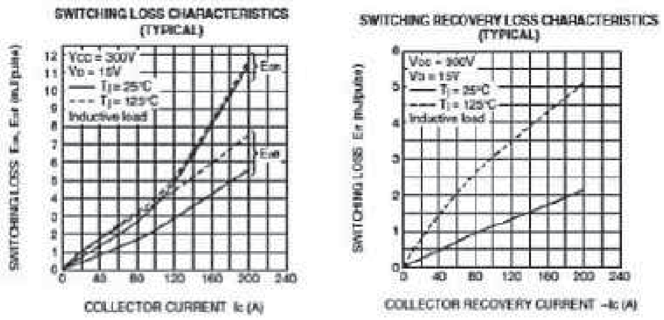

Figure 4: Switching Loss of PM200CS1D060 (Si-Module)

A substantial switching loss reduction in PMH200CS1D060 has been obtained. This is helping the inverter designer to overcome the typical for servo applications thermal constrains in high overload situations, particularly at high PWM switching frequency.

All other specific features of S1-series IPM have been preserved. For completeness they will be briefly reviewed as follows (see Figure 5):

- Short circuit protection by current sense emitters in each IGBT chip
- Over temperature protection by monolithically integrated Tj-sensors in each IGBT chip
- Control power supply under voltage protection
- Error output from n-side switches

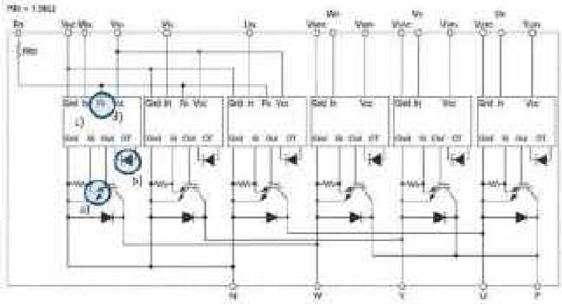

Figure 5: Functional block diagram PMH200CS1D060

Summary

Mitsubishi Electric has developed a new 200A/600V 6in1 Intelligent Power Module with Silicon Carbide (SiC) Schottky barrier diodes and improved Si-IGBTs. This hybrid SiC design approach leads to a substantial reduction of switching losses, particularly in the free-wheeling diode. In combination with the slim module package and the dedicated protection functions of S1-series IPM the newly developed hybrid SiC IPM type PMH200CS1D060 is offering an excellent technical solution for new multi-axis servo inverter designs.

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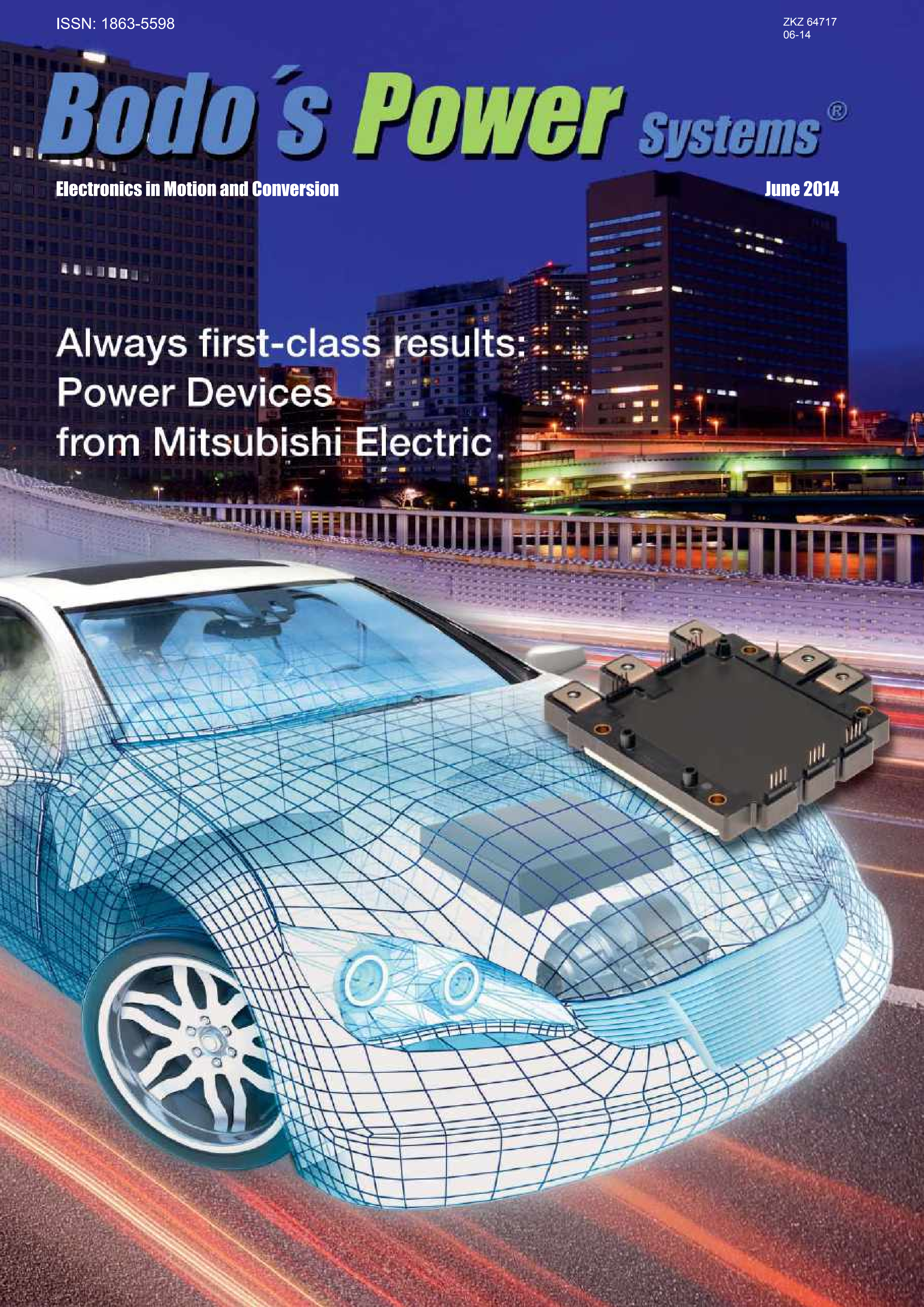
Bodo´s Power Systems®

Electronics in Motion and Conversion

June 2014



Always first-class results: Power Devices from Mitsubishi Electric

Power Modules for Electric and Hybrid Vehicles

This article presents 2 new Mitsubishi Electric power module series for Electric Vehicle (EV) and Hybrid Electric Vehicle (HEV) power-train inverter and converter applications.

By Mikio Ishihara, Mitsubishi Electric Corp. Power Device Works, Fukuoka, Japan
and Seiichiro Inokuchi, Marco Honsberg and Eckhard Thal
Mitsubishi Electric Europe B.V., Ratingen, Germany

The J1-Series

First a new 6-in-1 IGBT module ("J1-series") with integrated water cooled Al-fin and Direct Lead Bond (DLB) structure is described [1]. Compared to conventional products, the adoption of these innovative technologies has led to an improved thermal performance of 30%, has reduced the cooling stack's footprint by 40% and its weight by 76%.

Introduction

The market for EV/HEV is growing by increasing global environment protection awareness. The power semiconductor module has become an important part to determine vehicle performance. Having pioneered the first mass production of dedicated automotive power semiconductor modules in 1997 already, the products of Mitsubishi Electric have been used in various mass-produced EV/HEV ever since.

The evolution of EV/HEV has been remarkable in this time frame and the power semiconductor module has become the key part for EV/HEV applications providing the required high performance, small size and light weight. In addition, a wide variety of EV and HEV covering various sizes and power requirements have been developed and power semiconductor modules were required with matching wide product line-up responding to these market requirements.

The J1-Series

Under these circumstances a family of new automotive power semiconductor modules "J1 Series" has been developed based on the concept of "high performance" and "compact size and light-weight" (Figure 1).

The J1 series modules are using a 6-in-1 topology (see Figure 2).

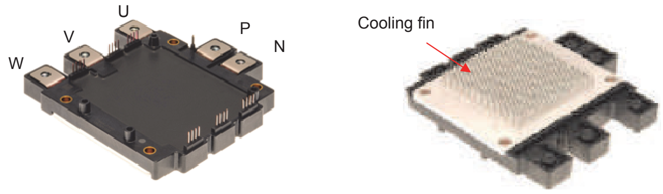


Figure 1: External appearance of the J1-Series Power Module

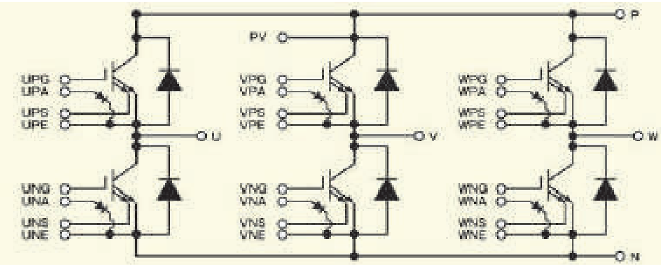


Figure 2: J1-Series circuit diagram

All IGBT-chips have integrated current sense emitters and integrated temperature sense diodes.

The module ratings and package dimensions are given in Table 1.

The excellent Vce(sat)-values are the result of using the latest CSTBT chip technology.

Type name	Ratings (Ic/Vces)	Vce(sat) Typ. @Ic, 25°C	Package Size (mm)
CT600CJ1A060	600A/650V	1.4V	120x115.2x31 (6-in-1)
CT400CJ1A090	400A/900V	1.7V	

Table 1: J1-Series Power Module Line-up

Package structure

J1-Series modules are employing a built-in Aluminium cooling-fin. A cross sectional drawing is shown in Figure 3.

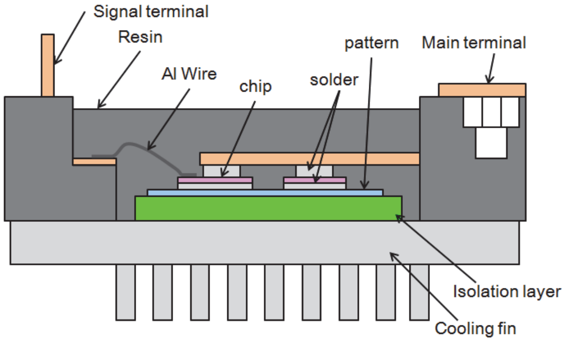


Figure 3: Internal structure of J1-Series

The directly water cooled module base plate allows to eliminate the thermal contact resistance between module base plate and external heat sink that is unavoidable for inverter designs with conventional modules. In this way a remarkable reduction of total Rth(j-w) compared to conventional designs is possible to achieve. For utilizing this benefit a reliable water cooling system must be designed for fitting the J1-module into the direct water cooling.

Direct Lead Bonding

The new J1-Series is using a highly reliable Direct Lead Bonding (DLB) structure [3] instead of conventional Al wire-bonding (W/B) technology. The principle difference between both technologies can be seen in Figure 4.

The DLB structure provides increased chip surface contact area greatly improving the power module current carrying capability. Compared to W/B packages, by utilizing the DLB structure, the package's internal lead resistance and the parasitic internal package inductance can be reduced by more than 50% [4].

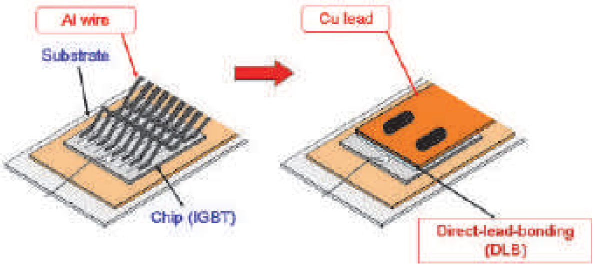


Figure 4: Conventional W/B vs. DLB structure

One further important advantage of the increased chip surface contact area is the uniform temperature distribution across the chip surface reducing the peak temperature value, and hence, resulting in lower stress for the emitter side chip contacting system. In other words, the DLB structure addresses the power-cycling stress issues usually encountered in conventional WB packages.

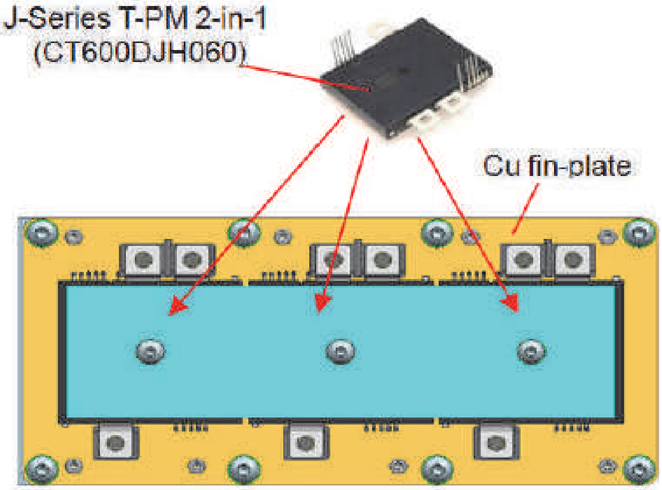


Figure 5: Cooling stack assembly with conventional 600A/650V J-TPM modules

Compact cooling stack design

In comparison with more conventionally packaged products (J-Series T-PM [2], see Figure 5), the new J1-Series reduces the footprint of a 3-phase cooling stack by 40% (Figure 6).

Despite the fact that aluminium cooling-fins have lower thermal conductivity compared to copper cooling-fin structures, this selection provides several advantages to EV/HEV applications. Among these advantages the most prominent one is durability when Aluminium is exposed directly to coolants and its light weight. As shown in Figure 7 and 8, as much as 76% weight reduction and 30% thermal performance improvement was achieved when comparing 6-in-1 power module inverter solutions. The two solutions compared in Figure 7 are based on same module current and voltage ratings (600A/650V) for three-phase EV/HEV motor drives.

Evaluation Kit

Since the package size is not differing for several voltage and current classes, the test and evaluation of new J1-Series modules can be facilitated by a unique test environment that provides a DC-link capacitor, a simple and efficient cooling system (water jacket) and an interface circuitry with dedicated ICs controlling the state-of-the-art chip technology comprising an on-chip-diode for temperature sensing as well as the proven mirror emitter technology to detect over current situations before the IGBT de-saturates naturally.

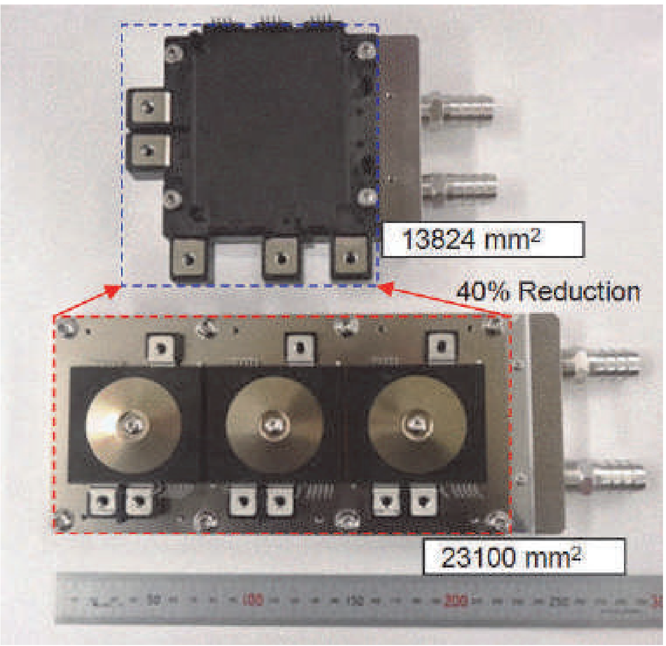


Figure 6: Cooling stack footprint of J1-Series and conventional J-TPM

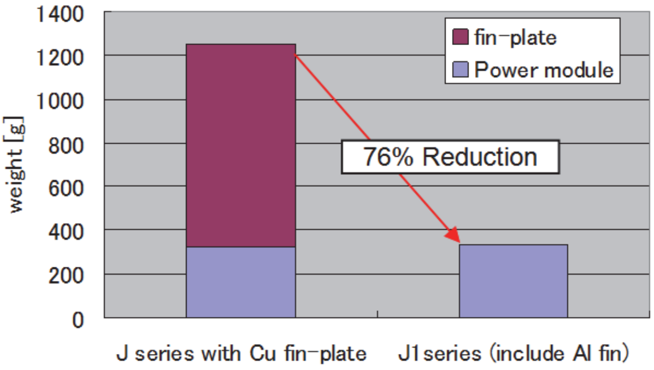


Figure 7: Cooling stack weight comparison

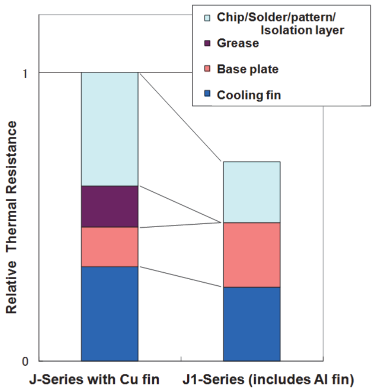


Figure 8: Thermal resistance Rth(j-w) comparison

The evaluation kit (gate drive board, DC-link capacitor, water jacket) is available for the evaluation of this new J1-Series IGBT module family (Figure 9 and 10). The comprised drive and protection circuit for short circuit (SC), over temperature (OT) and under voltage (UV) along with a switching mode power supply is optimized for the J1-Series. It is simply mounted on top of the J1-Series IGBT module and provides a comprehensive interface to a superimposed system control unit.

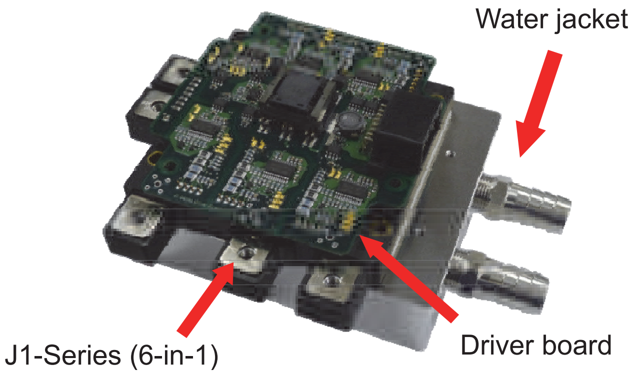


Figure 9: Water jacket and driver board

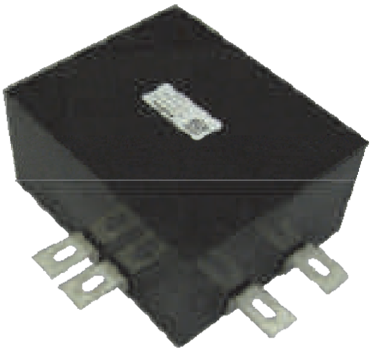


Figure 10: DC-link capacitor

Experimental results

The new J1-Series' power handling capability in conjunction with the performance of the thermal interface construction was experimentally verified under the following test conditions: main battery voltage = 350V; PWM switching frequency (fc) = 5kHz, 10kHz; coolant temperature (Tw) = 65°C; coolant flow-rate = 10 l/min. The proposed evaluation kit for J1-Series IGBT modules (Figure 9) has been used to carry out this investigation. Under these conditions the inverter output current can exceed 420Arms (corresponding to more than 80kW output power) at a maximum junction temperature of below 150°C as graphically presented in Figure 11.

J1-Series summary

A new series of automotive power semiconductor modules "J1-Series" has been developed to meet the requirements of the evolving EV/HEV market. The J1-Series achieves high performance, compact size and light weight and contributes to the evolution of automotive inverter system by providing state-of-the-art chip technology employing on chip temperature sensing and mirror Emitter current sensing technology paired with proven high reliability core packaging technologies like Direct Lead Bonding (DLB) and Aluminum cooling fin.

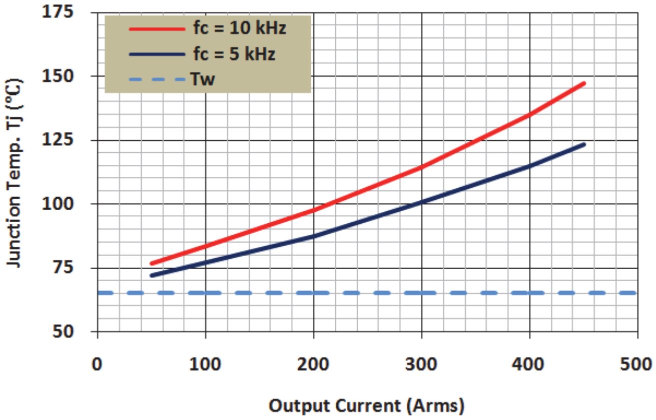


Figure 11: Experimental Inverter performance of a J1-Series Power Module (600A/650V) sample

The J-Series IPM “+B”

The second part of this article presents the extension of Mitsubishi’s 6-in-1 Intelligent Power Module Series for EV and HEV applications [2]. The newly developed “+B” J-IPM series is offering enhanced power ratings in a more compact package design, an integrated switching mode power supply (SMPS) and an improved thermal cycling capability. All dedicated functions for controlling IGBTs safely under EV/HEV application conditions (driving, protection and sensing) are integrated into the J-IPM.

Simplifying the testing of this new technology, an optimized evaluation kit comprising a water-cooling jacket and a driver board with dedicated drive and protection circuitry has been developed for this new family of automotive 6-in-1 IGBT modules.

Intelligent Power Modules (IPM) have been widely used in motor control applications in industry and in High Voltage (HV) traction applications. A dedicated series of IPMs (“J-Series IPM” [2]) has been designed for automotive applications for providing both high functionality and high reliability. The “J-Series IPM” lineup has been extended by 2 new modules, the so called “+B types” [2] with increased current handling capability. The target for this new development was to offer a “ready-to-use” solution to heavy electrical or heavy hybrid electrical vehicles designers. The “+B type” module ratings are given in Table 2.

Type name	Vces-rating	Ic-rating	Package Size (mm)
PM800CJG060G	650V	800A	165x144.2x32 (6-in-1)
PM500CJG120G	1200V	500A	

Table 2: J-Series Intelligent Power Modules “+B type”

Figure 12: J-Series IPM “+B” package outline

Both “+B” IPM types are configured as “6-in-1” and are using the package outline shown in Figure 12:

Integrated functions
The integrated functionality is given in the block diagram in Figure13. The power block consists of 6 freewheeling diodes and 6 IGBTs with integrated current sense emitters and temperature sense diodes. The protection block covers the following functions:

- IGBT chip over temperature protection
- Short circuit current protection
- Power supply under voltage protection
- DC-link voltage detection (optional)
- Analogue chip temperature detection circuit

The control block consists of the IGBT drivers and a fault output logic responsible for generating a single fault output signal Fo in case one of the protection functions had operated. The isolation block is using automotive grade high speed opto couplers for signal isolation. The power supply & I/O block contains a built-in switch mode power supply for feeding all IGBT drivers from a single +12V external power source as well as I/O processing circuits.

Input signals are: a) the PWM input from the Control MCU and b) the mandatory for automotive applications “ready” state monitoring signal.

Output signals are: a) the fault output signal Fo; b) the analogue chip temperature signal Tout and c) the analogue DC-link voltage signal VDC out (optional).

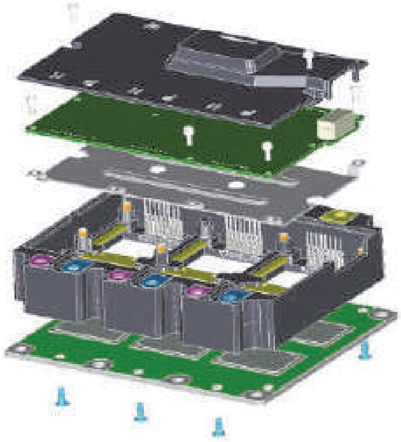


Figure 14: Three-Dimensional (3D) view of the “+B” IPM’s construction

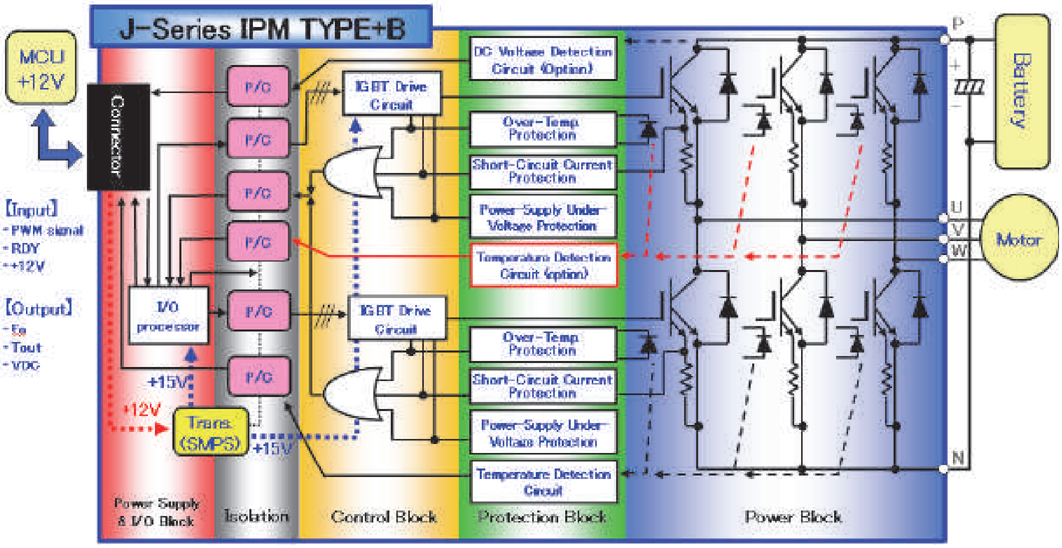


Figure 13: J-Series IPM type +B Block diagram

Module structure and robustness against vibration

A 3D-view of the +B type IPM is shown in Figure 14. A shielding plate is inserted between the power part and control PCB to prevent IGBTs and FWDis radiated noise to interfere with the IPM’s control board and disturb the overall control of the inverter.

Lead-free solder has been employed to comply with the “End of Life Vehicles” (ELV) directive.

For ensuring a reliable electrical connection to the superimposed control system a dedicated automotive grade connector has been used to facilitate the needed simplicity of assembly on one hand and robustness against vibration on the other hand. Furthermore, the entire IPM structure has been analytically modeled and simulated under vibration stress. The outcome of this investigation has influenced the outer and inner construction of the IPM resulting in robustness of the case and especially the sensitive control board against mechanical stress. Finally the mechanical ruggedness has been confirmed by actual vibration tests under the following conditions: acceleration > 10G, frequency = 100 ~ 1000Hz, direction = X, Y, and Z Axis.

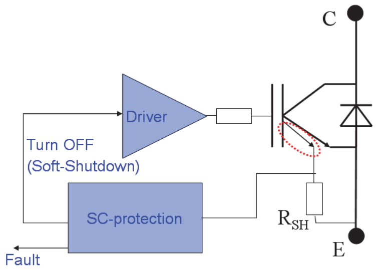


Figure 15: Short circuit protection circuit

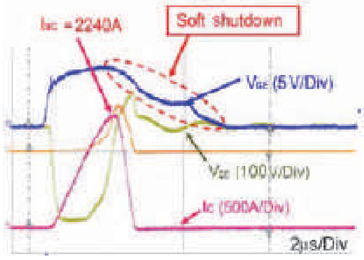


Figure 16: Short circuit turn-off waveforms PM-800CJG060G

Short circuit protection

One highlight of J-Series IPM is the over-current protection, employed by a fast response on-chip current sensor. This mirror Emitter sensing function shown in Figure 15 along with the soft shutdown approach provides a comparatively low current and voltage stress to the IGBT throughout the entire short circuit event that in turn provides a higher reliability than conventional de-saturation based detection methods. Figure 16 shows the typical short circuit turn-off behavior of a J-Series IPM.

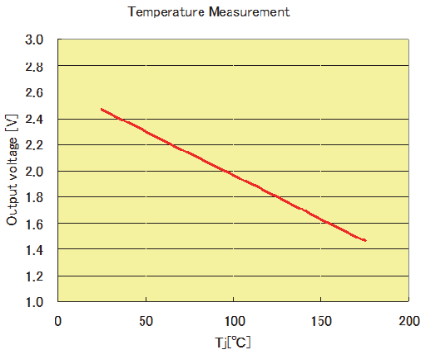


Figure 17: On-chip temperature measurement result: Vout vs. Tj

Enhanced input / output functions

The “RDY” input terminal acts as an added input fail-safe protection measure. In case of an error situation the superimposed control system can directly shut down the IPM by sending a corresponding logic signal to this terminal.

The employed IGBT temperature monitoring function provides an analogue output signal Tout indicating the IGBT chip actual surface temperature through the utilization of a built-in temperature sensor located at the center of the chip. Compared to conventional temperature monitoring with thermistors located on the base plate, this approach provides higher accuracy and a linear output over a wide temperature range as indicated in Figure 17.
The J-IPM type “+B” comprises a new function, e.g. a Tout output selection. This new feature selects automatically the hottest chip and routes the temperature information to the Tout terminal. Especially under locked rotor mode condition or at low output frequency operation at high load current the system control has the advantage to always look at the most stressed chip. This information, besides the efficient protection against chip over temperature, creates the possibility to adjust the inverter output power, the switching frequency or early warning messages and contributes to the reliability of the entire drive system.
The DC-link voltage monitoring function (optionally available) provides an analogue output signal (VDC out) indicating the voltage across the IPM’s main P and N terminals, giving valuable information to battery management functions.

Reliability

The optimization of the base plate’s and the substrate’s match of linear expansion coefficients (CTEs) as well as the interconnection between chip and substrate and the bonding technology itself have a great impact on the module’s reliability [5]. The J-Series IPM type “+B” employs a “low linear expansion coefficient” base plate resulting in a substantial improvement of the T/C capability by about 5–10 times to that of general industrial power modules.
In line with the high reliability targets of the mechanical construction the integrated control board has been verified specifically for automotive applications by dedicated high-temperature and high-humidity bias stress tests.

J-Series IPM “+B” summary

The new J-IPM “+B” modules provide a complete “easy-to-use” 6-in-1 system solution for high power HEV/EV applications. It allows building compact, robust and reliable propulsion systems for heavy electrical and heavy hybrid electrical vehicles. The use of J-IPM “+B” helps to reduce the propulsion system development time as the implemented IPM functionality is providing ready state-of-the-art answers to all needs of an automotive inverter design.

Literature

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[2] S. Inokuchi et al.: “A new versatile Intelligent Power Module (IPM) for EV and HEV applications”, PCIM 2014 conference proceedings
[3] T. Ueda, et al. ‘’Simple, Compact, Robust and High-performance Power module T-PM (Transfer-molded Power Module)’’ ISPSD2010, pp. 47-50, 2010
[4] M. Ishihara, et al., “New Transfer-mold Power Module Series for Automotive Power-Train-Inverters”, PCIM 2012, Proceedings, pp. 1408-1413.
[5] K. Hussein, et al., “IPMs Solving Major Reliability Issues in Automotive Applications”, IEEE-ISPSD 2004, Proceedings, pp. 89-92.

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Bodo´s Power Systems®

1200V SiC Hybrid IGBT Modules for High Frequency Applications

Dedicated IGBT-modules for high switching frequency operation have been successfully introduced to the market over the past years. Typical applications are X-ray generators, CT-scanners, induction heating, welding, plasma cutters or inverters for isolated or contactless electrical power conversion.

By Eckhard Thal, Mitsubishi Electric Europe B.V., Ratingen, Germany

The switching frequency in those applications is usually higher than 20kHz, thus exceeding the range for which standard industrial IGBT-modules are optimized for. Since several years Mitsubishi Electric is offering a dedicated IGBT-series for those high frequency applications, called NFH-series. For reducing the switching loss it is using IGBT-chips with an optimized trade-off between Vce(sat) and Eoff. As next innovation step Mitsubishi Electric now is introducing it's Silicon Carbide Chip technology to this proven NFH-series design.

Hybrid SiC-IGBT module approach

A series of 1200V dual modules with current ratings between 100A and 600A was developed [1] by using SiC Schottky Barrier Diodes (SBD). This approach is called "Hybrid SiC" module. For better understanding the used terminology, please refer to Figure 1. A hybrid SiC module is containing Silicon-based IGBT in combination with SiC-based Schottky Barrier diodes. The IGBT-chips are kept the same in both the conventional NFH-series and new hybrid SiC NFH-series.

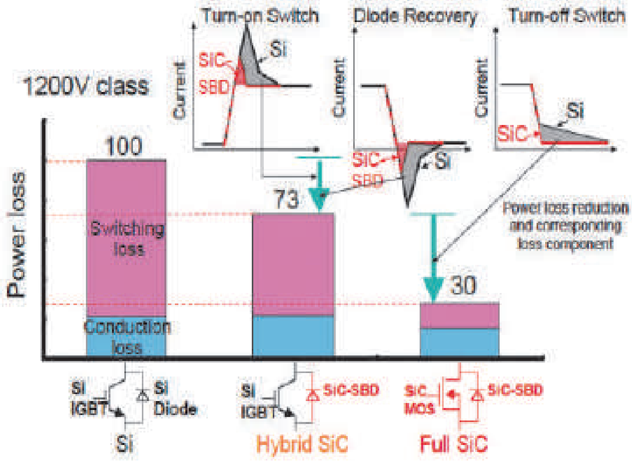
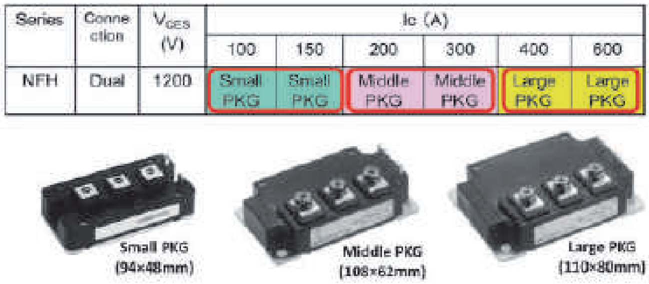


Figure 1: Evolution of SiC technology in power modules

Type	Voltage	Current	Connection	Baseplate size
CMH100DY-24NFH	1200V	100A	2in1	48x94mm
CMH150DY-24NFH		150A		
CMH200DU-24NFH		200A		62x108mm
CMH300DU-24NFH		300A		
CMH400DU-24NFH		400A		80x110mm
CMH600DU-24NFH		600A		

Table 1: Line-up



Series	Connection	V_{CES} (V)	Ic (A)					
			100	150	200	300	400	600
NFH	Dual	1200	Small PKG	Small PKG	Middle PKG	Middle PKG	Large PKG	Large PKG

Figure 2: Line-up and Package outlines

The principle switching waveforms are given in Figure 1. Due to the fact that Schottky diodes as unipolar semiconductors don't have any reverse recovery charge, there is no reverse recovery loss. The absence of diode reverse recovery current on the other hand leads to a substantial reduction of IGBT turn-on energy.

A further reduction of total power loss can be achieved if both the active switch and the free-wheeling diode are made of SiC. This approach is called "Full SiC" module.

Line-up & Package outlines

The line-up of new hybrid SiC NFH-series is shown in table 1; the package outlines are given in Figure 2. For the middle and large size packages the main terminals are located at the side of the housing. This arrangement allows using a laminated main terminal structure inside the module for reducing the internal package inductance Lint. For all current ratings of both middle and large size package this internal package inductance is in the range of 18…22nH (defined between P- and N- main terminals).

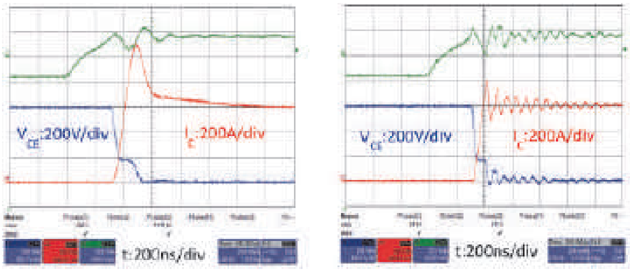
Switching behavior

The turn-on waveforms under inductive load condition of conventional NFH-module CM600DU-24NFH and new hybrid SiC module CMH600DU-24NFH are shown in Figure 3. Taking into account that both module types are using exactly the same IGBT-chips the difference in switching waveform is entirely the result of difference in free-wheel diode behavior. The key difference between both current waveforms can be explained by the lack of reverse recovery charge (and consequently the diode's reverse recovery current) in the hybrid SiC module CMH600DU-24NFH as the Schottky Barrier Diode is a unipolar semiconductor. Consequently both the turn-off loss of freewheeling diode and the turn-on loss of IGBT under inductive load switching are drastically reduced, as it can be seen in the switching energy diagrams given in Figure 4 and 5.

Loss performance comparison

A power loss simulation under inverter operation conditions (hard switching) with sine-wave PWM reveals the big impact of using SiC Schottky diodes instead of conventional Si-diodes for the NFH-series modules: at fc=30kHz the hybrid SiC module has just half of the total losses of its Si-counterpart, see Figure 6.

The dependency of total module power loss on PWM switching frequency fc is given in Figure 7. From this diagram it can be derived that the total power loss of new hybrid SiC type CMH600DU-24NFH at fc=50kHz is at the same level as its full Si-counterpart at fc=17kHz. Considering that both modules CMH600DU-24NFH and CM600DU-24NFH have the same power loss handling capability (same baseplate size and hence the same Rth(c-f); same Rth(j-c) for IGBT) it seems to be possible for such applications to triple the switching frequency fc while keeping the module power loss at the same level.



Conditions: Tj=125degC, V_{GE}=15V, V_{CC}=600V, R_G=0.52ohm

Figure 3: Ic-waveforms at turn-on

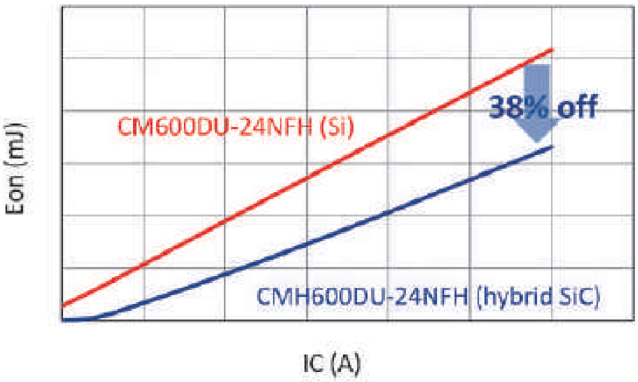


Figure 4: IGBT turn-on energy E(on) vs. current

Application benefits

The described improvements in switching loss performance under hard switching conditions are offering system benefits basically in two directions when using the new hybrid SiC NFH-series:

The most obvious one is the possibility of increasing the switching frequency fc. The size of inductive components in a power electronic system is often determined by the switching frequency.

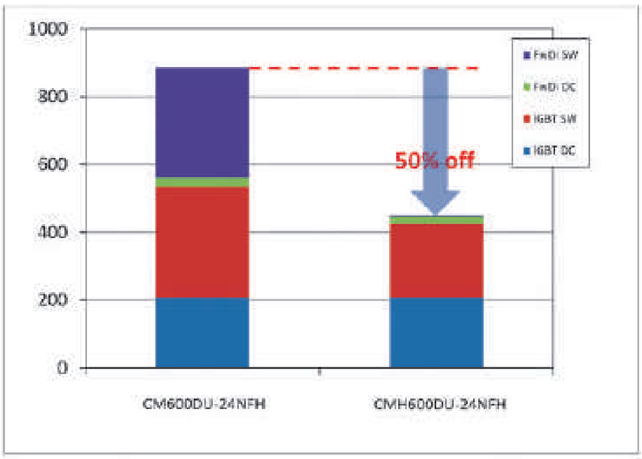
Consequently an increase of fc can help to reduce size (and cost) of those inductive components.

Also the dynamic response of a power electronic system can be improved by increasing fc.

Another direction is improving the energy efficiency of a power electronic system. This is an interesting option especially in application where low system efficiency is penalized.

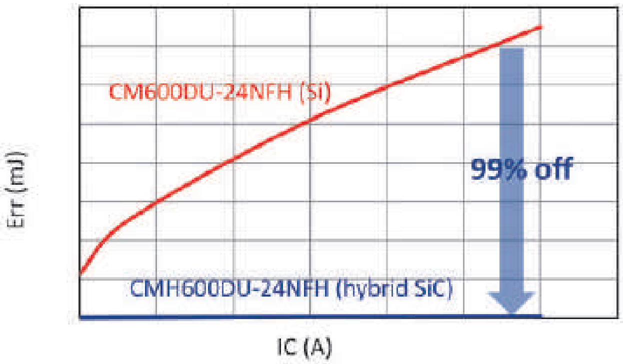
In general reducing the power loss dissipated in the IGBT modules will help to reduce heat sink size. This is interesting for such applications where heat sink is the limiting factor for system size reduction.

Another potential benefit of using the new hybrid SiC series can be expected in soft switching applications. Here the principle absence of reverse recovery charge at diode turn-off can contribute to a further power loss reduction.



Conditions: Io=300A; fc=30kHz; PF=0,8; M=1; Vcc=600V; Vge=+/-15V; Rg=0.52Ω; Tj=125°C

Figure 6: Power loss simulation (inverter operation with sinus PWM)



Conditions: Tj=125degC, V_{GE}=15V, V_{CC}=600V, R_G=0.52ohm, 100A/div; 5mJ/div

Figure 5: Freewheeling diode turn-off energy vs. current

Summary and outlook

By using Mitsubishi’s new hybrid SiC IGBT modules for high frequency applications a drastical reduction of switching loss is possible. The use of SiC Schottky Barrier diodes instead of conventional Silicon diodes as freewheeling diodes in the modules of NFH-series is eliminating the reverse recovery charge at freewheeling diode turn-off. Under hard switching inverter operation conditions this allows to increase the switching frequency by a factor of 2…3 compared with conventional Si-based IGBT modules.

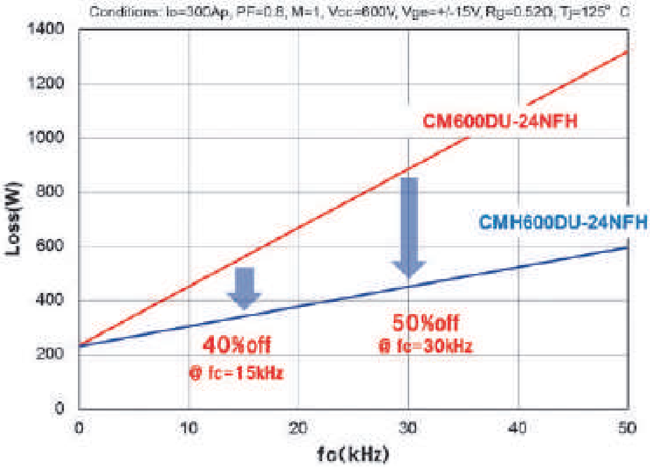


Figure 7: Power loss versus PWM switching frequency fc

Application benefits can be also expected when using the new hybrid SiC modules in soft switching applications due to the absence of reverse recovery charge at diode turn-off. Here further investigations are needed.

Literature

[1] “Mitsubishi Electric to Ship Sample Hybrid SiC Power Semiconductor Modules for High-frequency Switching Applications”; Press Release of Mitsubishi Electric Corporation; Tokyo, May 15, 2014

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Bodo´s Power Systems®

4in1 400A/1200V Module with T-type Topology for 3-Level Applications

A growing demand for 3-level inverter technology combining reduced power loss and increased power capacity is originating from power conversion applications like wind and PV inverter as well as from industrial equipment such as uninterruptible power supplies (UPS) and recently active frontends of 4-quadrant drives.

By Marco Honsberg and Thomas Radke, Mitsubishi Electric Europe B.V.

Much attention has focused on the further development of power semiconductor modules being the key devices in inverters, that offer low power consumption, reduced package size and especially low inductance to help maximizing the 3-level inverter's performance.

Figure 1: Photo of CM400ST-24S1

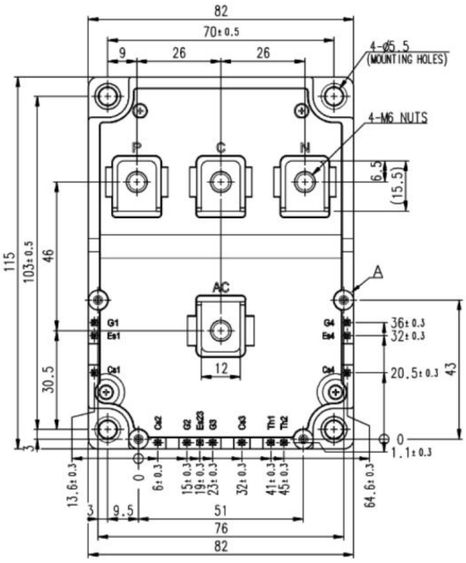

Figure 2: Outline drawing

Mitsubishi Electric launched the CM400ST-24S1 IGBT, e.g. a 4in1 400A/1200V IGBT module as part of a new family of power semiconductor modules optimized for 3-level inverters to meet these demands by adopting new packages that help reducing inductance, thereby contributing to reduced power consumption and downsizing in large-capacity industrial equipment.

Module ratings

This new 400A/1200V module represents the biggest current rating of a planned lineup of 4in1 3-level IGBT modules planned in the same package. Based on electrical and thermal evaluations the CM400ST-24S1 is supposed to operate in 125kW-class inverters.

The photo of the CM400ST-24S1 reveals the outline of the package and figure 2 indicates the drawing of this new package. With baseplate dimensions of 115mm x 82mm and the innovative step terminal design this new outline provides new degrees of freedom in designing a power stage including the mechanical design of a gate driver Printed Circuit Board and an efficient utilization of the heatsink in case of parallel connection of modules. The next paragraph will introduce the design features that have led to such an innovative IGBT module packaging concept.

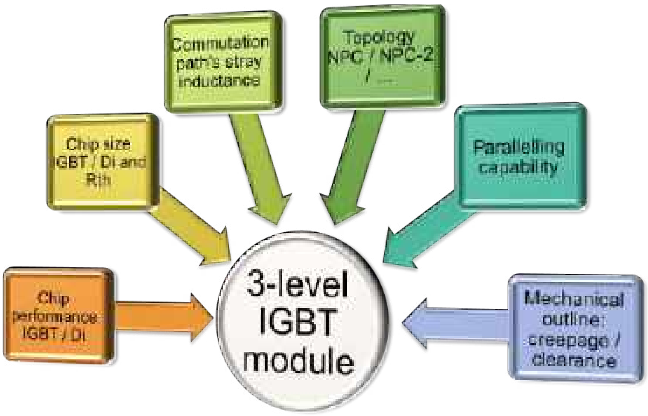

Figure 3: Design considerations for 3-level modules

Design considerations for the CM400ST-24S1

Figure 3 shows at a glance the design considerations that have significantly influenced the concept of this new IGBT module CM400ST-24S1. In fact a state-of-the-art 3-level IGBT module shall reflect a best adoption of design aspects as shown in figure 3 to deliver the desired performance.

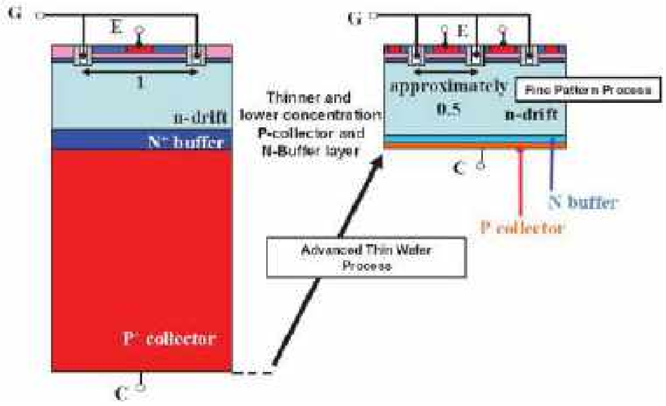

Figure 4: 7^{th} generation chip technology

Chip performance IGBT / Di

Obviously the chip performance itself of the IGBTs and Diodes play one major role in the design of a 3-level IGBT module. In case of the CM400ST-24S1 the latest chip generation of Carrier Stored Trench gate Bipolar Transistors (CSTBT™) have been adopted. Thus, for 1200V blocking voltage class a 6.1^{st} generation CSTBT™ chip has been selected offering today's best trade-off between switching and conduction loss in this voltage class along with 650V CSTBT™ chip of the 7^{th} generation chip technology for the first time introduced in an industrial grade IGBT module. Figure 4 shows the innovative 7^{th} generation chip technology which has improved trade-off between static loss Vce(sat) and dynamic loss as specific turn off energy E(off).

In this 7_{th} generation 650V chip substantial modifications of the fabrication technology have led to a significant performance improvement. The manufacturing techniques applied to this novel 650V CSTBT™ allowed an about half-size shrinkage of the transistor unit cell through a fine pattern process and a LPT (Light Punch Through) structure utilizing an advanced thin wafer process technology.

Topology

For DC-link voltage ranges up to about 850V a so called “T-type” topology has proven to be the best choice considering the switching frequency range of the application. The CM400ST-24S1 is made for DC-link voltages of up to 850V and is following this topology indicated in figure 5 utilizing the aforementioned 6.1st generation CSTBT™ 1200V class IGBT and anti-paralleled diodes for Tr1 and Tr4 and the novel 650V 7^{th} generation CSTBT™ chips with anti-paralleled diode for Tr2 and Tr3.

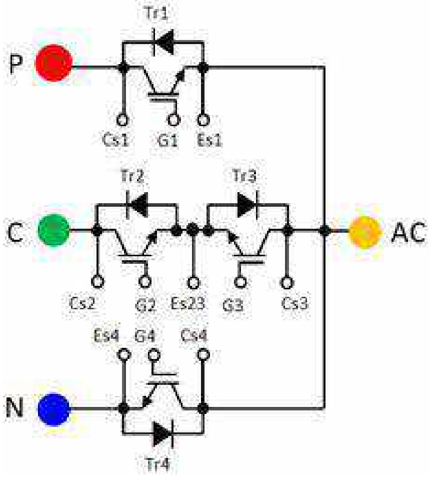

Figure 5: “T-type” topology

Stray inductance

The module's internal stray inductance in conjunction with the blocking voltage capability of the chosen chips their dynamic loss performance and the desired performance of the module are key optimization objectives. Referring to the complexity of potential current and commutation paths of a T-type 3-level IGBT module, e.g. at least from terminal “P” to terminal “C” and from terminal “C” to “N” in a typical 3L commutation loop the module design must minimize the inductance for at least those two commutation paths. The CM400ST-24S1 has reached for both mentioned 3-level commutation loops stray inductance levels of less than 30nH (approximately 26nH) and additionally a commutation stray inductance of about 30nH in the 2-level commutation path from terminal “P” to terminal “N”. The balanced low stray inductance layout of this new package incorporates a new degree of freedom to alter from 3-level commutation strategy to a 2-level commutation operation providing a better thermal exploitation of the semiconductor chips at high current and low modulation indices to cover for example extraordinary operating conditions of uninterruptible Power Supplies (UPS).

Chip size and thermal resistance (Rth)

The CM400ST-24S1 employs Silicon – Nitride substrate (Si3N4) to provide the required thermal performance of the package. This material's thermal conductivity is in between the superior performance of the Aluminum Nitride (ALN) and the worse performing Aluminum oxide (Al2O3). Referring to the topology as shown in figure 5 the thermal performance of each chip could be optimized for certain applications. Hence, an anti-paralleled Di to Tr1 or Tr4 could be sized comparatively small for a motor drive application operating at high power factor but they should be sized much bigger for a module placed in an active frontend mainly operating in Power factor Correction (PFC) mode. Indeed the CM400ST-24S1 chip size ratio has been selected to satisfy both applications.

Paralleling capability

Paralleling capability is an essential feature of the CM400ST-24S1, since it permits utilizing the same module for a modular design for output power requirements of more than the mentioned 125kW. Providing paralleling as dedicated feature implies constructing the module in order to minimize the distance between DC-link terminals of the paralleled modules and to provide a (simple) layout that utilizes the heatsink area and blower construction efficiently. The module dimensions of 82mm x 115mm, whereas the shorter 82mm is the dimension that advantageously decreases the distance between two adjacent modules efficiently. The step terminal approach for the output terminal simplifies the connection to parallel modules while this different height level will refrain from disturbing the DC-link construction of terminals “P”, “C” and “N”.

The CM400ST-24S1 has been designed to provide a high performing low inductive IGBT module solution for 3-level applications with a maximum DC-link voltage of 850V. The innovative package construction realizes low inductance in all possible commutation loops and by the step terminal it is dedicated for paralleling application for active frontend (PFC) as well as for PV and UPS output application. The low thermal resistance along with the loss performance of the latest generation of utilized IGBT and diode chips provides unprecedented output power performance of a 3-level IGBT module in this configuration. The first module that is available is a 400A class current rated module. A further lineup of smaller current ratings is planned.

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New 800A/1200V Full SiC Module

By using SiC-based semiconductors the performance of power electronic systems can be drastically improved.

By Eckhard Thal, Koichi Masuda and Eugen Wiesner,
Mitsubishi Electric Europe B.V., Ratingen, Germany

The evolution of SiC technology in power modules and its principle loss reduction potential are shown in Figure 1. Mitsubishi has developed two new full SiC module types with 800A and 1200A rated currents and 1200V rated voltage [1]; [2]. This article is describing the 800A module.

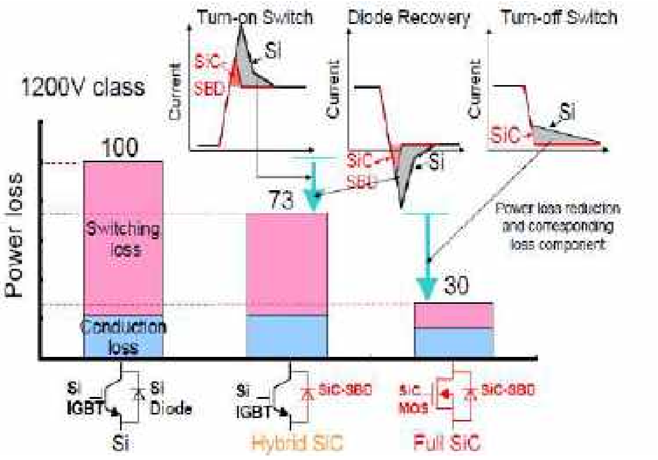


Figure 1: Evolution of SiC technology in power modules

Package outline and circuit diagram

The appearance of new 800A/1200V full SiC module (type name: FMF800DX-24A) and its internal circuit diagram are shown in Figure 2. The module contains 2 x 400A half bridge configurations. By externally paralleling the main P-, N- and AC-terminals an 800A/1200V 2in1 configuration is formed. By this paralleling approach the internal package inductance LS has been decreased to less than 10nH, which is important for limiting the overvoltage spikes at chip level due to high di/dt at switching of SiC-MOSFET.

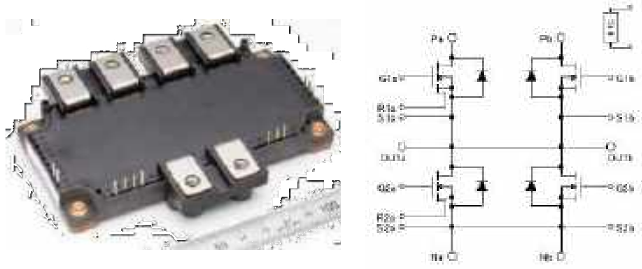


Figure 2: FMF800DX-24A package outline and internal circuit

The baseplate dimension of FMF800DX-24A is 62mm x 121mm. Thus the module size of new 800A/1200V full SiC module is about 1/2 compared with conventional Si-based IGBT modules having the same current rating, see Figure 3.

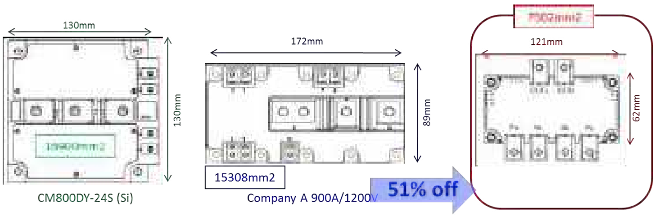


Figure 3: Footprint comparison

For monitoring the baseplate temperature TC a NTC-sensor located close to the MOSFET/FWDi chips is incorporated into the module. For short circuit and overcurrent protection MOSFET-chips with on-chip current sensing are used in one of the half bridge configurations (see Figure 2).

Main module parameters

The main parameters of 800A full SiC module are shown in Table 1. The values of VDS, RDS(on) and VSD are given on chip level.

Symbol	Parameter	FMF800DX-24A
V_{DSX}	Drain-source voltage (at V_{GS}=-15V)	1200V (max)
I_D	Drain current	800A
$I_{D(max)}$	Max. drain current (pulse)	1600A
$T_{J(max)}$	Max. junction temperature	150°C
$V_{DS(on)}$	Drain-source On-voltage @ I_D; T_J=150°C	2,4V (typ)
$R_{DS(on)}$	Drain-source On-resistance @ I_D; T_J=150°C	3,0mΩ (typ)
V_{SD}	Source-drain voltage @ -I_D; T_J=150°C	2,2V (typ)
$V_{GS(+)}$	Gate-source On-voltage	13,5V…16,5V
$V_{GS(-)}$	Gate-source Off-voltage	-9V…-16,5V
$R_{th(j-c)Q}$	MOSFET thermal resistance	42 K/kW
$R_{th(j-c)D}$	FWDi thermal resistance	61 K/kW

Table 1: Main FMF800DX-24A parameters

Switching characteristics

Typical turn-on and turn-off switching waveforms at VCC=800V; TJ=150°C; RG(on)=RG(off)=5Ω are shown in Figure 4 and 5 for different drain currents ID=140A…1400A.

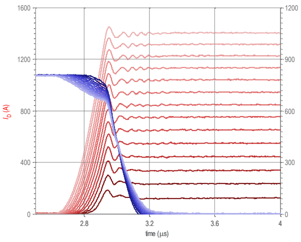


Figure 4: Turn-on waveforms

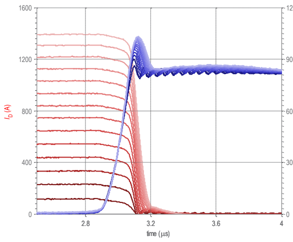


Figure 5: Turn-off waveforms

For limiting the turn-off overvoltage spike a cross-snubber capacitor of CS=6µF was connected between P- an N-terminals. The dependency of switching speed di/dt on drain current ID is shown in Figure 6 and 7 for different junction temperatures TJ=25°C; 75°C; 125°C; 150°C and different DC-link voltages VCC=600V; 800V.

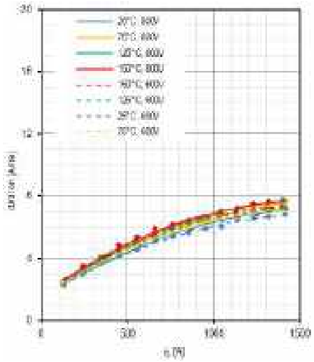


Figure 6: Turn-on di/dt versus I_D

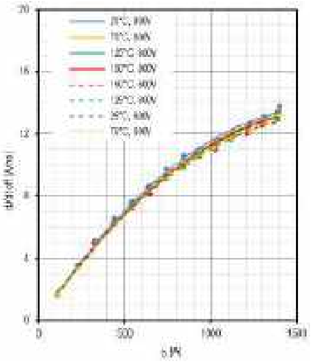


Figure 7: Turn-off di/dt versus I_D

Two comments can be derived from Figure 6 and 7:

a) The current slopes at turn–on and turn-off don't show a strong dependency on chip temperature TJ and DC-link voltage VCC. This behavior differs from today's IGBT-modules.

b) The maximum di/dt at turning-off ID=1400A was about 13A/ns, which is quite similar to the switching speed known from today's high current 1200V IGBT-modules.

Loss comparison with Si-based IGBT modules

The typical forward characteristics of new 800A full SiC module and existing 800A Si-based IGBT module are compared in Figure 8.

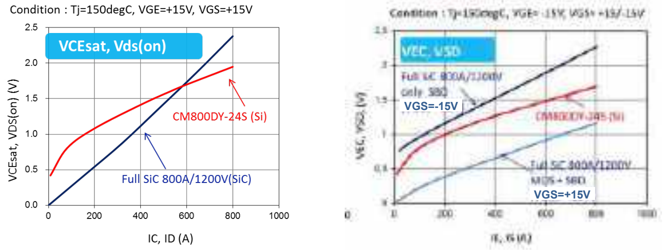


Figure 8: Forward characteristics

The comparison of switching energies in Figure 9 is indicating a key benefit of SiC technology: the switching losses can be drastically reduced compared with Si-based IGBT modules.

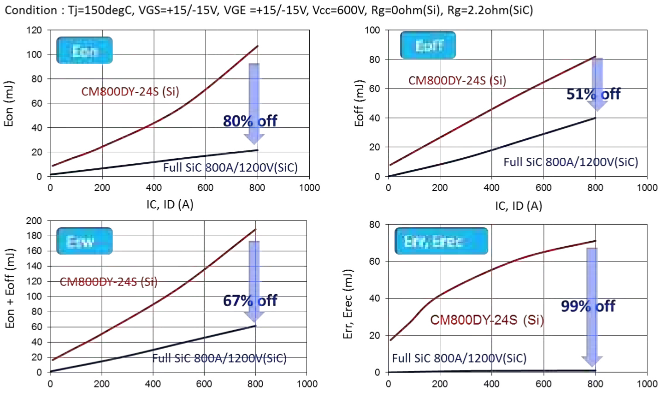


Figure 9: Switching energy comparison

This benefit can be seen in the power loss simulation results per Transistor/FWDi-pair in inverter operation for two different PWM frequencies 15kHz and 30kHz and the corresponding temperature rise ΔT(j-c) in Figure 10 and Figure 11.

The total power loss can be drastically reduced (by 71% for 15kHz and 76% for 30kHz) when full SiC-module is used. This loss reduction is mainly due to reduced switching loss. Conclusion: full SiC modules are very well suited for applications requiring high switching frequencies, where conventional Si-IGBT modules are reaching their thermal limit.

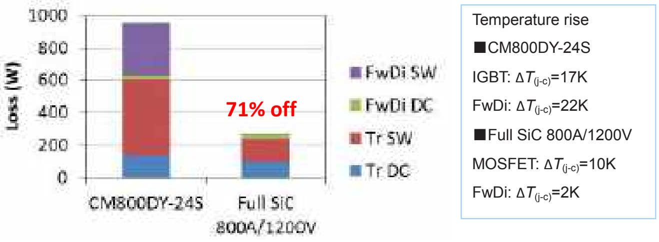


Figure 10: Loss and ΔT(j-c) simulation at fc=15kHz; VCC=600V; IO=400A(peak); PF=0,8; M=1,0

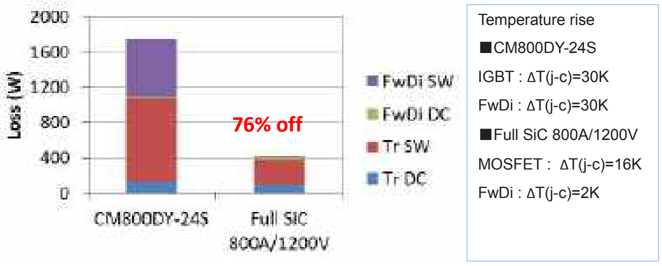


Figure 11: Loss and ΔT(j-c) simulation at fc=30kHz; VCC=600V; IO=400A(peak); PF=0,8; M=1,0

Gate Driver with SC-protection

The new 800A/1200V full SiC-Module can withstand a short circuit current for a limited time of tSC(max)=2,5μs. This limit is given in the SCSOA specification.

For conventional Si-IGBT modules typically a short circuit capability of tSC(max)=10μs is specified. In such conventional IGBT drivers a blanking time between desat-detection and SC-turn-off of typically to=1 3μs is installed, which is sufficient to ensure both: no false SC protection tripping and safe SC-turn-off.

Considering the relatively short tSC(max)=2,5μs specified for the new 800A/1200V full SiC-module another SC-protection method is proposed, known as RTC (Real Time Current Control). For this purpose one p-side and one n-side SiC MOSFET chip are equipped with a current sense electrode (refer to Figure 2). The equivalent circuit and the external view of this SiC MOSFET chip are shown in Figure 12.

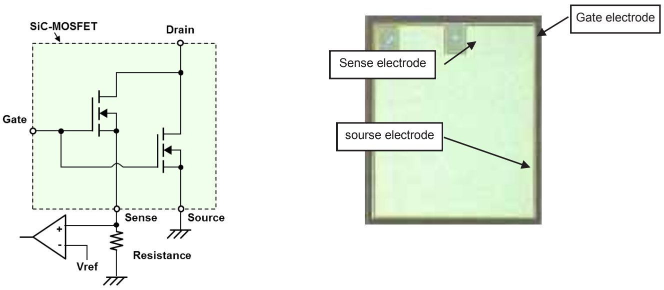


Figure 12: SiC MOSFET chip with current sense terminal

The functional block diagram of a dedicated gate driver for FMF800DX-24A using the proposed RTC protection is given in Figure 13. The measured short circuit waveforms during RTC operation are shown in Figure 14.

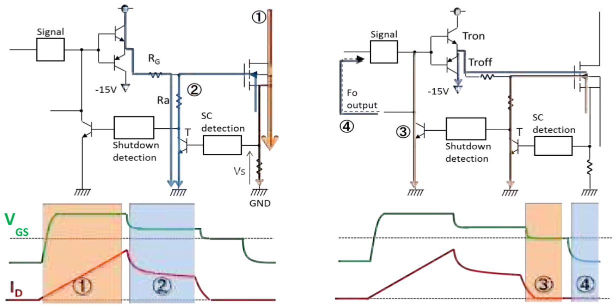
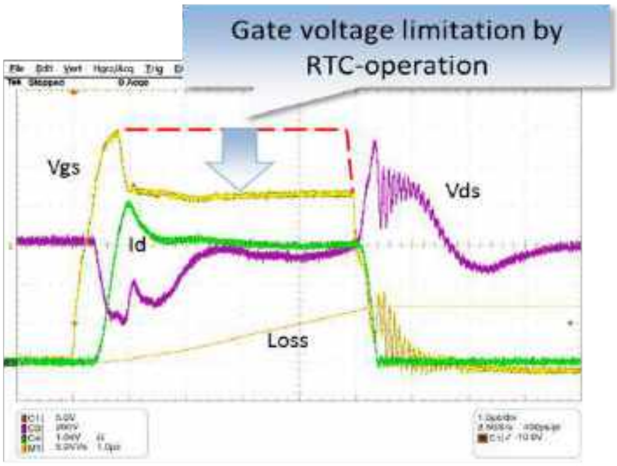


Figure 13: Principle of SC-protection by RTC



Vgs : 5V/div.、Vds : 200V/div.

Id : 1kA/div.、Time : 1μs/div.

Figure 14: SC-waveforms during RTC-operation

During SC-turn-off operation by RTC four modes can be distinguished. In mode ① the main current ID is increasing until the voltage Vs across the shunt resistance is reaching a defined trip level. After reaching this trip level the mode ② starts: the transistor T is turned on and the Gate-Source voltage is reduced from +15V to about +7V resulting in a decreased SC-saturation current. Due to this SC-current reduction the allowable short circuit time is increased again to the well-known from IGBT drivers tsc(max)=10µs. Means from now on the conventional IGBT gate driver timing can be applied. During phase ③ the gate driver transistor Tron is switched off and VGS becomes Zero thus causing a soft turn-off of the short circuit current. In the final phase ④ the driver transistor Troff is turned on thus applying a negative VGS to the SiC MOSFET in off-state.

Summary and outlook

This paper is describing a new 800A/1200V full SiC dual module. Its type name is FMF800DX-24A. Compared with conventional Si-based IGBT modules the following unique points are confirmed:

- Module size reduced by 50%
- Switching loss (Esw= Eon + Eoff + Err) reduced by 75%
- Reliable SC-protection by RTC

Based on these features the new 800A/1200V full SiC module provides an interesting alternative to conventional IGBT modules in power electronic systems up to several 100kW, especially if one of the following system characteristics is of specific importance:

- Compact equipment size/high power density
- High efficiency
- High switching frequency (beyond the today's limit reachable with IGBT modules)

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Transfer Mold IPM Family "SLIMDIP" with 5A/15A 600V RC (Reverse Conducting) – IGBT in a Compact Package

A very compact Dual-In-line Package Intelligent Power Module SLIMDIP with ratings of 5A and 15A /600V has been developed employing Reverse Conducting (RC) IGBT chip technology. This technology integrates the required freewheeling function for inductive loads into the developed RC-IGBT chip and, hence, makes the Diode that usually is connected antiparallelly to a conventional IGBT redundant.

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Mitsubishi Electric Europe B.V. and
Teruaki Nagahara, Power Device Works,
Mitsubishi Electric Corporation Japan

As a consequence the employment of reverse conducting IGBT chips save space and that resulted in the new package of the SLIMDIP being designed very compact. The SLIMDIP provides protection functions for under voltage, short circuit and over temperature as well as a linear output signal for the case temperature. The interface circuit of the SLIMDIP is 3,3V to 5V compliant and the pin terminal assignment simplifies the printed circuit board layout design.

Variable speed Inverters are increasingly used to drive small motors aiming to increase the efficiency of motor control systems. This development has become visible also in the white goods and small fan and pump application field that are driven by small motor drives with a rating of up to about 2,2kW. Responding to this demand the continuously further developed Super Mini DIPIPM has been developed in 2004 already and has set package standards in this specific market segment. Now a further technology step has been realized and a new smaller transfer mold IPM has been developed, actually mainly addressing the white goods application market segment such as washing machines and air-conditioner. This new SLIMDIP significantly improves compactness, power density, efficiency and controllability of systems. Today two devices have been developed for the two main existing application segments: A SLIMDIP "small" ("S") with a typical collector current rating of 5A is mainly addressing the power requirements of typical European household washing machines, e.g. driven by a motor of around 750W of shaft power or smaller applications and the SLIMDIP "large" ("L") with a typical Collector current rating of 15A focuses on the higher power demand of air conditioners or drives for professional heavy duty washing machines. Since these applications usually do not use an isolated interface between the IGBT driver stage and the microprocessor the SLIMDIP family is

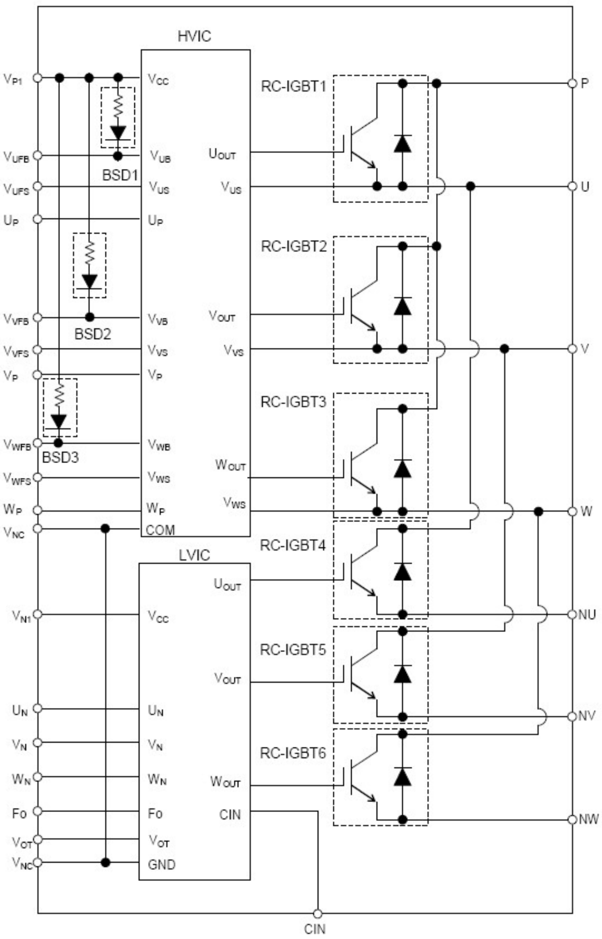

Figure 1: Shows the internal block diagram with RC-IGBT, the LVIC and HVIC and the integrated bootstrap circuitry.

equipped like all transfer mold IPMs with the latest generation of High Voltage Integrated Circuits (HVIC) to drive and to protect the power stage. Simplifying the peripheral circuit the SLIM DIP has got robust bootstrap diodes and corresponding current limiting resistors for the bootstrap operation integrated into the package.

RC-IGBT merits

The RC-IGBT technology provides merits in the fabrication process of the SLIMDIP mainly in the assembling process since it is simpler with a half power-chip-die bonding and without Al wire-bonding from IGBT to the Diode. The availability of a free-wheeling function of the RC-IGBT chip itself, e.g. without an externally connected dedicated diode is saving module space and provides cost efficient and compact package design.

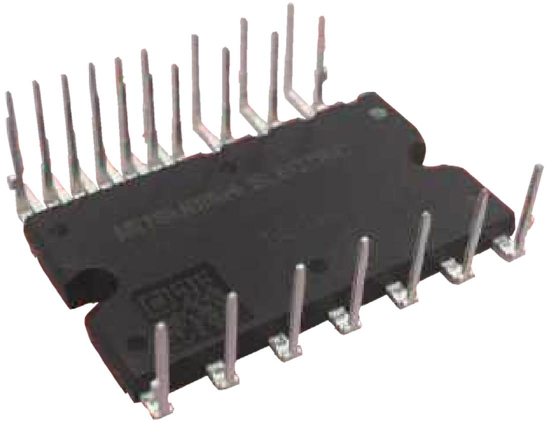

Figure 2: Photo of the SLIMDIP

Package design

This new SLIMDIP package is following the DUAL INLINE concept known from the version 6 Super Mini DIPIPM but with a further development of the lead frame and integrated functions. The compact package of only 18,8mm x 32,8mm has got control terminals arranged in zig-zag shape providing sufficient clearance between the holes, the outer annular ring avoiding expensive printed circuit board fabrication processes like fine pattern structures with the utilized pitch etc. The control and power terminal structure and arrangements are indicated in Figure 2.

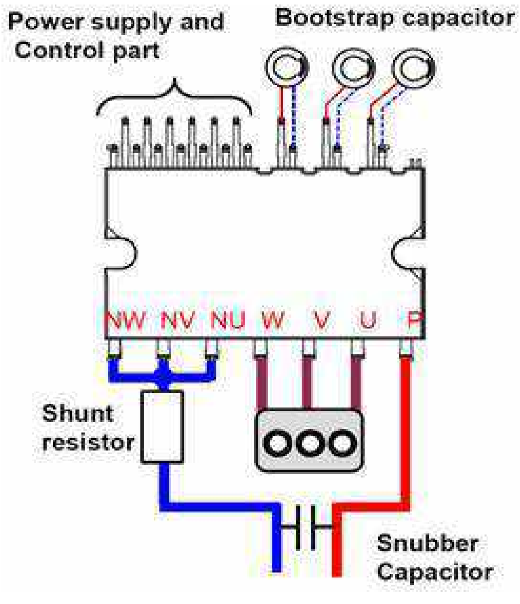

Figure 3: Shows the improved pin terminal layout

The arrangement of the terminals has been further improved versus the Super Mini DIPIPM version construction since the bootstrap capacitors have dedicated terminals assigned and a crossing of PCB traces under the footprint of the SLIMDIP to the corresponding output terminal is not required anymore.

Hence, the improved lead frame pin terminal assignment simplifies the design of a printed circuit board and total cost optimized designs targeting the realization of the complete motor drive on only a single sided printed circuit board become possible easier. As shown in this figure the SLIMDIP provides an open Emitter structure that permits the acquisition of phase currents when all low side IGBTs are turned on, e.g. during the lower zero vector of the Pulse Width Modulation (PWM). These shunt resistors if selected as surface mounted device ideally fit under the footprint of the SLIMDIP and would reduce the stray inductance of the complete DC-link construction accordingly.

Performance comparison

Besides the improvement of the construction of the new SLIMDIP housing a set of performance extensions have been reached with this new developed device. Indeed the maximum case temperature has been specified higher: While previously the Super Mini DIPIPM package has been specified for a maximum of 100°C of case temperature, the new SLIMDIP's maximum case temperature has been extended to 115°C. As a consequence of this extended specification the internal over temperature (OT) threshold has been adjusted accordingly now starting at 115°C. Concerning the isolation voltage the specification has been increased by over 500Vrms from the 1500Vrms that have been specified for the Super Mini DIPIM to the level of 2000Vrms for the SLIMDIP. Along with the more compact dimensions of the case these improvements have been summarized in table 1 showing the extended specification of the SLIMDIP.

Figure 4: Evaluation board

Protection functions:

The protection of the power stage is an essential task of an IPM and a dedicated circuitry is employed in the control part or both the Low Voltage Integrated Circuit (LVIC) and the High Voltage Integrated Circuit (HVIC) that contains the level shifting function, too. Under voltage protection, Short Circuit protection are the standard protection functions integrated in the transfer mold IPMs, but as innovation the newly developed SLIMDIP contains a thermal protection function "over temperature protection" and issues at the same time an accurate temperature proportional signal “VOT” that allows to take action when the thermal limit, e.g. the over temperature threshold is close in order to avoid a sudden interrupt of the drive operation.

Tc max	115deg C	+15deg C ←	100deg C
Package	SLIM 18.8x32.8x3.6	-30% ←	Super mini 24x38x3.5
Viso	2000Vrms	+500V ←	1500Vrms

Table 1: Extended specification of the SLIMDIP

Evaluation platform:

The features and the new extended functionality of the SLIMDIP can be verified by the developed evaluation board. The photo shows the evaluation platform employing the input rectification circuit the bulk DC-link capacitors a 15V/5V DC-DC converter stage and an isolated input circuitry for a safe connection to a microprocessor board.

The board uses clamp connectors for the power connections like AC in, 3~ motor connector etc. which provide a quick connection of cabling to this evaluation board. On the control terminal side a standard self-locking JST connector type is foreseen to connect control signals safely to the evaluation board.

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Power Modules for Combining Innovation, Flexibility and Power Capability in the Various 3-Level Topologies

Three level topologies have demonstrated higher efficiencies, filter optimization potential and the capability of handling high DC-link voltages. To maximize the advantages offered by the 3-level topologies, Mitsubishi Electric offers new power modules which unlock the potential to realize innovative solutions for different power segments.

By Narender Lakshmanan and Thomas Radke, Mitsubishi Electric Europe B.V. and Satoshi Kawabata, Mitsubishi Electric Corporation Japan Power Device Works.

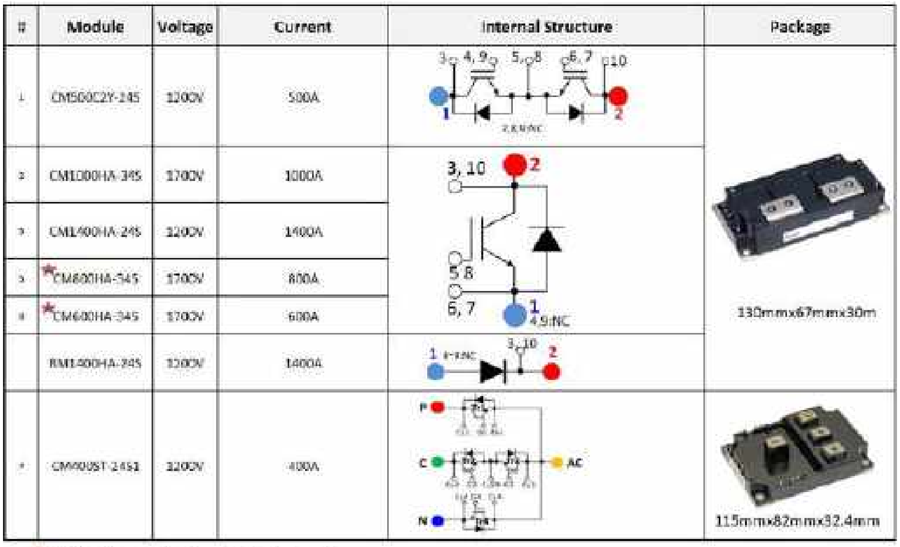
Power conversion applications have always had to deliver high performance while maintaining the required quality of power. The harmonic profile of the output power can be improved by increasing the switching frequency. However, an increase in switching frequency compromises the inverter efficiency. Historically, the conventional 2-level inverters have served the industry with its seemingly uncomplicated topology where developers have always had to strike a balance between efficiency and filter optimization. With the invention of the 3-level topologies, many new avenues are now open for improving the output harmonic profile without compromising on the system efficiency. With the option of being able to apply the 'zero' level, this topology brings with it the following inherent benefits:

1. Efficiency and output power capability [1]: The superior switching loss profile of a 3-level inverter ensures that better efficiencies can be achieved. Thus, for the same dc-link, a 3-level based inverter can deliver a higher output power compared to the corresponding 2-level inverter.
2. AC filtering [5]: For the same switching frequency, the 3-level topology utilizes the availability of the 'zero' level to deliver an AC output of higher power quality than the corresponding 2-level inverter. This naturally allows a significant reduction of the output filter inductance.
3. dv/dt Filter [5]: Since the phase to neutral output of a 3-level inverter shifts between 0V and (+/- Vdc)/2 (unlike the 2-level output), the corresponding dv/dt across the load is naturally reduced by about 50%.
4. Common mode voltage reduction [5][6]: In comparison with 2-level, significant reduction (about 25%) of common mode voltage is possible in the 3-level topology.

While every segment of the inverter industry can avail the benefits associated with the 3-level topologies, grid connected inverters (Solar, Wind, HVDC), UPS and medium-to-high power drives stand to benefit significantly by employing this innovative approach[3][4].

Power Modules from Mitsubishi Electric for 3-level NPC inverters

The CM400ST-24S1 module has already been introduced and presented in good detail ([2] Bodos article Feb'2015). A new series of power modules with innovative packaging



#	Module	Voltage	Current	Internal Structure	Package
1	CM500C2Y-24S	1200V	500A		
2	CM1000HA-34S	1700V	1000A		130mmx67mmx30m
3	CM1400HA-24S	1200V	1400A		
3	*CM800HA-34S	1700V	800A		
4	*CM600HA-34S	1700V	600A		
	RM1400HA-24S	1200V	1400A		
5	CM400ST-24S1	1200V	400A		115mmx82mmx32.4mm

* NOTE : New products under development

Figure 1: Line-up of the products dedicated for 3-level solutions

optimized for 3-level applications has been developed. The comprehensive line-up is shown in Figure 1. The CM500C2Y-24S is provided as a dedicated neutral clamp switch for efficiently realizing the T type 3-level topology.

These power modules from Mitsubishi Electric are optimized for 3-level topologies with regards to the following parameters:

1. **Compact package size:** For realizing an I type topology, in comparison with its counterparts from other manufacturers, the 1 in 1 modules (each 130 mm x 67 mm x 30 mm in size) offer about 20% reduction in mounting area. This was achieved by taking advantage of the superior thermal behavior of the Aluminium nitride (AlN) substrate and combining it with the CSTBT^{TM} chip technology.
2. **Reduced internal inductance:** The 1 in 1 modules have an internal inductance of only 8 nH. Internal stray inductance plays an important role in 3-level topologies as several elements are connected in series unlike the traditional 2-level topologies.
3. **Reduced overall inductance:** The combination of a low internal inductance, a reduced mounting area and the location of terminals for easy connections ensure a reduced overall inductance for the set-up.
4. **Access to auxiliary terminals:** The module provides access to the auxiliary terminals on two sides for the connecting the gate driver (without having the need to disturb the bus bar arrangement).

An example of how low inductance I-type and T-type 3-level topology bus bar designs can be realized is represented in Figure 2. As shown in this example, it is obvious that these modules are specifically optimized for 3-level topologies, thereby addressing the challenges associated with DC bus bar inductance, power density and flexibility.

Figure 3 shows the different power levels achievable by developing various 3-level topologies employing power modules from Mitsubishi Electric. The power levels are based on a conservative dimensioning of junction-case temperature rise of 25K considering a switching frequency of 2 kHz. Depending on the cooling system and the switching frequency, the output can obviously be further maximized.

Power levels

1. **125 kW to 500 kW range:** For a DC link voltage of 850 V, the CM400ST-24S1 with its inbuilt T type topology can deliver up to 250 kW in stand-alone mode. When used in parallel, about 500 kW output can be delivered.
2. **500 kW to 2 MW range:** When a DC link voltage of 1200V is utilized, two CM1000HA-34S (1000A/1700V) together with two CM500C2Y-24S (500A /1200V) in parallel can be employed to achieve more than 1 MW output. On the other hand, when an 850V DC link is considered, two CM1400HA-24S (1400A/1200V) can be employed together with two CM500C2Y in parallel to achieve more than 1 MW output power. With a DC link

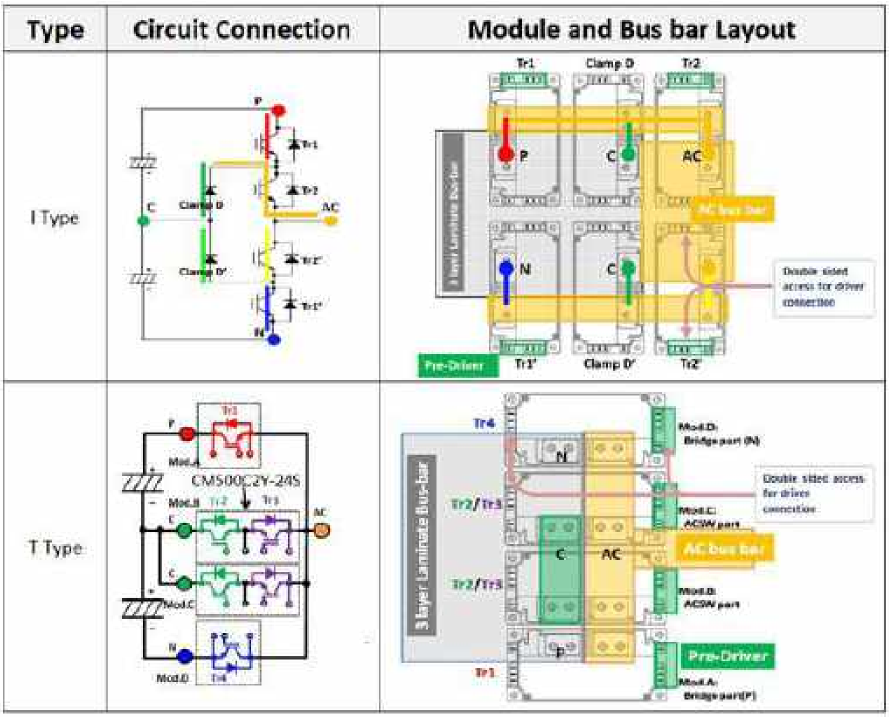


Figure 2: Sample 3-level constructions which can be realized for using Mitsubishi Electric power modules

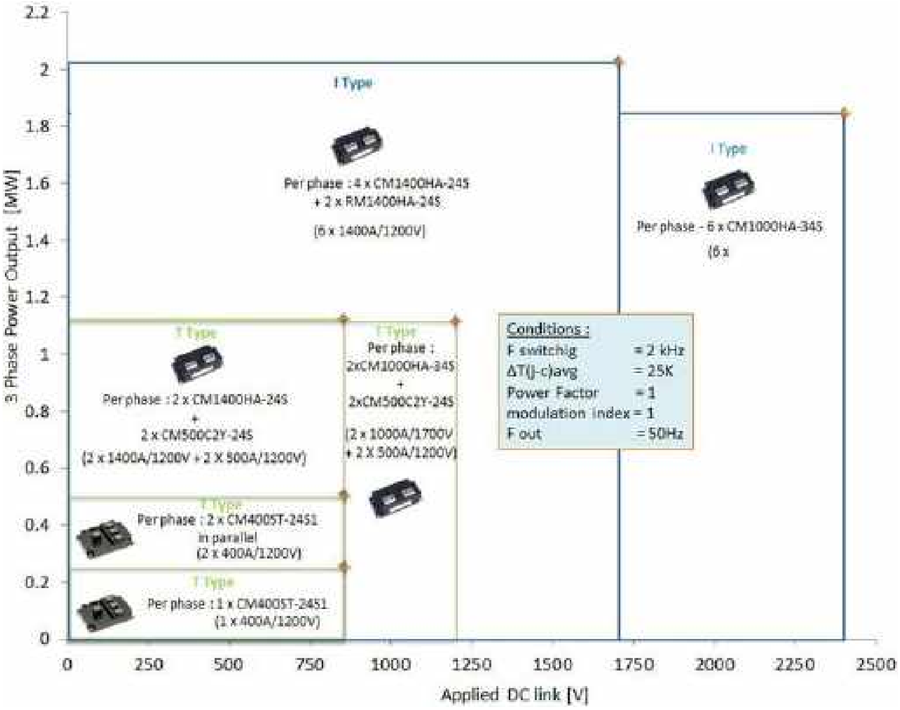


Figure 3: Power capability matrix for different 3-level solutions

of 2400V, six CM1000HA-34S can be employed to develop a 1.8 MW inverter. Remarkably, utilizing a 1700V DC link, more than 2 MW output can be achieved by employing four CM1400HA-24S modules along with two RM1400HA-24S (neutral clamp diodes).

3. **Extended Megawatt range:** It is obvious that by paralleling the options provided above, extended megawatt range inverters can be realized. An alternative solution for this class is to employ multi-level topologies.

As a result of these new products being available, the designer can choose the best fitting solution considering the power and DC voltage requirements. The designer is thus able to evaluate and accordingly select a suitable system voltage to achieve significant system level benefits and thereby maximize overall efficiency.

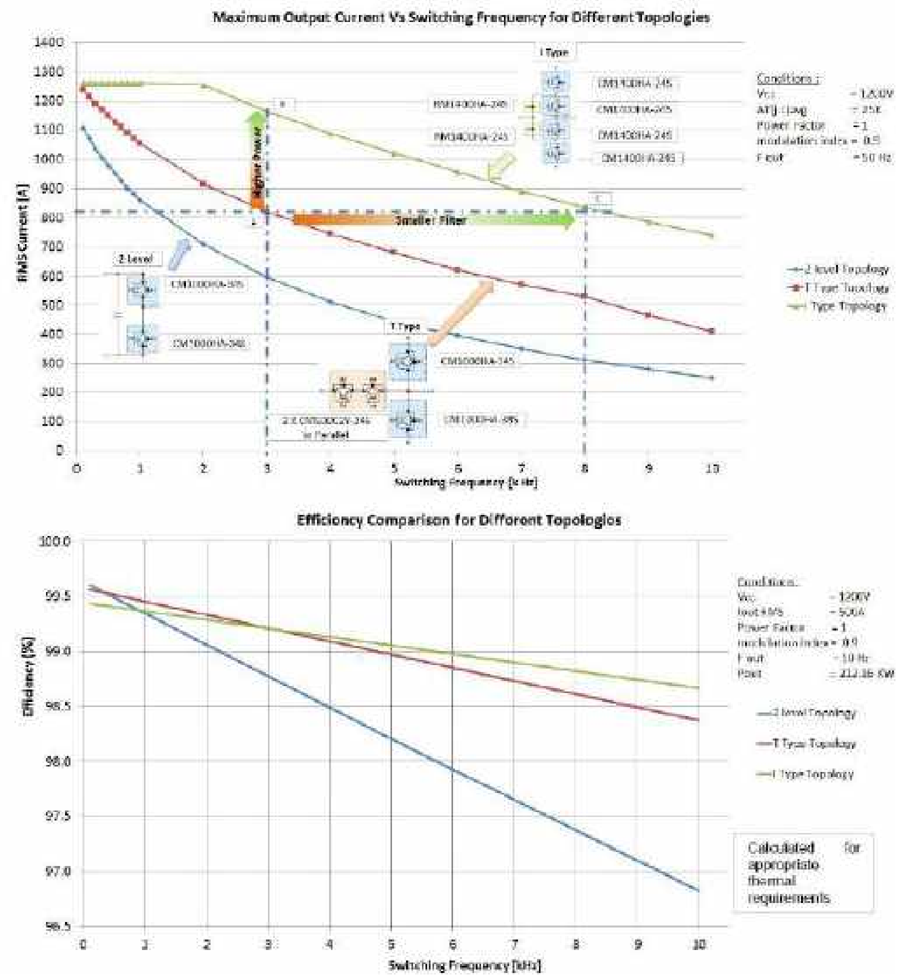


Figure 4: Analysis and comparison of performance using 3-level and 2-level topologies

Employing the appropriate solution

Figure 4 shows that for an inverter with 1200V dc-link voltage, the maximum output current achievable for different switching frequencies for a maximum allowable ΔT(j-c) avg = 25K (imposed on the first element in any module to reach this limit) depends on the topology employed. The T type topology has advantages with respect to a lower part count and the corresponding volume reduction. However, the equivalent I type topology brings forth interesting system level benefits. Considering a fixed switching frequency of 3 kHz, it can be seen that the I type inverter is capable of delivering 1.41 times more current than the equivalent T type topology. Such benefit in power capability can also be used to allow an increase in the switching frequency (a factor of 2.66 for the 800A range) bringing significant benefits in passive component reduction. Depending on the weightage allocated to passives dimensioning and device count, an appropriate decision can be made.

Conclusion

While each module is designed to deliver the best electrical performance, the module packaging itself and the layout as well is optimized for 3-level inverter design. Combining these aspects with the variety of combinations possible using these different modules, designers now are allowed greater flexibility in realizing solutions which cater to their specific needs. To sum things up - it is clear, that there is flexibility in mechanical layout and flexibility in system level design parameters (choice of DC-link, filter). By addressing the specific needs of individual applications, it is obvious that solutions based on Mitsubishi Electric 3-level modules help achieve the maximum possible overall efficiency along with the best possible performance.

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„All-In-One“ DIPIPM+™ Series for Compact Inverter Designs

A novel family of compact Intelligent Converter-Inverter-Brake-modules was developed. This new DIPIPM+TM series incorporates optimized IGBT- and FWDi-chips, low voltage and high voltage driver ICs in a compact transfer molded dual-inline package. The new DIPIPM+ TM series is providing smart answers on the 2 key questions a designer is facing when developing a new inverter design: How to reduce the system cost? How to reduce the inverter size by compact design?

By Muzaffer Albayrak; Eckhard Thal and Kosuke Yamaguchi,
Mitsubishi Electric Europe, Germany
and Teruaki Nagahara, Mitsubishi Electric Power Device Works, Japan

Introduction

The newly developed DIPIPM+™ series was introduced recently [1]; [2]. It consists of 6 different module ratings in 2 selectable configurations: Converter-Inverter-Brake-topology (see Figure 1) or Converter-Inverter-topology (see Figure 2).

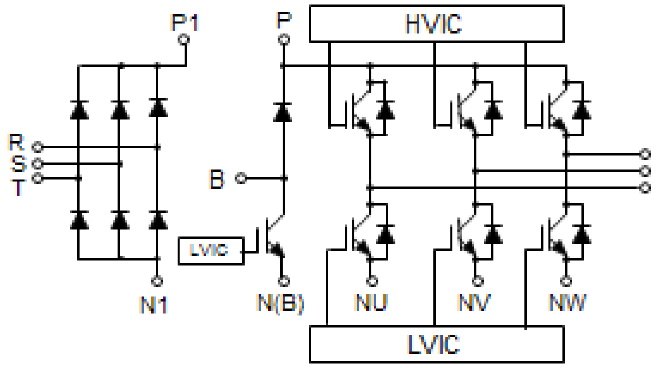


Figure1: DIPIPM+™ line-up and circuit diagram with brake

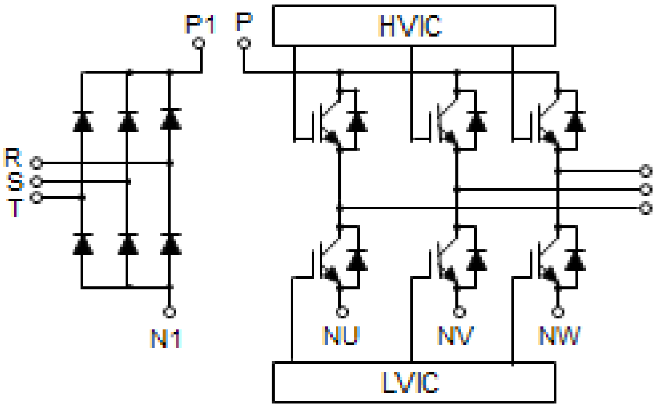


Figure 2: DIPIPM+™ line-up and circuit diagram without brake >

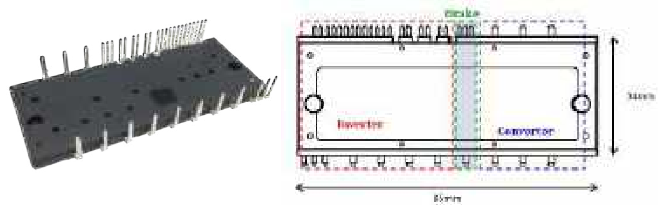


Figure 3 DIPIPM+™ photo & dimensions

All the DIPIPM+™ modules are encapsulated into the same very compact dual-inline package according to Figure 3.

An overview of the implemented DIPIPM+™ functions [2] is shown in the block diagram in Figure 4:

- The P-side IGBTs are driven by a HVIC with input signal conditioning, level shifter and under voltage lock out

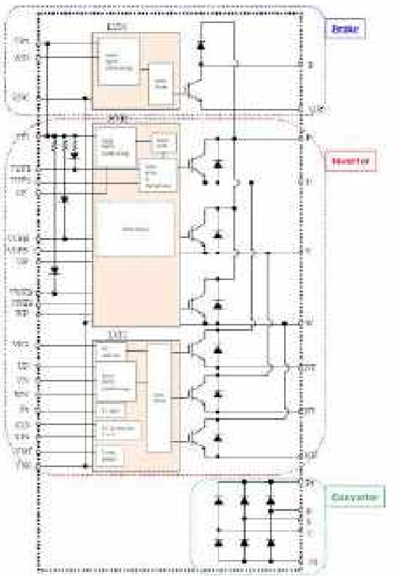


Figure 4: DIPIPM+™ internal block diagram

- The P-side control power is provided from a single external 15V supply via integrated bootstrap diodes and resistors
- The N-side IGBTs are driven by LVIC with input signal conditioning, SC-protection and under voltage lock out
- The LVIC also contains an analogue temperature signal VOT and is generating a fault output Fo in case of protection trip

Cost reduction

When developing a new general purpose inverter reducing the system cost is a key motivation. Basically 3 cost factors must be considered: a) development cost; b) material cost and c) manufacturing cost. All 3 factors are addressed by the new DIPIPM+™ series.

Reducing Development Cost and Time

The DIPIPM+™ is an “all-in-one” inverter module, consisting of a 3-phase input rectifier, a brake chopper and a 3-phase output inverter having all dedicated gate driver and protection functions integrated (see Figure 4). For reducing the development cost (and respectively the time to market of the new inverter) a plug-and-play evaluation board has been developed [3], see Figure 5.

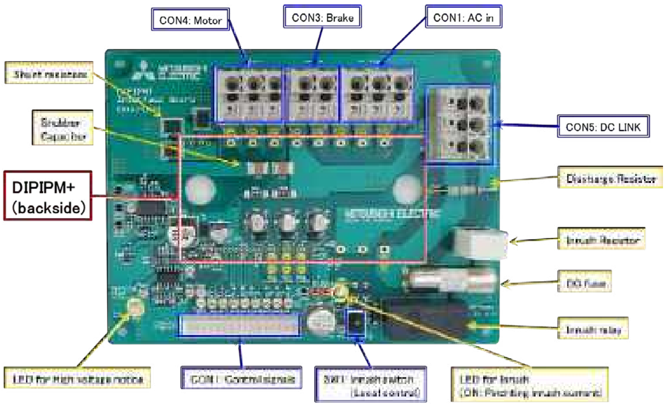


Figure 5: DIPIPM+™ evaluation board. The position of DIPIPM+™ backside the PCB is indicated with red color

It contains all required peripheral components to get quickly an inverter prototype running with the DIPIPM+™: snubber capacitor; non-isolated interface connector to the microcontroller; shunt resistors and comparators for overcurrent protection; bootstrap capacitors for p-side IGBTs; inrush current limiter and numerous test points for acquiring the signals. An easy test setup with the DIPIPM+ ™ Evaluation Board is shown in Figure 6.

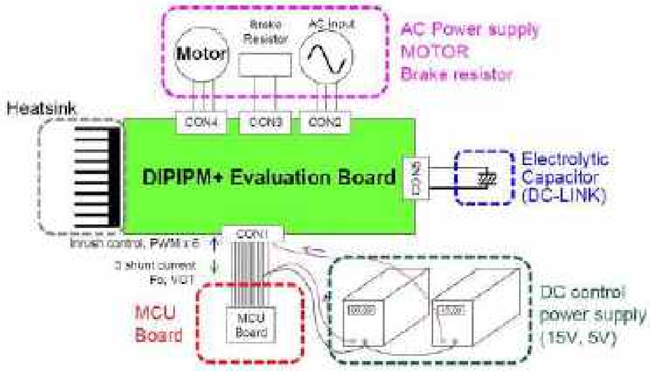


Figure 6: Test setup using the DIPIPM+™ evaluation board

All power connections to AC-line; brake resistor; motor and DC-link capacitor can be done solder-less. The DIPIPM+™ is the only component mounted from the bottom side of the PCB. Thus, even with such first functional prototype arrangement, the best fitting heat sink structure can be verified experimentally in real inverter operation. Particularly such early heat sink confirmation may help reducing the total development time of a new inverter design.

Material Cost Reduction

Several aspects how to reduce material cost by using DIPIPM+™ will be discussed next.

A. By using HVIC with level shifting technology and bootstrap power supply only one external +15V control power supply is needed. As the microcontroller is operating DC-link N-potential no isolation is needed between high voltage part and low voltage control part of the inverter. In this way the additional cost for individual +15V control power supplies and signal isolation for each IGBT-channel is eliminated. Only 3 bootstrap capacitors need to be added at the PCB for providing the control power to the p-side IGBTs. The safety isolation to the outside world should be implemented by the inverter designer into the HMI (human-machine-interface), which can be done much more cost-efficiently, than individually for each IGBT-channel.

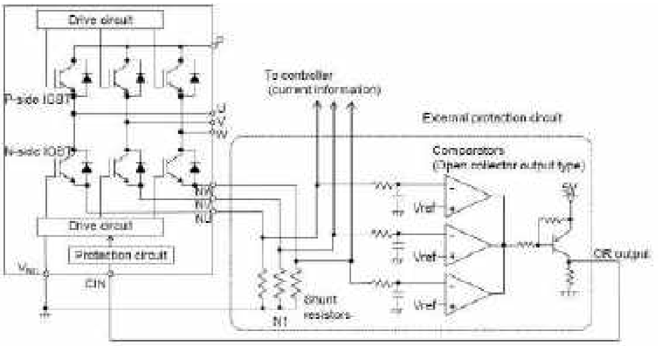


Figure 7: Using open emitter shunts for SC-protection and phase current sensing

B. For vector control the instantaneous values of inverter output currents must be monitored. By utilizing the open n-side emitters in DIPIPM+™ the inverter phase currents can be measured by shunts in each phase. The same shunt signals can be used to for tripping the DIPIPM+ ™ short circuit protection (see Figure7). In this way the higher cost for individual AC-current sensors in each inverter output can be avoided.

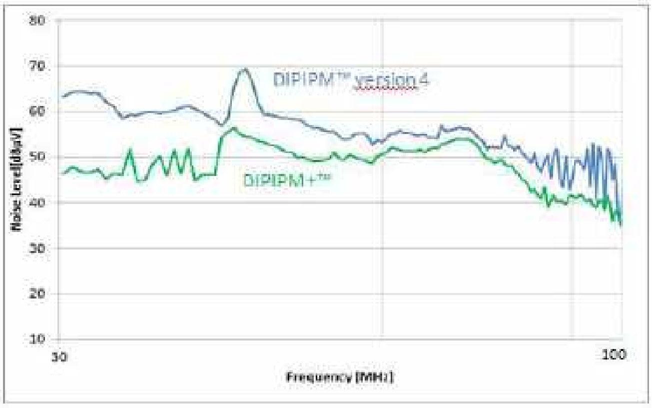


Figure 8: Radiated noise of DIPIPM+TM vs. previous generation DIPIPM ™ Version 4

C. New inverter designs must meet the EMC-requirements according to EN 61800-3. For this purpose either external or inverter-built-in EMC-filters are used. Reducing the EMC-filter cost is an efficient way for reducing the total cost for an inverter system.

In Figure 8 the radiated EMI noise of DIPIPM+™ is compared with the previous IPM-generation (DIPIPM ™ Version 4) under real inverter operation conditions. Due to the reduced noise emission of the new DIPIPM+™ a remarkable reduction of EMI-filter efforts can be achieved.

D. The package size of DIPIPM+™ is about 35% reduced compared with today's state-of-the-art 1200V DIPIPM ™. The well-organized pin out of the DIPIPM+™ permits using a low cost double layer PCB to ensure low inductive connection of the power stage to the DC-link capacitor. Furthermore, the Dual–Inline structure itself enables an easy signal and power terminals separation at the PCB (see Figure 9) thus allowing a very compact and thereby low cost PCB-design.

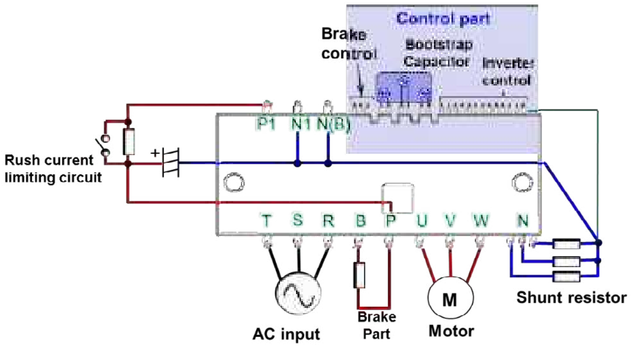


Figure 9: Pin terminal assignment of DIPIPM+™

E. The package of DIPIPM+™ is the same for all current ratings between 5A and 35A/1200V. This allows the use of the same PCB-platform for different inverter ratings and topologies. Reducing the variety of inverter frame sizes is one way of reducing material cost.

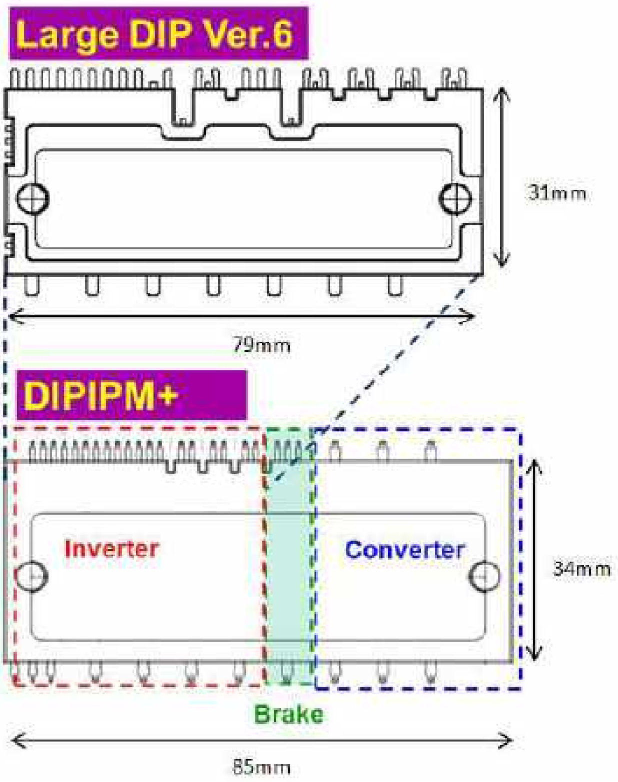


Figure 10: Conventional Large DIPIPM Ver.6 versus DIPIPM+™

F. The all-in-one DIPIPM+™ concept reduces the space needed for the 3-phase inverter part by about 50% compared with today's state-of-the-art 1200V DIPIPM, see Figure 10. In combination with optimized low loss IGBT-and FWDi-chips this leads to a remarkable reduction of heatsink size and thereby also to reduced dimensions of the inverter housing itself. As result the cost for mechanical parts in the inverter construction can be reduced.

Reducing the manufacturing cost

A. The high integration rate of DIPIPM+™ drastically reduced the parts count. Compared with an inverter design using a conventional 7in1 IGBT-module with separate driver ICs and a 3-phase input rectifier module the number of components to be placed at the PCB is reduced to about half, thus reducing the PCB-manufacturing cost.

B. Another cost reduction factor is the simple flow soldering process that can be used for the DIPIPM+™ assembly to the PCB. As the inverter bridge, the brake transistor and the input rectifier are integrated into the same module package no special care for height adjustment during soldering must be taken for controlling the distance between PCB and heat sink; simple spacers will be sufficient. If for example 2 separate power modules for inverter and input rectifier are used at the same PCB, in this case individual height adjustments for each module are necessary during soldering process for ensuring an equal distance between PCB and module's baseplates and thus a good thermal contact of both modules to the heat sink. This complicates the assembly process.

Inverter size reduction (increasing the power density by compact inverter design)

The inverter compactness is the second key objective when doing a new inverter design as the power density (kVA/dm³) is one of the key benchmarking criteria for comparing general purpose inverters from different manufacturers. Basically most of the discussed in chapter 2.2 aspects of reducing the material cost are in a similar way also relevant for increasing the inverter power density:

- Using the bootstrap-technology for control power supply of p-side IGBT
- Substituting the inverter output current sensors by emitter shunts
- Reducing the EMI-filter size
- Very compact PCB design
- Reducing the heat sink size

Besides for compact general purpose inverters the DIPIPM+™ is an interesting solution when the inverter needs to be incorporated into a pre-defined limited space, for example for motor integrated inverters ("Klemmkasten-Umrichter"). For those applications the high integration rate of DIPIPM+™ series is a big benefit.

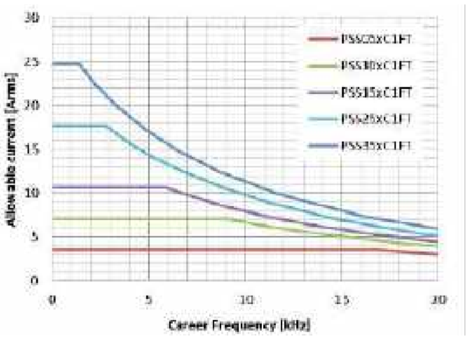


Figure 11: Inverter output current Io(rms) versus PWM switching frequency

Increasing the inverter performance

The allowable inverter output currents Io(rms) for different DIPIPM+TM module types are calculated in Figure 11 for different PWM carrier frequencies fc based on the assumption of ∆T(j-c)=25K for the conditions Vcc=600V; Tc=100°C; Tjavg=125°C cosφ=0,8; sinewave PWM; Modulation Ratio=1; Rth(j-c)=max. Based on this quite conservative approach the motor ratings given in Table 1 are derived [4] assuming a 150% overload capability for 1min.

Recently it became popular to specify dual (or multiple) inverter ratings for different overload capabilities: if a low overload (LO) capability is required the maximum motor rating can be selected one rank bigger than for a drive with high overload (HO) capability. By this approach the thermal impedance (capacitance) of the heatsink is utilized for absorbing the dissipated excess-power during short overload situations. In this way more output power can be obtained for a short time from a given inverter hardware by using the built-in thermal system margins. For doing this an accurate information about the actual temperature of power module is needed. Usually this is done by putting an NTC to the heatsink (or to use a power module integrated NTC). The DIPIPM+™ is offering an analog temperature output signal VOT having a linear transfer characteristic over the whole operation temperature range, see Figure 12. By using this accurate analogue VOT-signal it's possible to allow significantly higher inverter output currents than indicated in Figure 11 without the risk of tripping the thermal inverter protection.

Type name	Rated current	Rated voltage	Motor ratings
PSS05xC1FT	5A	1200V	0.75kW/400V_{AC}
PSS10xC1FT	10A		1.5kW/400V_{AC}
PSS15xC1FT	15A		2.2kW/400V_{AC}
PSS25xC1FT	25A		3.7kW/400V_{AC}
PSS35xC1FT	35A		5.5kW/400V_{AC}

Table1: Motor ratings vs. DIPIPM+TM types

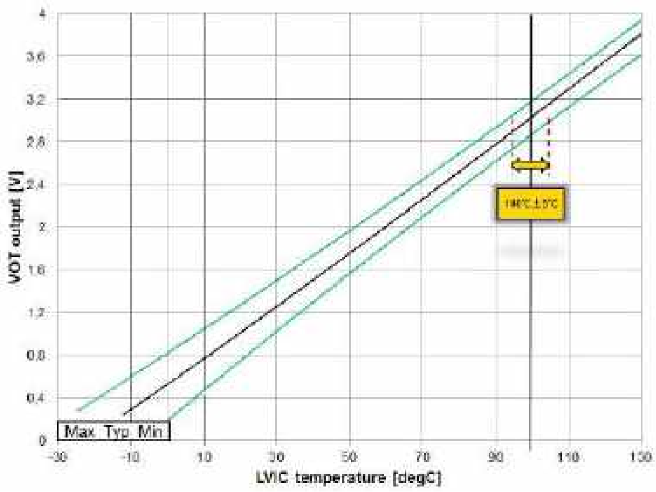
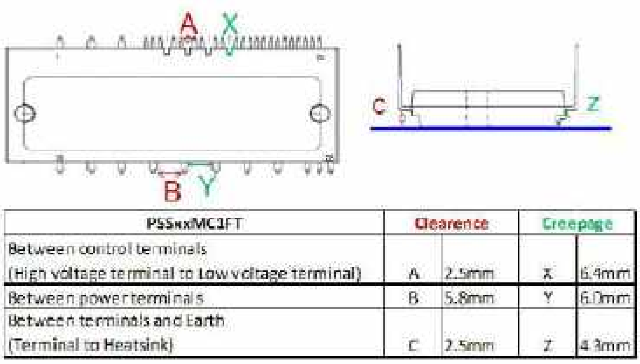


Figure 12: Analogue temperature output signal VOT from DIPIPM+™

The analogue VOT-signal of DIPIPM+™ can also be used to increase the robustness of the inverter against harsh environmental conditions. Usually the inverter specification is given for maximum ambient temperature of Ta=+40°C. For higher ambient temperatures an inverter de-rating has to be considered when installing the drive. By using the VOT-signal several options can be activated for an adaptive inverter de-rating during operation in case of reaching a critical device temperature before the over-temperature protection would turn-off the drive: for example by reducing the switching frequency fc or by reducing the inverter output current as a function of the VOT-signal.



PSSxxMC1FT	Clearence		Creepage	
Between control terminals (High voltage terminal to Low voltage terminal)	A	2.5mm	X	6.4mm
Between power terminals	B	5.8mm	Y	6.0mm
Between terminals and Earth (Terminal to Heatsink)	C	2.5mm	Z	4.3mm

Figure 13: Creepage and clearance distances of DIPIPM+TM package

Well suited for industrial inverter drives

The DIPIPM ™ technology was originally developed for the needs of high volume inverterized white goods applications like washing machines, air-conditioners, refrigerators etc. Over the past 20 years more than 450Mio pieces DIPIPM have been manufactured by Mitsubishi Electric in different packages, voltage and current ratings [5]. For industrial drive applications usually 1200V DIPIPMs are being used. The new DIPIPM+TM series was developed for the specific needs of compact industrial 400VAC-inverters. It is compliant with Viso = AC2500V industrial isolation standards and meets all relevant industrial creepage and clearance requirements, see Figure 13.

The DIPIPM+™ package is siloxane free and therefore well suited for applications where IGBT modules with silicone gel are not allowed. The DIPIPM+™ series is UL-approved (UL1557 File E323585) and ROHS compliant.

Summary

The new DIPIPM+™ series is an excellent answer to the needs of compact AC400V inverters in the power range between 0,75kW… 5,5kW. It helps to reduce both cost and size of a new inverter design. A plug-and–play evaluation board is available for shrinking the inverter development time. Based on 20 year experience with manufacturing of dual-in-line packaged IPMs for white good applications, with the new DIPIPM+™ series Mitsubishi Electric is now introducing an "all-in-one" DIPIPM-solution that meets all requirements of an industrial inverter design.

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Innovative 7in1 IGBT Packages for Scalable and Easy Design of Industrial Drives and Inverters

Industrial drive applications require scalable IGBT modules to simplify the design and to provide the possibility of utilizing the same components like driver boards and bus bars for different inverter power ratings. The Mitsubishi NX-series 7in1 IGBT packages provide such scalable solutions combined with high power density and simplified inverter assembly.

By Thomas Radke and Narender Lakshmanan Mitsubishi Electric Europe B.V

Introduction

Different motor control inverters require different IGBT power module package sizes. Conventionally, for smaller inverter power ratings, the 6in1 IGBT power modules are used. For higher ratings, inverters are conventionally built by using three half bridge power modules. As a result the inverter construction is different for different power ratings, thus the driver boards, bus bars and heatsinks cannot be reused for achieving higher power ratings. This necessitates higher development expenditure alongside the requirement for complicated logistics for the sourcing of new and unique components. In several motor drive applications, reactive power required for the motor operation has to be considered and an additional brake unit has to be incorporated. To address the requirements of scalability and reducing the number of components, the NX-series 7in1 IGBT packages have been developed. The NX-series 7in1 packages include a three phase inverter bridge plus an additional brake chopper IGBT with a current rating between 75A and 300A in the 1200V class.

NX-series 7in1 IGBT Modules

The NX-series 7in1 IGBT modules contain a three phase inverter bridge and a brake chopper as shown in the internal circuit diagram in Figure 1. A thermistor is implemented to monitor the baseplate temperature.

	75A	100A	150A	200A	300A
650V/600V		CM100RX-12A small	CM150RX-13T small	CM200RX-13T small	
1200V	CM75RX-24S small	CM100RX-24T small	CM150RX-24T small	CM200RXL-24S large	CM300RXL-24S1 large
1700V	CM75RX-34SA small		CM150RXL-34SA large		
internal conection		small pkg. (RX)		large pkg. (RXL)	

Figure 1: Line-up and circuit diagram of NX-series 7in1 IGBT Modules

Two different packages were developed in order to cover the whole line-up from 75A to 300A. An inverter with the high power density can be achieved by implementing these current ratings into the 122x62mm² footprint (small pkg.) and the 122x122mm² footprint (large pkg). The 17mm module height is already compatible to other existing standard IGBT power module housings and therefore various compatible rectifier modules from different manufactures are available. To provide full scalability for small and large packages, the same arrangement of power and control terminals are designed. This offers the possibility of using the same components like driver boards and bus bars for different power ratings. This approach - multiple utilization of components is a key factor in minimizing the development effort, time and costs. The separation and the orthogonal arrangements of the dc-terminals (P/N) and the ac-output allows for a simplified inverter construction. In cases where the brake chopper is not required, the unused IGBT can be turned-off by short circuiting the gate and emitter pins. Therefore, depending on the requirement, the 7in1 module can also be easily utilized as a three phase inverter without the brake chopper.

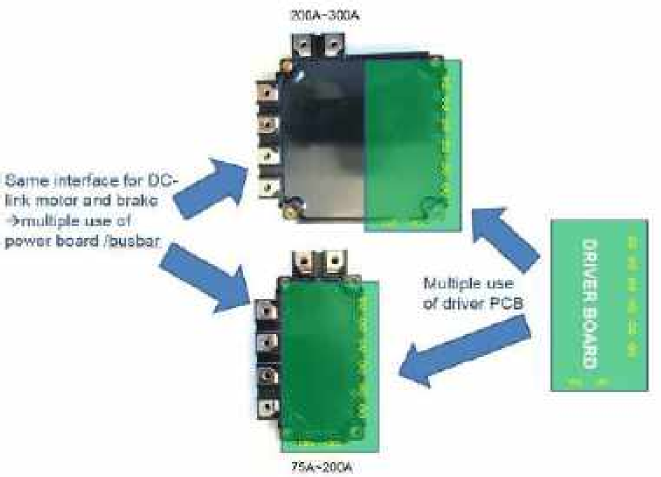

Figure 2 Multiple use of components enabling scalability

Inverter Benchmark

Conventionally, the 6in1 IGBT modules are available in a package with 122x62mm² footprint with a current rating up to 200A. Usually pin terminals are used which limit the current capability of the contacts. An additional limitation is the high heat concentration in air cooled heat sinks due to the small package footprint. Due to this reason, the inverter power rating based on 6in1 modules is limited to about 55kW. Inverters for power ratings above 55kW conventionally employ three half bridge modules with an additional optional brake chopper module. This change from a compact 6in1 IGBT module to three half bridge modules translates into a heatsink size increase of about 210%, greater complexity in design and an expensive inverter construction. In place of just 1 power module four power modules have to be assembled. The compact NX-series 7in1 package offers a power range comparable to the conventional 6in1 module. The large package version of the NX-series 7in1 module allows for an extension of up to 90kW in the inverter power range. Therefore the large package version of the 7in1 modules offer an intermediate solution between the compact 6in1 / 7in1 modules and the high power half bridge modules. The high power density of the large 7in1 package is achieved by using low loss CSTBT^{TM} IGBT chips combined with a thermally optimized package structure and additionally utilizing the maximum allowed junction temperature of 175°C. A thermal simulation by using Mitsubishi's Melcosim software ([3] publically accessible Ver. 5.3) has been performed and the result is shown in Figure 3. This simulation considers typical conditions for motor control applications with a switching frequency of 4 kHz. The heatsink temperature is considered as 100°C which is typical for air cooled applications. As demonstrated, one 200A / 1200V 7in1 module (CM200RXL-24S in the large package) has performance comparable to three 2in1 modules with 225A /1200V rating (CM225DX-24S1). This alternative 7in1 solution instead of three, (or with brake chopper - four) 2in1 modules reduces the size by about 50% as shown in Figure 4. The 300A / 1200V 7in1 (CM300RXL-24S1) module is able to deliver an even higher performance. The 6in1 module, with 200A rated current has thermal limitations and cannot provide the inverter output power equal to an inverter employing the 7in1 or the 2in1 modules as shown in Figure 3. Additionally an air cooled heat sink design which maintains the sink temperature (Ts) below 100°C will be quite difficult to achieve using the 6in1 module (considering the relatively small foot print of 122x62mm²). Considering an optimistic assessment where a heat sink temperature of 100°C can be maintained, the maximum output current of the 6in1 200A module is limited to 120Arms at an IGBT junction temperature of about 125°C. Considering the same condition (125°C junction temperature), the 7in1 200A/1200V module is able to deliver an output current of about 150Arms. The heat sink design for the baseplate of the 7in1 will be much simpler since the base plate area of the 7in1 module is two times greater than that of the 6in1 module. Therefore it is reasonable to consider operating the heat sink at 100°C while utilizing the large 7in1 module.

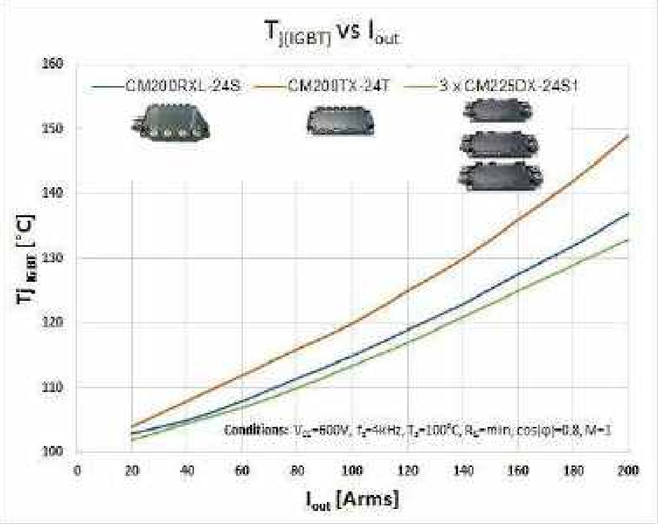

Figure 3: Thermal performance comparison

Conclusion

The NX-series 7in1 IGBT modules provide an optimized package for the requirements of motor control inverters. Taking advantage of this demonstrated scalability offered by the large and small packages, the same inverter construction concept can be utilized for developing an extended inverter series capable of delivering higher power levels. The efforts required for designing and implementing the extension of the inverter power range compared to the conventional approach (using 6in1 modules) is greatly reduced because components like bus bars and driver boards can be reused. The low loss CSTBT^{TM} chips in combination with the superior thermal performance offered by the thermally optimized package structure in the large package delivers a high power density.

Therefore the 7in1 modules offer an optimized solution to design a scalable cost effective motor drive inverter.

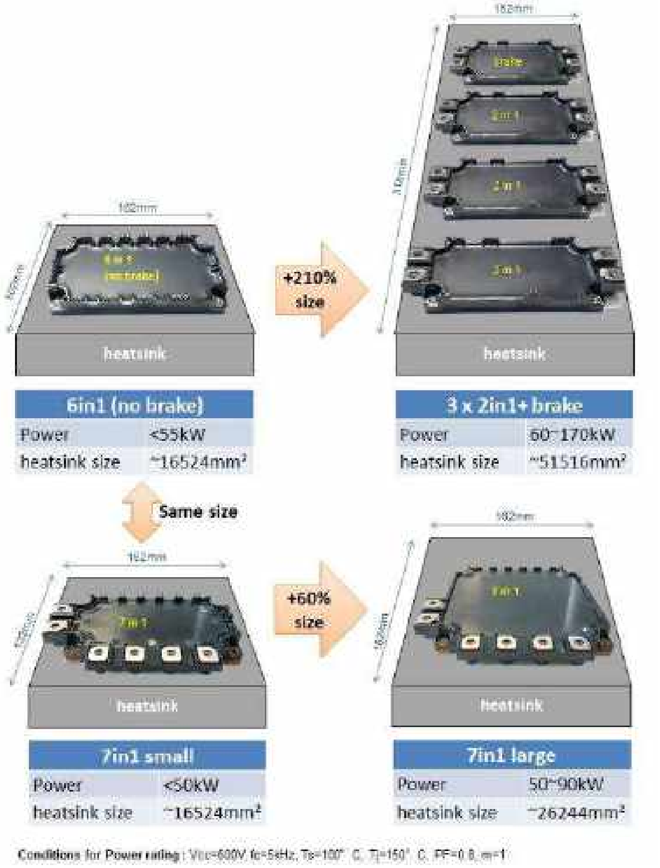

Figure 4: Heatsink size and inverter power comparison

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Bodo´s Power Systems®

High Power Density, High Performance X-Series 4500V IGBT Power Modules

Mitsubishi Electric has developed high performance 4500V IGBT power modules providing reliable solutions for medium voltage drive, railway and power transmission applications.

By Eugen Wiesner, Dr. Nils Soltau, Eugen Stumpf, Mitsubishi Electric Europe B. V. and Kenji Hatori, Hitoshi Uemura, Mitsubishi Electric Corporation

Introduction

Originally, Mitsubishi Electric started the development of the 4500V IGBTs in the middle of 90s. The first commercialization of standard IGBT modules in this voltage class was started in beginning of 2000s. It was a more efficient and compact solution compared to existing 4500V GTO press pack devices. Mainly this development was driven by railway and medium-voltage (MV) drive applications. Meanwhile, a wide variation of the 4500V IGBT modules is available, such as: dual diode modules, modules with copper and AlSiC base plate, modules with standard (V_{ISO}=6 kV) and high isolation packages (V_{ISO}=10.2 kV).

Targets of 4500V X-Series IGBT Modules

The newly developed 4500V X-Series is already the third series after H-Series and R-Series of MITSUBISHI ELECTRIC IGBT power modules. The line-up of the new X-Series is expanding the existing line-up towards higher power densities (refer Figure 1). The current rating of the large package (footprint: 190mm x 140mm) increases from 900A to 1350A. On the other hand, the 900A rated current also will be made available in smaller package size of 140mm x 130mm.

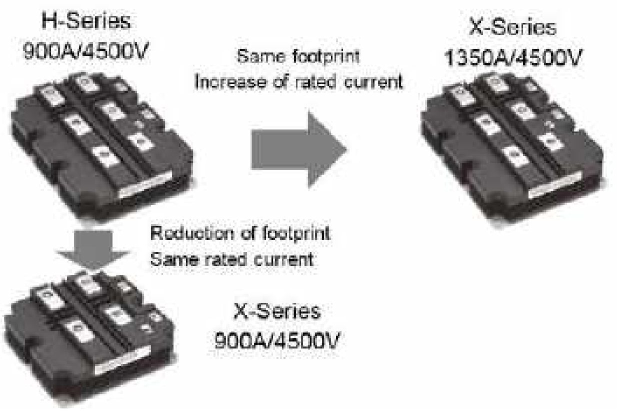

Figure 1: 4500V X-Series line-up expansion

The standard package type is still very important for different applications due to availability of second source from many IGBT device manufacturers and its proven reliability record in the field for many years. Furthermore, the upgrade or increase of the inverter output power is easily achievable by using the widely commercially available components in the market like heatsinks, gate drivers and bus bars.

The targets for 4500V X-Series device development have been defined based on feedback from customers. These were the following:

- Increasing current rating and module power density.
- Reduction of module power losses.
- Suitable for various applications having different switching frequency ranges.

Six modules have been developed [1] to fulfill the above mentioned market requirements. The overview of the developed 4500V X-Series modules is shown in table 1

Isolation voltage	Foot print	Type name
V_{ISO} 10.2 kV	190mm x 140mm	CM1350HG-90X (V_{CCmax}=3400V) CM1500HG-90X (V_{CCmax}=3200V)
	130mm x 140mm	CM900HG-90X (V_{CCmax}=3400V) CM1000HG-90X (V_{CCmax}=3200V)
V_{ISO} 6 kV	190mm x 140mm	CM1350HC-90X (V_{CCmax}=3400V) CM1500HC-90XA (V_{CCmax}=3000V)

Table 1: 4500V X-Series Line-up

Improving the Module Power Density

The most challenging requirement was increasing the module power density. The development target was achieved mainly by using the new 7th Gen. Chipset. The 7th Gen. IGBT chip, shown in Figure 2, contributes several significant cutting-edge features. The Carrier Stored Trench-gate Bipolar Transistor structure (CSTBT^{TM}) allows reduction of the IGBT forward voltage. The new LNFLR (Linearly-Narrowed Field Limiting Ring) chip termination structure allows for an increase in the active chip area and thereby a reduction of the thermal resistance. Finally, the partial P-Collector technology allows a special capability to manage a wide RBSOA.

Furthermore, the overall packaging technology of 4500V X-Series is improved for managing the increased power density. The optimized internal chip layout reduces the module thermal resistance and increases the power cycling capability. As a result, the junction-to-case thermal resistance was reduced by more than 20% compared to previous R-Series (CM1350HG-90X and CM1200HG-90R). The module performance has been proven and specified for a wide operation temperature range from -50°C to 150°C. The previous 4500V module generations were specified up to 125°C.

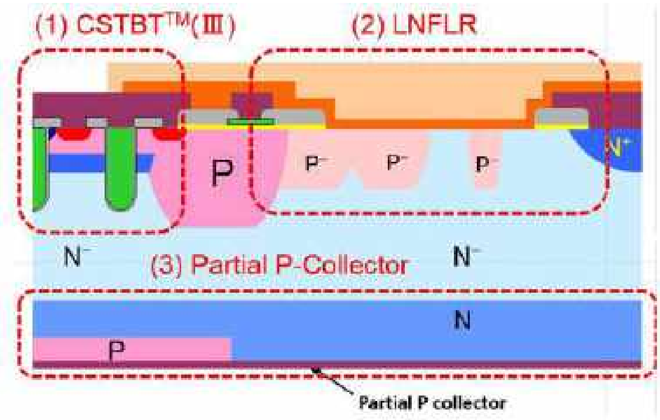

Figure 2: 4500V 7th Gen. Chip structure

Two different 7th Gen chip set are available, optimized for high and low switching frequency applications respectively. The X-Type chip set is designed for high switching frequency application (> 350Hz). The XA-type chip set achieves the lowest possible forward voltage for the IGBT and the diode. The intended switching frequency ranges from 100Hz to 350Hz. The trade-off between the forward voltage and reverse recovery switching energy for X- and XA- diode is shown in Figure 3.

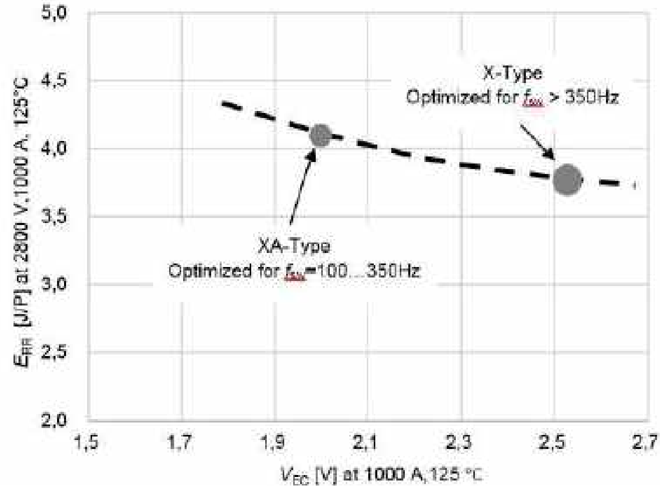

Figure 3: Diode trade-off between X- and XA device type

Safe Operating Area (SOA) for Each Application
The DC-link voltage is one of the most important stress factors influencing the SOA of IGBT module. Some applications do not require high DC-link voltage. For such cases, the SOA and with it the permitted maximum current rating increase.

The 4500V X-Series device is designed to operate at a maximum DC-link voltage of 3400V. In this case, the module's rated current is 1350A (CM1350HG-90X). If the required maximum DC-link voltage is reduced to 3200V, the rated current increase up to 1500A (CM1500HG-90X). Both modules have the same electrical characteristics but have different SOA specifications. Each device undergoes shipping tests according to the defined maximum DC-link voltage respectively.

Example of a 3-level NPC Inverter Application
One of the targeted applications for the 4500V modules is the medium voltage (MV) drive application. For these drives, the output voltage range is between 2.3kV and 13.2kV [2]. The most common voltage levels are: 3.3 kV, 4.16kV, 6kV and 6.6kV. For these output voltages, 3-level topology is widely used. For example, these voltages can be covered by devices such as the CM1500(1350)HG-90X (as shown in Table 2). For output voltage levels higher or equal than 4160V - series connection of 4500V modules becomes necessary.

Inverter output voltage V_{OUT} [Vrms]	**Total required inverter DC-Link voltage V_{DC_link} [V]**	**IGBT blocking voltage V_{CES} IGBT [V]**	**IGBT Series connection**	**IGBT DC-Link voltage V_{CC_IGBT} [V]**
3300	4800	4500 (CM1500HG-90X)	No	2400
4160	6200	4500 (CM1500HG-90X)	Yes	1600
6000	8800	4500 (CM1500HG-90X)	Yes	2200
6600	9600	4500 (CM1500HG-90X)	Yes	2400

Table 2: Example for 4500V IGBT module based 3-level NPC configurations

Scalability towards lower power ranges can be realized with the CM900HG-90X device or the H- and R-Series modules. The following example shows the potential of the new X-Series compared to the first H-Series in terms of power loss reduction. For the V_{OUT}=3300V output voltage, the necessary DC-Link voltage is about 4800V. In 3-level NPC-configurations, the IGBT module would experience the half the total DC-Link (2400V). In case the heatsink potential would be connected to the middle of the DC-Link the IGBT Module isolation voltage of 10.2 kV(rms) would be sufficient to cover in Table 2 mentioned inverter output voltages.

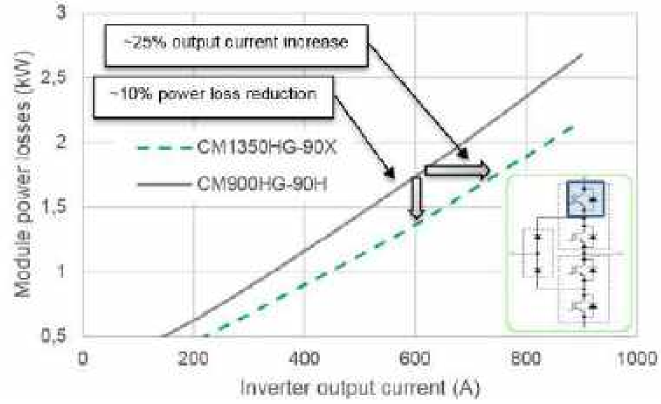

Figure 4: Comparison of the power loss simulation result using the H- and X-Series 190mm x 140mm modules.

Figure 4 shows the power loss simulation versus output current for CM900HG-90H H-Series device and CM1350HG-90X X-Series device. The simulation conditions are:

- Switching frequency fsw=0.5kHz,
- Power factor p.f.=0.85,
- Modulation index m=1,
- Junction temperature T_J=125°C.

There are two possibilities for utilizing the performance of new X-Series power modules. One possibility is a reduction of the IGBT module power losses. The power losses decrease by about 10% compared to the H-Series. The other possibility is increasing the inverter output current. The output current can be increased by about 25% compared to the H-Series. In addition, 150°C operation of X-series enables to increase even more output current than 125°C operation.

Conclusion

The newly developed 4500V X-Series enables significant increase in the inverter output power. Key enabling factors are an increased maximum junction temperature of 150°C, an improved thermal management and reduced power losses in the module. A large line-up and backward compatibility to H-Series and R-Series ensures a flexible converter design and an easy design-in. Furthermore, two different chip sets (X-type and XA-type) facilitates the optimal operation at required switching frequencies.

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3.3 kV Full SiC MOSFETs – Towards High-Performance Traction Inverters

Mitsubishi Electric is developing a new Full SiC device rated for 3.3 kV and 750 A. The device comes in the most recent LV100 package, which is especially suitable for traction application and modular converter designs. This article introduces the new Full SiC device and demonstrates the benefits in traction applications.

By Dr. Nils Soltau, Eugen Wiesner, Mitsubishi Electric Europe B.V., Ratingen, Germany and Kenji Hatori, Hitoshi Uemura, Mitsubishi Electric Corporation, Fukuoka, Japan

1. Introduction

Power semiconductor devices made of silicon carbide (SiC) are regarded as the major innovation in modern power electronics. Compared to classical silicon (Si) devices, SiC enables more efficient and more compact converters to save electric energy and valuable materials.

Over the last 20 years, Mitsubishi Electric has developed and commercialized SiC devices for several voltage classes and various applications [1]. Now, after years of in-field experience with different SiC modules in traction application [2], Mitsubishi Electric makes the next big step. With a rated voltage of 3.3 kV and a current of 750 A, the new Full SiC dual module is especially intended for high performance traction converters and flexible converter designs. The type name of this new device is FMF750DC-66A.

Due to the fast switching transients, Full SiC devices require an appropriate package offering low stray inductance. Therefore, the FMF750DC-66A, as shown in Figure 1, comes in the most advanced package for this voltage and power class: the LV100 package. This package offers a stray inductance below 10 nH and simpler parallel connection of several modules. Moreover, the internal package design ensures optimal current sharing among the semiconductor chips inside a module.

Figure 1: The new 3.3 kV Full SiC device is rated for 750 A and comes in the most recent LV100 package

2. Comparison with Silicon Devices

The following chapter compares the FMF750DC-66A with two different Si devices that also come in the same LV100 package. These two devices of the same voltage class are rated for 450 A and 600 A. In the following, they are referred to as CM450DA-66X and CM600DA-66X according to their respective type name. Figure 2 shows the static characteristics of all modules and, hence, demonstrates nicely the general difference between bipolar IGBTs and unipolar MOS-

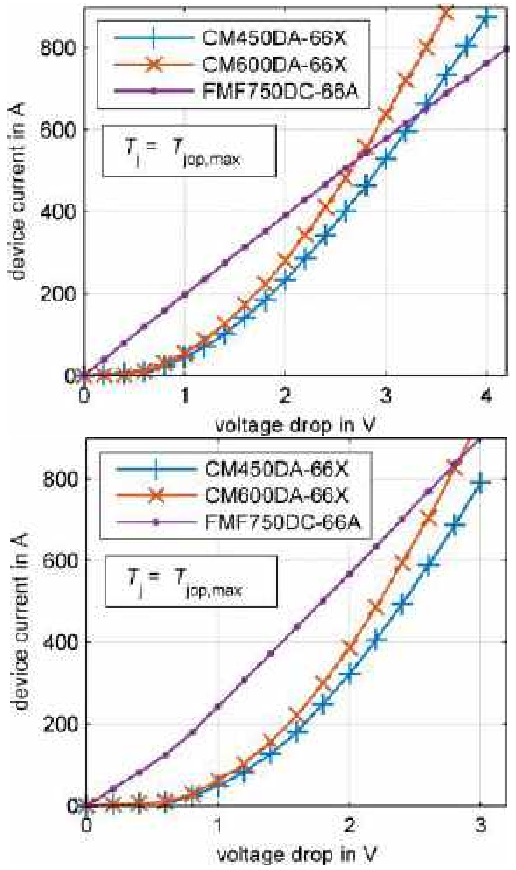

Figure 2: Static characteristic of the Full SiC devices compared to the 450 A and 600 A silicon-based modules

FETs. It should be noted that all device characteristics are given for the respective maximal junction temperature being 150°C for the Si devices and 175°C for the FMF750DC-66A. Due to the linear current-voltage dependency of MOSFETs, the voltage drop at low currents is substantially lower than for bipolar IGBTs (cf. Figure 2 (a)). As shown in Figure 2 (b), also the voltage drop of the FMF750DC-66A in reverse direction is much smaller compared to the freewheeling diodes of the Si modules, if both, diode (SBD) and MOSFET, are conducting the reverse current (synchronous rectifier mode). Consequently, especially at low-load conditions, the use of unipolar devices increases converter efficiency significantly. The subsequent chapter quantifies this for a traction application.

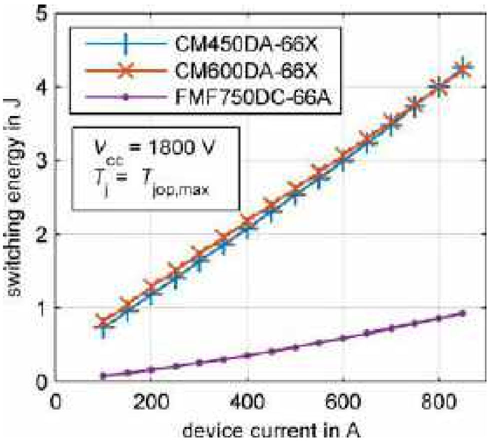

Figure 3: Switching losses of the Full SiC module compared to Si-based modules

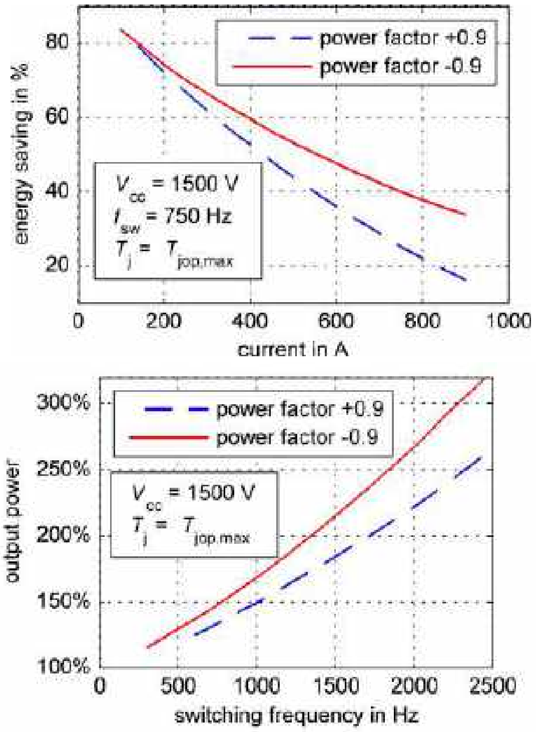

Figure 4: Comparison of FMF750DC-66A with CM600DA-66X

Another very prominent advantage of Full SiC devices is the reduction of switching losses. Again, this effect results from the unipolar nature of the devices. The lack of reverse recovery and tail currents decreases switching energy and allows higher switching frequencies compared to Si devices. Figure 3 shows the sum of energy loss during turn-on, turn-off and reverse recovery. Compared to the Si-based IGBTs, the switching losses in the Full SiC module are reduced by 80 – 90 %.

The following chapter quantifies and discusses advantages for the converter design and intended applications.

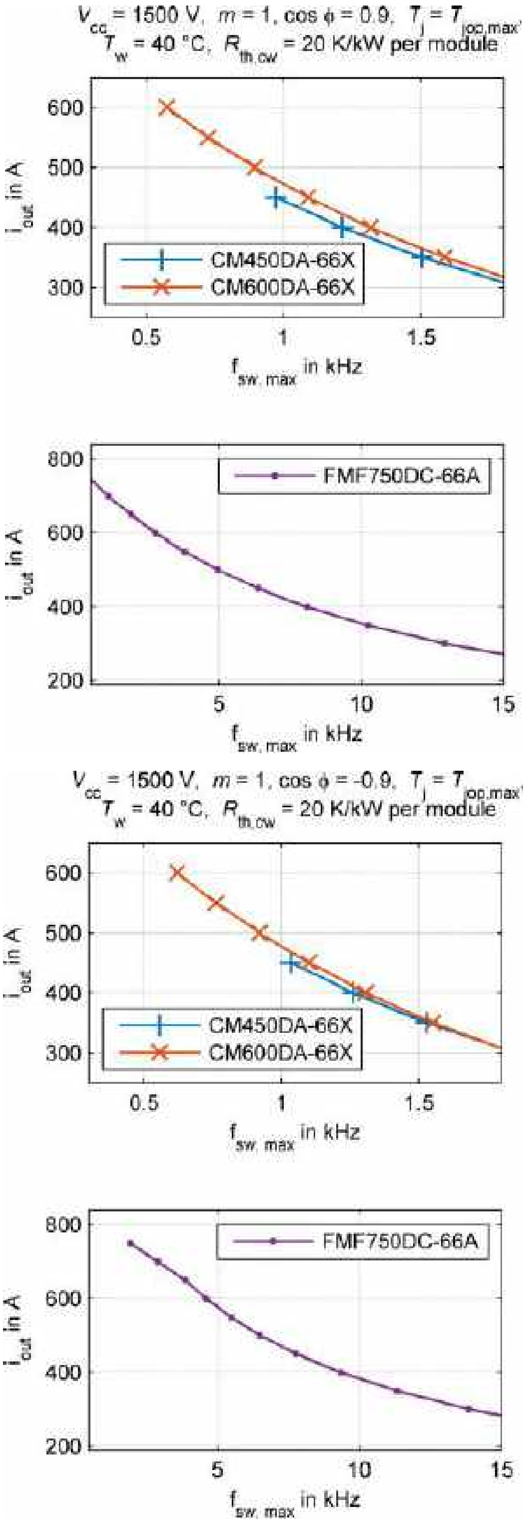

Figure 5: Maximal output current in dependence on switching frequency

3. System Level Advantages

The first example regards traction inverters with 750 Hz switching frequency at 1500 V dc-link voltage. The losses generated by the Si-based CM600DA-66X and the SiC-based FMF750DC-66A are compared. Figure 4 (a) shows the energy savings using the FMF750DC-66A instead of a CM600DA-66X. Especially at vehicle's part-load condition, saving potential is enormous. Below 400 A output current, the Full SiC devices saves more than 50 % - 80 % of the energy loss by semiconductors (at the same device footprint).

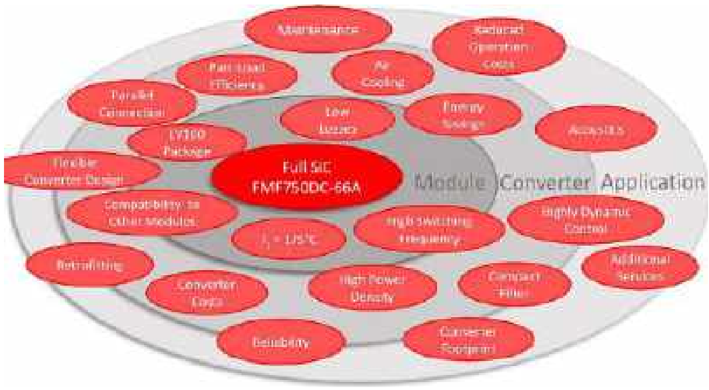

Figure 6: Opportunities enabled by the Full SiC FMF750DC-66A

Especially at part load, operational energy costs can be reduced. Moreover, due to higher efficiency and the higher operational junction temperature of the FMF750DC-66A, the maximal power in rectifier operation increases. As illustrated in Figure 4 (b), maximal output power increases by roughly 60 % at exemplary switching frequency of 750 Hz. Since the rectifier mode serves the recovery of energy when the vehicle slows down, potentially more energy can be recycled and fed back into the electricity network. Moreover, this reduces stress on the conventional braking system.

The second example considers a grid-connected converter operating at a power factor of 0.9. The maximal switching frequency in dependence on the output current is calculated. Figure 5 shows the results considering cooling water temperature of 40°C. Consequently, the maximal switching frequency for the FMF750DC-66A increases by a factor of 5 to 9 compared to the CM600DA-66X at same current level.

The higher switching frequency allows converter manufacturers a grid-filter design for higher resonance frequencies. Consequently, the required inductance and capacitance values for an LCL filter decrease. This in turn decreases filter's size, cost and losses. Moreover, the converter achieves a more dynamic control. Furthermore, for machine-side inverters or dc-dc converters, the higher switching frequency enables the design of more compact high-speed drives and medium-frequency converters [3,4].

Besides the switching frequency increase, Figure 4 (b) has already demonstrated that keeping the switching frequency constant, the converter achieves significantly higher output power. The fact that the FMF750DC-66A comes in the same package as the CM450DA-66X and CM600DA-66X allows more flexible converter designs and fast development (having a similar inverter configuration as Si-based inverter).

Beyond the discussed benefits in traction and grid applications, the FMF750DC-66A make further benefits accessible. Figure 6 tries to illustrate the advantages of the FMF750DC-66A at different system levels: at module level, at converter level and at application level. In general the use of new FMF750DC-66A makes sense in those applications where these system-level advantages potentially over-compensate the higher costs of today's SiC-modules compared to established silicon devices.

4. Conclusion

Mitsubishi Electric offers an extensive line up in the state-of-the-art LV100 package. Now, a 750 A Full SiC module is added to the 3.3 kV line up.

The FMF750DC-66A Full SiC module increases the converter's power density by increased switching frequency and higher maximal junction temperature of 175 °C. Moreover, the module achieves higher system efficiency. Especially at part load conditions or rectifier operation, the FMF750DC-66A reduces the inverter losses by 50 – 80 %. The FMF750DC-66A comes in the same low-inductive LV100 package as its Si counterparts. For converter manufacturers, this simplifies the transition from Si to SiC and gives tremendous flexibility.

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7th Generation 1700 V IGBT Modules: Loss Reduction and Excellent System Performance

For power electronic systems like industrial drives and converters for renewable energy applications, the major system requirements are: high reliability, high efficiency, high power density and competitive costs. In order to meet these requirements, power loss reduction is a key factor. Power loss reduction enables designs with higher power densities and lower IGBT junction temperatures. As a result, higher reliability can be achieved and the cooling system can be accordingly optimized. Therefore, Mitsubishi Electric has developed the new 1.7 kV 7th generation IGBT modules with improved performance.

By Masaomi Miyazawa, Thomas Radke and Narender Lakshmanan, Mitsubishi Electric Europe B.V.

1. Introduction

Power module performance affects the overall efficiency of the power electronic system. Accordingly, power modules have to be carefully chosen for a given application depending on various electrical and thermal performance parameters. Mitsubishi Electric had launched the latest 7th generation industrial IGBT modules in the 650 V and 1200 V classes [1]. These modules have already been well accepted by the market due to the advantages with regards to the key system requirements: high power density, high efficiency and high reliability. Subsequently, the 1700 V IGBT modules were developed to support applications with system voltages of 690 Vac.

For renewable applications, the AC-grid filter size can be reduced by increasing the IGBT switching frequency. In case of motor drives, higher switching frequencies are considered beneficial especially for operation at high output frequencies. Unfortunately, the switching loss behavior of the existing 1700 V modules available at the market has not encouraged the designers to explore the possibility of increasing the switching frequency for availing system level benefits. In order to enable operation at reasonable switching frequencies (above 1000 Hz) with the 1.7 kV IGBT modules, the 7th generation IGBT chips and the RFC (Relaxed Field of Cathode) diode chips [2] were developed and optimized for achieving a significant reduction in power loss.

An optimized line-up from 100 A to 600 A current rating has been developed. Further module developments with higher rated currents (up to 1200A) are ongoing.

2. 7th generation chip performance

In order to offer the best electrical characteristics, the latest 7th generation CSTBT^{TM} chip [4] and RFC diode have been used in the 1.7 kV IGBT modules. These chips possess an optimized structure and are thinner than previous generation devices. Additionally, the devices have been designed by selecting an appropriate trade-off between the DC performance and the switching performance.

2.1 IGBT chip

The IGBT power loss and the EMI profile has been optimized by designing an optimized MOS structure, advanced termination, and a reduction of the wafer thickness. Figure 1 shows the comparison of the trade-off between V_{CEsat} and E_{off} of the 7th generation IGBT with a standard IGBT chip available in the market today. The E_{off} of the 7th generation IGBT is approximately 30 percent lower in spite of the same on-sate voltage drop.

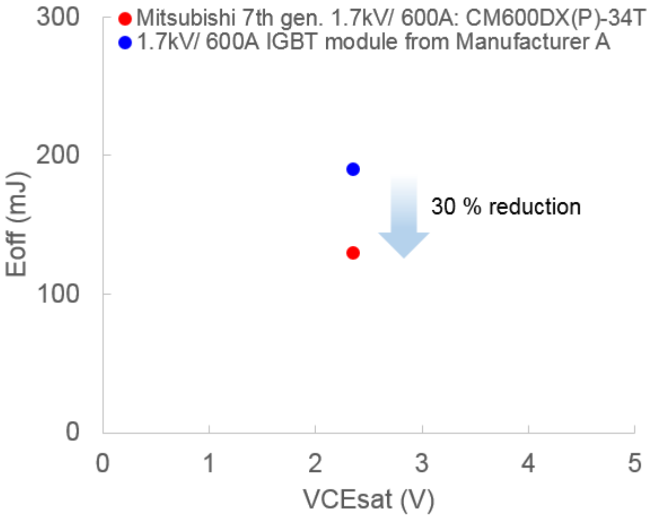


Figure 1: Comparison of the trade-off between V_{CEsat} and E_{off} Conditions: V_{CC}=1000 V, I_C=600 A, T_j=125 °C, R_G min.

2.2 Diode chip

The 7th generation 1.7kV IGBT module is equipped with the RFC diode in order to reduce power loss without generating unnecessary oscillations during switching. The RFC diode has a unique structure in which the P layer is partially added on the cathode side and holes are injected during the recovery period to soften the recovery waveform. Using the RFC structure, it was possible to develop a diode with a reduced wafer thickness and one which does not exhibit snappy behavior. Thus, it was possible to improve the diode trade-off (DC performance versus switching loss). Figure 2 shows the comparison of the trade-off between V_F and E_{rr}. A significant reduction (about 50%) of recovery losses has been achieved.

Additionally, the lower recovery charge Q_{rr} results in a reduction of IGBT turn-on switching losses.

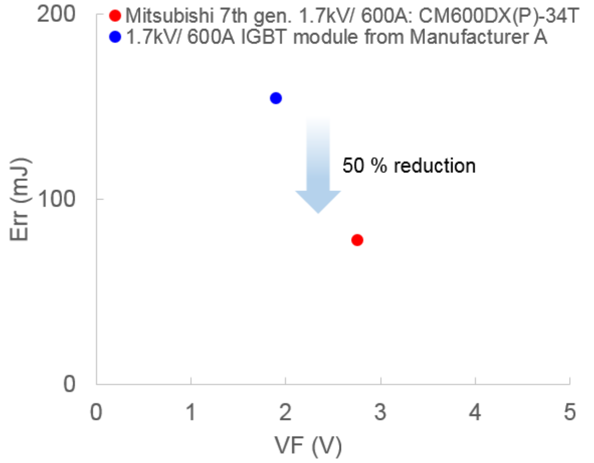


Figure 2: Comparison of the trade-off between V_F and E_{rr}
Conditions: V_{CC}=1000 V, I_C=600 A, T_j=125 °C, R_G min.

3. Power loss comparison

A loss simulation for several application conditions has been performed by using the free simulation software Melcosim [5]. Figure 3 shows the overall power loss comparison of 600A/1700V IGBT module CM600DX(P)-34T [6] with the IGBT module from Manufacturer A. As evident from Fig. 3, the power loss of the 7th generation IGBT module is approximately 30 percent lower under typical application conditions (considering a switching frequency of 2 kHz). It is clear that a major contributor to the loss improvement is the reduction of diode switching losses and the IGBT switching losses. For a heatsink with $R_{th(s-a)}$=90 K/kW, the resulting IGBT-chip temperature T_j is 22 K lower at the given application conditions. However, if the junction temperature T_j is to be maintained the same, the output current can be increased by approximately 30%. Figure 4 shows the comparison of power loss in the 600A/1700V IGBT module as function of switching frequency. As evident from Fig. 4, the improvement rate is getting higher at a higher frequency. For example the power loss of the IGBT module from Manufacturer A at 2 kHz is almost the same as the overall power loss considering the 7th generation technology's performance at 4 kHz switching frequency. As a result, by maintaining the same efficiency, the switching frequency could be doubled from 2 kHz to 4 kHz. This increase in the switching frequency enables a remarkable size and cost reduction of passive components like filter chokes.

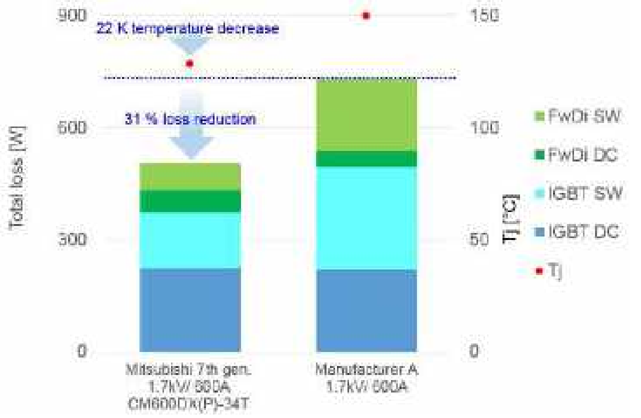


Figure 3: The Power loss comparison of the 600A/1700V IGBT module at 2 kHz
Conditions: V_{CC}=1000 V, I_O=270 A peak, f_c=2 kHz, cos(φ)=0.8, M=1, T_a=40 °C, $R_{th(s-a)}$=90 K/kW, R_G min.

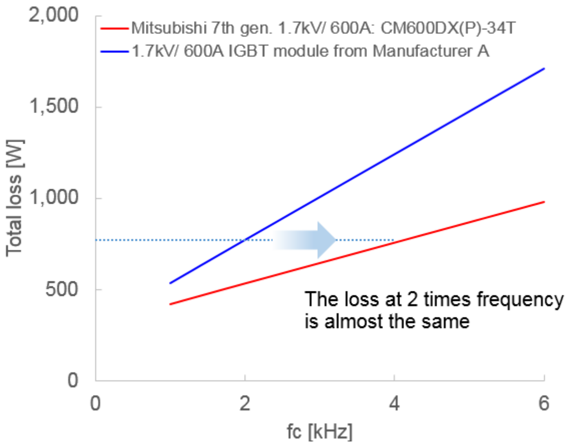


Figure 4: The power loss comparison considering the 600A/1700V IGBT module for several switching frequencies
Conditions: V_{CC}=1000 V, I_O=270 A_{peak}, cos(φ)=0.8, M=1, T_j=125 °C, R_G min.

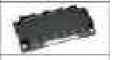
4. Expanded line-up

In order to meet various applications requirements, Mitsubishi Electric has developed a comprehensive modules line-up in 1.7 kV class. Table 1 shows the line-up which includes 12 module types in the NX-package ranging from 100 A to 600 A and 6 module types in the standard package ranging from 75 A to 400 A. In the NX-type package, both solder-pin and press-fit-pin options have been developed for each current rating. They have different terminals. The press-fit-pin package can be assembled by solderless press process to the PCB board.

Furthermore, in the NX-type module, the SLC (Solid Cover) technology delivers an improved thermal cycle capability by combining a resin-insulated metal baseplate and direct potting resin [3]. The advanced SLC technology enables the elimination of the internal bond wires between multiple ceramic substrates which resulting in lower parasitic inductance and higher reliability.

In the standard-type module (refer to Table 1), the TMS (Thick Metal Substrate) technology eliminates the solder layer under the substrate and increases the thermal cycle capability [1]. The parasitic inductance has been reduced by improving the internal layout. In addition, the main terminal pitch for the 62× 108 mm package is 28 mm, which is compatible to the existing package in Europe.

The 7th generation IGBT modules are available with the pre-applied PC-TIM (Phase Change Thermal Interface Material) optionally. It contributes to the simplification of the assembly process and improves the thermal contact between module base and heatsink.

Package Type	Model	Current Rating	Voltage Rating	Circuit	Packge Size W × D (mm)	Features
NX-type Package Solder-pin/ Press-fit-pin	CM100TX(P)-34T	100 A	1.7 kV	6 in 1	62 × 122	
	CM150TX(P)-34T	150 A				
	CM225DX(P)-34T	225 A		2 in 1	62 × 152	
	CM300DX(P)-34T	300 A				
	CM450DX(P)-34T	450 A				
	CM600DX(P)-34T	600 A				
Standard-type Package	CM75DY-34T	75 A		2 in 1	34 × 94	
	CM100DY-34T	100 A				
	CM150DY-34T	150 A			48 × 94	
	CM200DY-34T	200 A				
	CM300DY-34T	300 A			62 × 108	
	CM400DY-34T	400 A				

*"P" symbol means "Press-fit-pin". The model is for example "CM100TXP-34T".

Table 1: Expanded line-up in 1.7 kV class. In the NX-type package, there are two pin types (solder and press-fit) in the each current rating.

To support applications requiring higher power ratings, a new industrial IGBT module with a half bridge configuration is under development. This new power module package which is shown in Figure 5 has a dimension of 100x144x40 mm³. IGBT modules based on the 7th generation chip technology, with a current ratings up to 1200 A in the 1700 V category are under consideration. In case an application requires higher current (more than 1200A) this module is an ideal solution since it is optimized for parallel operation thereby providing a scalable and an efficient solution for high power applications.

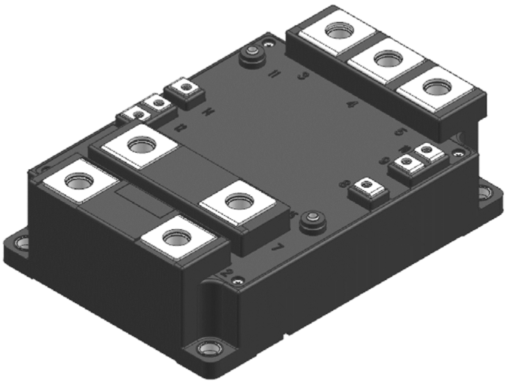


Figure 5: New industrial IGBT module

5. Summary

In the analysis presented here, the IGBT chip performance exhibits approximately 30% improved trade-off between the V_{CEsat} and E_{off}. The diode chip performance exhibits 50% lower E_{rr}. By utilizing these devices, the overall power loss is approximately 30% lower and Tj is 22 K lower than the performance of the IGBT module from Manufacturer A at 2 kHz and even more significant in case of higher switching frequencies. This enables either 30% higher output power or doubling the switching frequency (cost saving of passive components).

It is evident that Mitsubishi Electric offers several different types of power semiconductor modules (18 types of module designs) utilizing latest technologies in order to deliver the best system performance and the highest system reliability in the 1700 V category.

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Bodo´s Power Systems®

New Transfer Molded SMD Type IPM

Mitsubishi Electric has added a new transfer molded SMD type Intelligent Power Module to its line-up – the MISOP™. The MISOP™ is an ideal solution for high performance inverters in the range of 100W which require a high degree of compactness, high efficiency and easy assembly.

By Narender Lakshmanan and Muzaffer Albayrak from
Mitsubishi Electric Europe B.V, Germany
Teruaki Nagahara, Mitsubishi Electric Power Device Works, Japan

Introduction

Applications such as small drives (in the range of 100W output power) have certain special requirements with regards to the design of the power supply unit. The power supply unit encompasses the power semiconductor module and the associated peripheries (such as gate-drive, control, protection and heatsink) which are assembled using a single PCB. This unit must be able to deliver the highest possible efficiency and must offer a high degree of compactness. Additionally, it is expected that the modules must be mounted with minimum effort on the PCB. Considering the special requirements presented by such applications, the MISOP™ (Mitsubishi Electric Intelligent Small Outline Power Module) are being developed in the 1A/600V range and the 3A/600V range. The MISOP™ is SMD type Intelligent Power Module (IPM) which consists of integrated gate-driver components and bootstrap diodes. This product is a new addition in the Mitsubishi DIPIPM™ family of products which consist of transfer molded power semiconductors optimized for applications requiring a high degree of compactness and high operational efficiency.

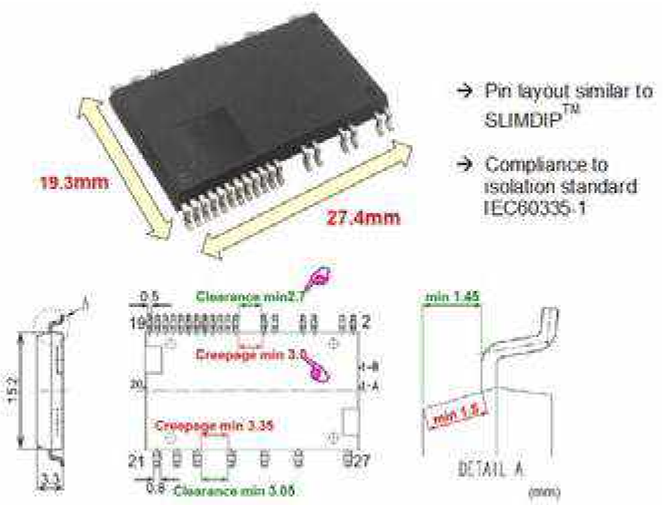

Figure 1 : Package dimensions of the MISOP™ and the pin layout indicating the compliance to the IEC60335-1

Highly Optimized SMD type Power module:

The MISOP™ is based on the Mitsubishi 7th generation Reverse Conduction (RC) IGBT chip technology. The 7th generation chip technology is a low loss thin wafer IGBT technology which allows an optimization of the balance between performance and IGBT chip size. In addition to the inherent benefits of the 7th generation chip technology, the RC technology enables a significant level of optimization of the power module's surface area requirement since the IGBT and the diode are effectively integrated into a single die. As a result, the chip surface which is normally used for the placement of diode dies are not required in this approach and therefore the IGBTs and the diodes necessary for a 3 phase inverter are effectively packed into a single package corresponding to the SOP footprint. Figure 1 indicates the size of the package and Figure 2 indicates the internal circuit topology of the power module. The pin assignment is similar to that of Mitsubishi's SLIMDIP™ module from the DIPIPM™ series

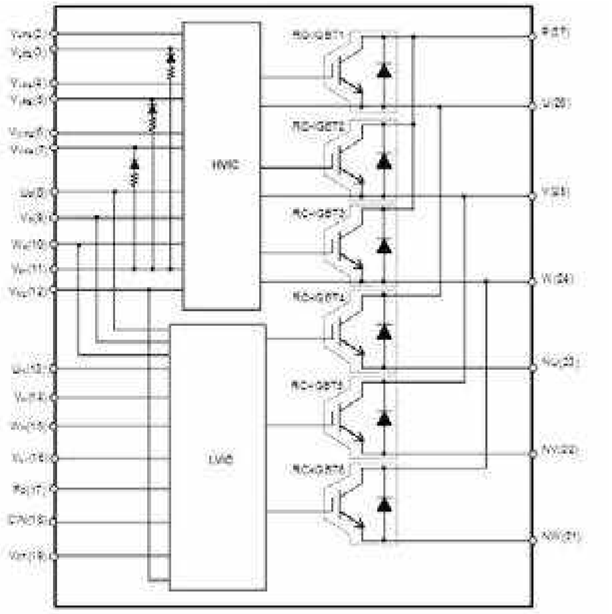

Figure 2 : The internal topology of the MISOP™

and the isolation standard has been designed under the consideration of market requirements of creepage and clearance distances. Pin design is also in accordance with the norm IEC60335-1. This product has been developed in the SMD package. It does not have through-hole pins and it can be soldered to the PCB using the reflow soldering technique which is intended to optimize efforts required in the assembly process. Continuing with the concept of the DIPIPMTM series, the MISOP™ is also equipped with integrated gate drive components. The module is equipped with embedded driver ICs: a Low Voltage IC (LVIC) which is responsible for driving the low side switches and a High Voltage IC (HVIC) which utilizes the bootstrap topology to drive the high side switches (with bootstrap diodes and current limiting resistors). The full integration of driver and protection functionality are guaranteed under Mitsubishi quality standards and allows to reduce the failure rate of whole inverter. Also, through the full integration, the number of peripheral components will be optimized and this would help the stock management. The embedded gate drive ICs also support several important protection functionalities. Figure 3 indicates the wiring pattern which has to be established in an application utilizing the MISOP™. The approach adopted by the MISOP™ avoids the needs for several undesirable cross points in the PCB tracks and even enables to use a single-side board. As a result, the PCB board design required for utilizing the MISOP™ is significantly simplified.

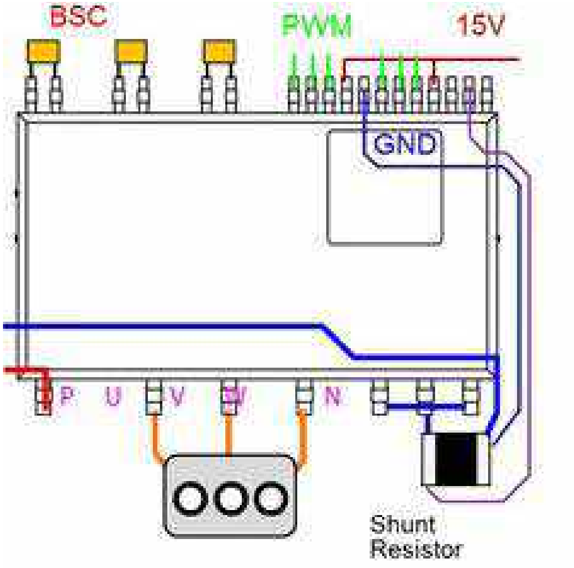

Figure 3: An example of the application circuit required for MISOP™ indicating the connections to the shunt resistors, Bootstrap-Capacitors, control input, control power supply and power terminals.

Performance Analysis

The increasing global awareness for carbon footprint reduction combined with the commercial benefit of reducing power consumption in appliances has motivated manufacturers of inverters (for applications such as small fans or pumps) in the range of 100W output power to adopt power semiconductors which deliver the highest possible efficiency during operation. Therefore, along with the advantage of offering compactness and easy design, the MISOP™ must be able to perform well under the required operating conditions. Figure 4 indicates simulation results of the power loss performance with the 1A device MISOP™ for different RMS inverter current Iout(rms) and the corresponding increase in the ΔTj-c(average) for the given values of the Iout(rms). Considering an inverter with the following nominal working conditions: Iout = 0.283 Arms, Vcc = 300V, fc = 20 kHz, pf = 0.8, modulation index = 1; the 3 phase output power is approximately 72W by using the 1A devices (SP1SK) from MISOP™ family. Using the data from Figure 4, we understand that the total power loss is around 2.76W. This performance indicates a power module efficiency of around 96%. Although the MISOP™ is highly compact in volume, it can be observed that this module is capable of delivering excellent thermal performance. With regards to the thermal performance, it is evident that the ΔTj-c(average) for this operating point is around 7 K for each RC-IGBT. Under these operating conditions, (considered an air cooled heatsink with effective Rthc-s =16 K/W for the entire module and ambient temperature of around 40°C) the temperature of the case remains at around 85°C and the average junction temperature remains at around 92°C. Figure 5 indicates the thermal performance of the module captured via a thermal camera (this analysis was performed without any external heatsink). A combination of high operational efficiency and good thermal performance enables the inverter to achieve maximum output power from this MISOP module.

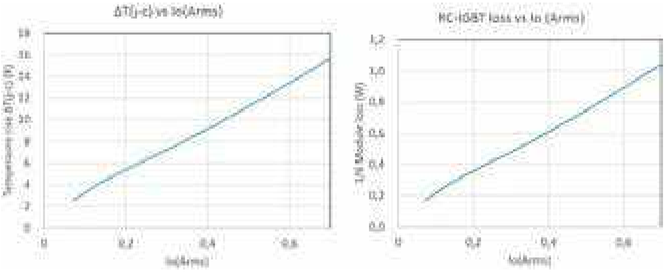

Figure 4: Tentative data pertaining to the thermal and electrical loss performance of a single RC-IGBT device (MISOP™). Conditions: Vcc = 300V, fc = 20 kHz, pf = 0.8, M = 1, Three Phase Modulation, Rth(j-c) maximum, Tj = 125°C, heatsink connected.

Integrated Protection Functions

Along with the requirement for high efficiency, it also necessary to ensure that the inverter is designed using a high performance power module with regards to protection against irregular operation modes. The MISOP™ is provided with several integrated protection functions (please refer to Table 1). The device offers the possibility to implement a short circuit protection via external shunt resistances which can be connected to each of the open emitter pins. To avoid the risk of overheating during operation, there is a built-in overtemperature protection function (OT) and there is a possibility of monitoring the module temperature with an accurate linear analog voltage output signals (VOT), which could help to define the derating points to use the module with high power density. The availability of the “interlock-protection” is an important implementation, this protection function prevents the simultaneous turn-on of both high side and low side switches (such a turn-on would lead to an arm-shot through short circuit). In addition, there is a system to detect and indicate a failure in the control supply voltage. An unstable input to the control power supply can lead to undefined switching states and subsequently thermal run-away of power chips. A failure event in any of the low side switches would be indicated via the Fo signal (except for interlock function).

#	Functions available in the MISOP^{TM}
1	Under voltage protection (UV)
2	Short circuit Protection (SC)
3	Over temperature protection (OT)
4	Temperature information output (VOT)
5	Arm short circuit protection → Interlock (IL)
6	Failure output (Fo)
7	Bootstrap diode (BSD)
8	Open emitter N side :Three shunts can be connected

Table 1 : List of internal functionalities available in the MISOP™

Summary

Indices such as the APF (Annual Performance Factor) pertaining to efficiency have gained significance in recent years and have motivated the manufacturers of appliances such as small fans, pumps and various other such appliances which require an output power in the range of 100W to consider power semiconductor devices which offer high operational efficiencies. Simultaneously, the demand for inverter size optimization has led to the demand for highly optimized power modules. On the other hand, such a compact power module must also be robust and offer high reliability. The MISOP™ is designed to address the requirements of this sector. In addition to the availability of integrated functionalities (such as protection functions), the MISOP™ package allows for easy and efficient assembly process. In addition, it must also be noted that the wiring scheme required for the MISOP™ facilitates an easy PCB design thanks to similar pin layout with Mitsubishi's SLIMDIP™ module and the secured pin to pin isolation distance in accordance with isolation standard IEC60335-1.

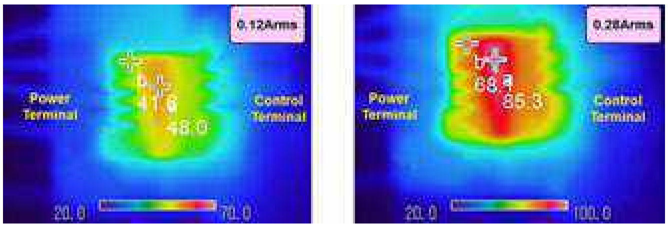

Figure 5: Heatsink-less operation captured using a thermal camera- Vcc=270V, VD=15V, Io=0.12 and 0.28Arms, fc=16kHz, Modulation=1, Three phase sine wave, Natural convection (no forced air), Ta=20.9~21.6°C, Evaluation board, typical data.

MISOP, SLIMDIP, and DIPIPM are trademarks of Mitsubishi Electric Corporation

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Bodo´s Power Systems®

7^{th} Generation NX type (NX7) Converter Inverter Brake (CIB) Modules

Developed to address the requirements of high performance drives by utilizing an innovative packaging concept and an advanced chip technology.

Applications such as elevator drives or servomotors have several special requirements. One on hand, high efficiency is important, while on the other hand, the inverter unit be resilient to the different types of load cycling. Furthermore, the inverter must be designed as compact as possible. NX7 CIB modules aim to address these challenges.

By Toshinari Hirai and Narender Lakshmanan, Mitsubishi Electric Europe B.V

Advanced Chip Technology Combined with a New Packaging Concept:
Each CIB module consists of an integrated 3 phase inverter part, a converter (3 ph diode rectifier) part and a brake chopper part. The line-up of the latest NX7 CIB modules is shown in Figure 1. The NX7 CIB modules utilize the latest 7th generation CSTBT™ IGBT along with the RFC (Relaxed Field of Cathode) diodes. The electrical characteristics of the new thin wafer 7th generation chips have been tuned for the reduction of overall power losses.

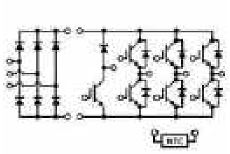
Topology	Appearance	Package W x D (mm²)	1200V	650V
		45 x107.5	35A	
			50A	50A
			75A	75A
				100A
		62 x 122	75A	
			100A	100A
			150A	150A

Figure 1: Line-up of the NX7 CIB Modules. NOTE: Pressfit and PC-TIM options available.

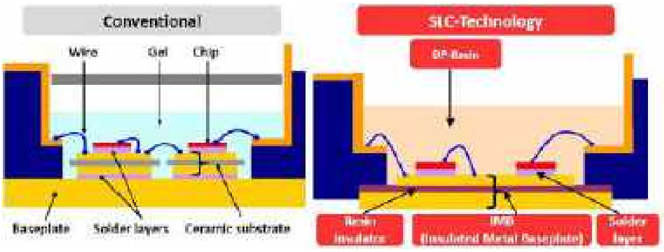


Figure 2: Cross section of the NX7 package versus a conventional module package.

The NX7 CIB employs a new packaging concept – the SLC (SoLid Cover) Technology which includes an insulated metal baseplate structure (refer to Figure 2). The conventional baseplate has been replaced by an insulated metal baseplate structure where the metal baseplate contains an organic insulation layer directly bonded to it. Therefore the conventional substrate solder between metal baseplate and isolation ceramic has been eliminated. The soft silicone gel of the conventional structure is replaced by the hard DP-resin (direct potting resin) [1].

Minimizing Losses and Maximizing Performance:
Operating the inverter at elevated switching frequencies helps in reducing the audible noise, hence low loss operation even at high switching frequencies is an important capability for applications such as elevators. In addition, limiting the IGBT chip temperature rise during low rotation speed (low output frequency) operation is a key requirement.

Figure 3 indicates the overall power loss comparison of an NX7 CIB module (CM50MXUA-24T) with a previous 6th gen. IGBT module (CM50MXA-24S) considering different switching frequencies and a low output current frequency of fout=5Hz. The benefit in terms of pow-

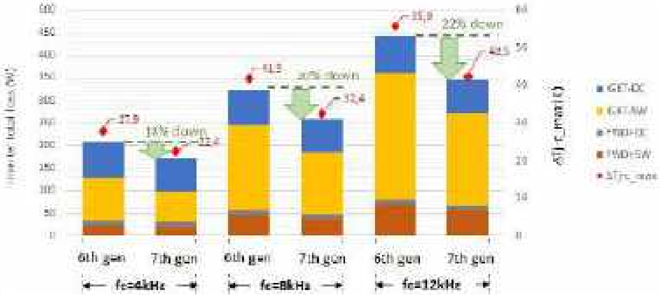


Figure 3: Power loss and junction temperature performance of the NX7 CIB vs conventional module. Conditions: VCC = 600V, Io = 24 Arms, PF = 0.9, M = 1, fout = 5 Hz, Data @ Tj = 125°C.W

er loss between a conventional module and an NX7 CIB module increases with increase in switching frequency. This can be attributed to the optimization in the trade-off between the switching losses and the ON state losses in the new 7th generation chip technology. A combination of loss reduction and the low thermal resistance (chip to case) offered by the 7th generation chip technology ensures that the maximum junction temperature can be reduced by utilizing the NX7 CIB module. The analysis indicated in Figure 3 has been carried out considering a target switching dv/dt (max)= 10 kV/µs.

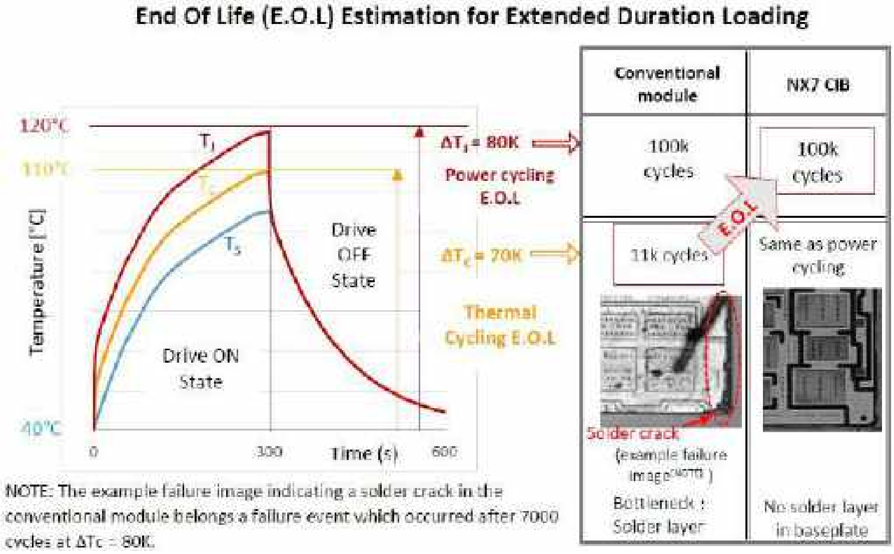
Designed for High Reliability:
Intermittent operation is a characteristic feature of applications such as elevators. The impact of load cycling can be categorized into two types of cycling phenomena: power cycling and thermal cycling. Power cycling refers to a cycling of the junction temperature which affects the reliability of the chip-to-bond wire contact whereas thermal cycling refers to the cycling of baseplate temperature which conventionally affect the solder layer connecting the isolation substrate and the baseplate. But due to the elimination of the ceramic substrate and the solder layer, the limitation pertaining to thermal cycling is not present in NX7 CIB modules.

Case 1: Extended Loading Conditions (temperature swing at the heatsink and case):
It is common for applications such as elevators to experience operation cycles where the heatsink temperature rises to an allowable point and then falls back to the ambient temperature. Session involving continuous operation which would generate a temperature swing at the heatsink, would also involve temperature swings at the case of the power module and at the chip surface (junction). An example of such operation is represented in Figure 4. For this analysis, the Mitsubishi Electric 6th generation modules represent the conventional modules.

The following points are the key conclusions from Figure 4:

1. Bottleneck identification: For conventional modules which utilize a baseplate solder layer, thermal cycling performance is the lifetime limitation factor for long operation cycles due to the degradation of the solder layer under such conditions.
2. Solution: The bottleneck (solder layer) has been eliminated in the new NX7 module due to the adoption of the IMB structure.

Case 2: Short term loading conditions (temperature swing predominantly at the chip):
Operating cycles (in the range of a few seconds) which generate temperature swings only at IGBT chip (ΔT_j) affect the reliability of the chip to bond wire contact. The amplitude of the ΔT_j is the deciding factor with regards to the power cycling lifetime. This point has been addressed by employing the low loss 7th generation chip technology



NOTE: The example failure image indicating a solder crack in the conventional module belongs a failure event which occurred after 7000 cycles at ΔTc = 80K.

Figure 4: Lifetime estimation for extended duration loading (Conventional module vs NX7 CIB).

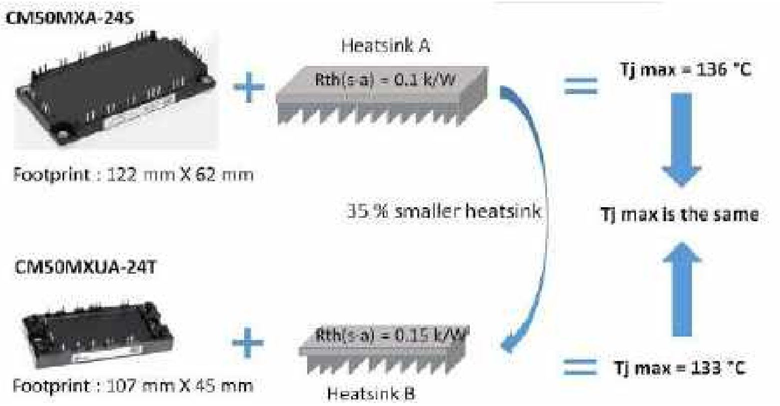


Figure 5: Compactness by heatsink reduction. Conditions: Vcc = 600V, fc = 12 kHz, fout = 5 Hz, M = 1, PF = 0.9, Ic = 24 Arms, Ta = 30 °C, data @ Tj = 125 °C

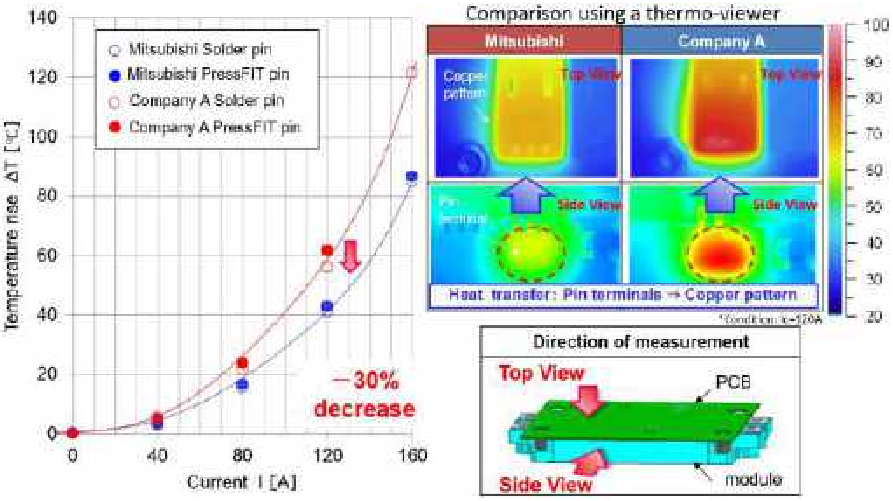


Figure 6: Optimization of terminal temperature in the NX7 CIB module.

in combination with the optimized chip to case thermal resistance in the NX7 module. This combination ensures that for the same operating condition, the corresponding ∆Tj is lower (compared the performance of the conventional module). This tendency can be understood from the following results indicating power cycling capability based on the conditions mentioned in Figure 3 (for fc = 12 kHz):

- Conventional CIB (CM50MXA-24S): ∆Tj = 54.52 K: 600 thousand cycles (approx.)
- NX7 CIB (CM50MXUA-24T): ∆Tj = 36.64 K:WWWW 6 million cycles (approx.)

Summary – Overall lifetime enhancement

Overall improvement in lifetime has been ensured by the following two-step strategy:

1. Elimination of the thermal cycling bottleneck
2. Reduction of ∆Tj to achieve better power cycling capability

Compact Design:

To achieve a compact design, several important considerations have to be made. The following points illustrate the advantage offered by adopting an NX7 CIB module.

1. Since the NX7 CIB module exhibits an improved loss performance and superior thermal performance (refer Figure 4), the designer can shrink the size of the heatsink in order to achieve an overall compact design. The example presented in Figure 5 illustrates a 35% reduction of the heatsink without causing an increase in the maximum junction temperature.

2. To achieve compactness, the classical copper busbar structure can be replaced by a PCB which would be connected to the terminals of the power module via pressfit or soldering. The challenge with this approach is that, due to high current density at the terminal pins, the temperature developed at the terminal could impose a limitation on the maximum operating current. This possibility has been taken into consideration while developing the NX7 CIB and accordingly the pin structure has been designed to reduce the temperature developed at the terminal during operation. As indicated in Figure 6, the temperature rise developed at the terminals of the Mitsubishi module (NX7 CIB) is lower in comparison with a competitor's design. The improved thermal conductivity of the potting material (DP-resin) versus gel is an added advantage.

Scalable solutions:

The NX7 CIB line-up allows the designer to develop platform solutions – one mechanical design for multiple power ratings. For example, (refer Figure 1), in the 1200V category, the 45mm x 107.5mm module is available in 3 different current ratings (35A, 50A and 75A and the 62mm x 122mm module is available in 3 different current ratings (75A, 100A, 150A). This allows the designer to develop one mechanical design for 3 different power levels.

Conclusion:

The requirements of applications such as elevator drives have been taken into consideration while developing the NX7 CIB module. The unique combination of the SLC technology packing and the 7th generation chip technology allows the designer to develop an efficient, reliable and a compact inverter that can be used as a platform solution for multiple power levels.

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www.mitsubishielectric.com/semiconductors

Bodo´s Power Systems®

1700V X-Series HVIGBT Power Modules with Excellent Performance and Reliability

High performance 1700V HVIGBT power modules providing reliable solutions for railway applications.

The railway applications require components with high quality and high efficiency, especially the converter drives should have reliable and robust switching devices. It is an established practice to utilize 1700V IGBT modules to operate directly on the catenary with the DC voltages below 1000V or in 3-level configuration with catenary DC voltages above 1000V.

By Eugen Wiesner, Dr. Nils Soltau MITSUBISHI ELECTRIC EUROPE B. V.
Nobuhiko Tanaka MITSUBISHI ELECTRIC CORPORATION

Mitsubishi Electric continuously improves the quality of the IGBT power modules concerning three key concepts:

- Robust power module design considering high margin of safe operating area,
- Low power losses using latest chip generation,
- Quality control with dedicated production lines and traceability.

Mitsubishi Electric has several years of experience and a long development history of 1700V modules for railway application from the start of this century. This year MITSUBISHI ELECTRIC has released the latest generation of 1700V IGBT power modules called X-Series that satisfies requirements of railway applications. Fig. 1 shows the historical evolution of the 1700V HVIGBT modules indicating the continuous reduction of the IGBT forward voltage. The IGBT forward voltage contributes to the converter power loss reduction. IGBT forward voltage reduction has continuously been achieved during the development of each series. The remarkable step in the reduction of the forward voltage was the implementation of the trench gate structure in the beginning of 2000s [1]. For further reducing the forward voltage the IGBT chip structure was optimized and thinner chips were used. In the latest 1700V X-Series the state of the art 7th Generation chip technology is applied in conjunction with a further reduction of IGBT thickness. Additionally, several optimizations on the chip back side (collector side) were carried out.

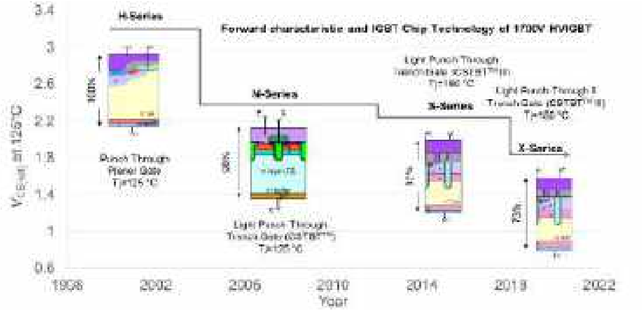

Figure 1: Chronology of 1700V IGBT chip forward voltage reduction.

Circuit	Foot print	Current rating	Type name
Single 1 in 1	190mm x 140mm 	2400A 3600A	CM2400HCB-34X CM3600HC-34X
Single 1 in 1	130mm x 140mm 	1600A 2400A	CM1600HC-34X CM2400HC-34X
Chopper	130mm x 140mm 	1200A	CM1200E4C-34X
Dual 2 in 1	100mm x 140mm 	1000A 1200A 1200A	CM1000DC-34X (Si) CM1200DC-34X (Si) CMH1200DC-34X (SiC hybrid)

Table 1: 1700V X-Series Line-up

The 1700V X-Series contains three module packages. The first is the conventional package with the footprint dimensions of 190mm x 140mm. The second type is also conventional having the footprint size of 130mm x 140mm. The third package is the new standard dual package called LV100 with the footprint of 140mm x 100mm. The complete line-up of the X-Series 1700V IGBT modules is shown in table 1.

High current 1700V HVIGBT X-Series single modules.
The conventional 1in1 packages were completely reworked compared to the previous N-Series. The chip layout inside the module was optimized for better thermal conductivity and better power cycling life time. Inside the module a newly developed high performance silicone gel is used. The operation temperature now is covering the range from -50°C to 150°C. The new X-series modules will receive the UL certification. Furthermore, these modules were proven during the qualification against the humidity influence. That is an important factor for the operation in the harsh railway environment.

Figure 2: 1700V X-Series single modules features

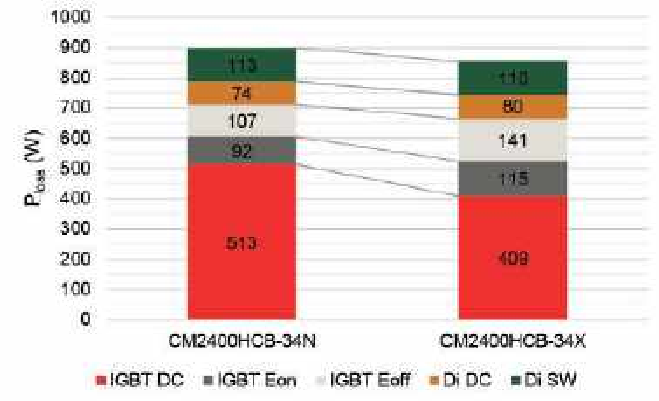

Figure 3: X-Series power loss simulation under the conditions: V_{CC}=850V, I_{peak}=1200A, PF=0.85, M=1, f_{sw}=1kHz, f_o=60Hz, T_j=125°C.

The standard package type is available since many years on the market. Then converter manufacturers have proven reliability records of the converters having this package type in the field. Now it is possible to boost the converter performance using the cutting edge technology of X-Series modules. The small size package (130mm x140mm) is favorite choice for compact water cooled application. The large package (190mm x 140mm) with its low case to heatsink thermal resistance Rth(c-f) is especially attractive for air cooled applications. In the Figure 3 is shown the potential of the power loss reduction for single X-Series device CM2400HCB-34X compared to the previous N-Series.

Dual LV100 X-Series 1700V modules
The standard LV100 package was developed with the target to cope with high switching speed devices like 1700V X-series modules and modules having Silicon Carbide technology. The low inductive package structure is one of the key advantages of this device.

Thanks to low package inductance and comfortable construction of the DC-Link connection, it is possible to switch off the device at high current without increasing the turn off gate resistance. The IGBT turn off measurement result at maximum turn off conditions V_{CC}=1200V, I_C=2400A, $R_{g(off)}$=$R_{g(nominal)}$, L_s=40nH and T_J=150°C is shown in Figure 4. Even at such conditions the overvoltage spike is below the maximum blocking voltage of 1700V.

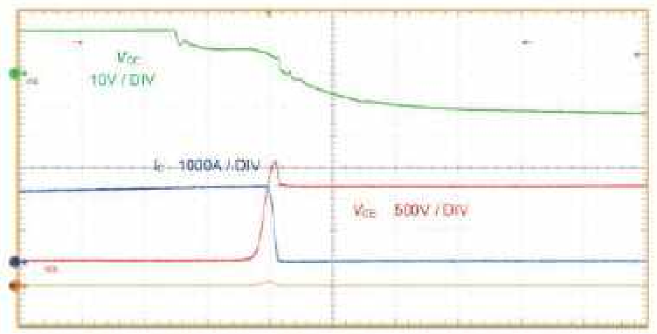

Figure 4: CM1200DC-34X turn off event at high current and maximum DC-Link voltage.

Furthermore the diode performance was enhanced in the LV100 module. Compared to the previous S-Series the diode forward voltage was reduced by more than 15%. At the same time the reverse recovery energy was reduced by more than 25%.

The current density in the LV100 package was increased by about 30% from 13.2A/cm^2 to 17.1A/cm^2 for CM1200DC-34X compared to CM2400HC-34N device. To carry the high output current the device has three screws at AC output terminal.

The forward characteristics of IGBT and FWDi has positive temperature coefficients that is essential for good module parallel operation.

Additionally this package provide the flexibility of converter power scaling by module paralleling. This point is also an additional challenge for converter designer. To overcome this challenge the proposed reference test setup [2] can be used in combination with these modules.

Conclusion
The introduced 1700V X-Series utilize the cutting edge chip and package technologies. The modules offers the highest reliability combined with low power losses and flexibility.

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Bodo´s Power Systems®

Switching Performance of 750A/3300V Dual SiC-Modules

Generally, the emerging SiC technology is associated with very high switching frequencies resulting in compact converters

This article focuses on this switching behavior of SiC devices and compares Full SiC and Hybrid SiC with the behavior of a silicon device. All considered modules are rated for 3.3 kV and similar current ranges to give a fair and illustrative comparison. Finally, the article gives an outlook on future higher-voltage 6.5 kV SiC technology.

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Introduction

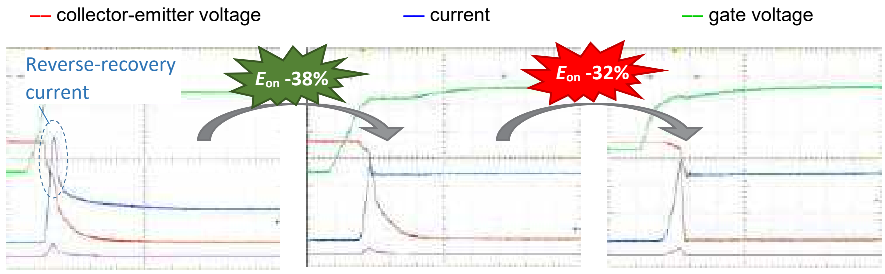
Since the 1990s, Mitsubishi Electric researches and develops semiconductor devices made of silicon carbide (SiC) [1]. Since 2017, the development of the 3.3 kV devices is finished. This 3.3 kV Full SiC module uses the most recent dual package, the LV100, and is rated for 750 A (cf. Fig. 1).

Figure 1: 3.3 kV / 750 A Full SiC module in the LV100 package

For increasing blocking voltages, the electrical resistance of MOSFETs increases steadily. Therefore, Silicon (Si) MOSFETs are usually available up to 600 V. For higher voltage levels, Si-based semiconductors require the use of bipolar devices, which are able to reduce the on-state voltage by conductivity modulation. Therefore, high-voltage Si devices are usually bipolar IGBTs and PiN diodes.

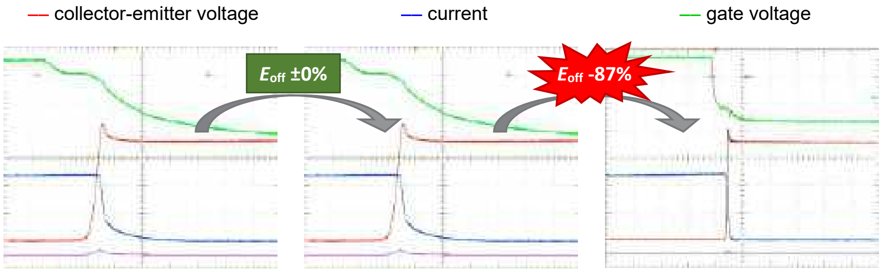
Owing to the higher dielectric breakdown, SiC may use unipolar MOSFETs and Schottky Barrier Diodes (SBDs) even at high-voltage levels. The advantage of unipolar devices is the absence of charge carrier accumulation. Hence, these unipolar devices switch faster and have lower switching loss compared to their bipolar counter parts.

In this article, a comparison of the switching behavior of bipolar Si devices and unipolar SiC devices, all rated for 3.3 kV and similar current ratings, is shown. The measurements demonstrate the nature of these two different semiconductors regarding their switching performance.



(a) Si [500 A/div; 500 V/div; 1 µs/div]
(b) Hybrid SiC [250 A/div; 500 V/div; 1 µs/div]
(c) Full SiC [250 A/div; 500 V/div; 1 µs/div]

Figure 2: Turn-on waveforms (V_{cc} = 1800 V, I_C = 600A, T_j = 150 °C, L_s = 65 nH



(a) Si [250 A/div; 500 V/div; 2 µs/div]
(b) Hybrid SiC [250 A/div; 500 V/div; 2 µs/div]
(c) Full SiC [250 A/div; 500 V/div; 2 µs/div]

Figure 3: Turn-off waveforms (V_{cc} = 1800 V, I_C = 600A, T_j = 150 °C, L_s = 65 nH)

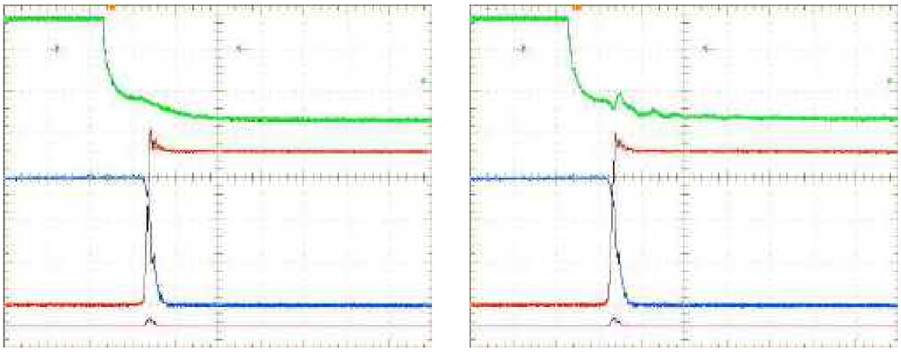
Switching Performance of Full SiC

Recently, Mitsubishi Electric has released its LV100 package. This package is regarded as an additional standard package for high-voltage power modules. The advantages are easy parallel connection and high power densities (per heat sink area). Moreover, the module contains a half-bridge phase leg and is designed for low-inductive connection of the dc link. This is mandatory to utilize the full potential of fast-switching SiC. In a similar LV100 package, Mitsubishi Electric offers semiconductor made of Si and SiC. Also a SiC hybrid module is available, which utilizes a bipolar Si IGBT together with a unipolar SiC diode. These three modules are compared in the following.

Figure 2 (a-c) show the turn-on waveforms of the Si, Hybrid SiC and Full SiC modules respectively. While the active devices (IGBT or MOSFET) turn on, the corresponding free-wheeling diodes is turned off. If this is a Si diode, a reverse-recovery current is generated which also flows through the active devices. This reverse recovery current appears as current peak during turn on. This can be observed nicely in Fig. 2 (a). In case the free-wheeling diode is made of SiC, like in the Hybrid SiC module, this current peak almost disappears (cf. Fig. 2 (b)). This results in a reduction of turn-on energy Eon by 38%. Using a Full SiC MOSFET and utilizing steeper voltage transients further reduces the turn-on energy by additional 32%. Moreover, the reverse recovery energy loss Erec in the diode for the Hybrid SiC and Full SiC are zero.

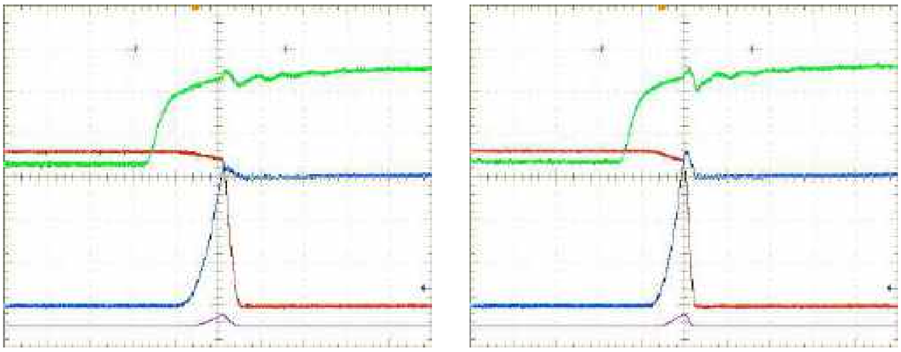
Analogously, Figure 3 (a-c) shows the switching waveforms during turn-off. The waveforms at turn-off for Si and Hybrid-SiC are same and, consequently, turn-off energy of both modules are same. In fact in both cases the same IGBT is turned off and the turn-off behavior is independent from the diode. The use of Full-SiC, however, reduces the turn-off losses due to the absence of the tail current and the increased switching speed. In the measurement, a reduction by 87% is achieved. Of course this reduction of switching loss implies fast voltage transients. The performance at lower switching speeds is discussed in [2].

Reverse recovery and tail currents of Si devices usually show significant temperature dependency. Consequently, switching losses increase with higher chip temperature. In SiC devices, this effect is less pronounced. As shown in Fig. 4, switching behavior at Tj = 25°C and Tj = 150°C is quite similar. The switching-loss change at nominal current between 25°C and 150°C is only about 10 % therefore.



(a) Turn-Off, T_j=25°C

(b) Turn-Off, T_j=150°C



(a) Turn-On, T_j=25°C

(b) Turn-On, T_j=150°C

Figure 4: Full SiC switching waveforms for different junction temperatures (V_{cc} = 1800 V, I_C = 750A, L_s = 65 nH, [250 A/div; 500 V/div; 1 µs/div])

Reduction of Switching Losses

After explaining the physical background for the lower switching losses, the impact over the operating range is discussed in more detail. Figure 5 shows the total switching energy, meaning the sum of turn-on, turn-off and recovery energy loss, for different switching currents. As discussed before the switching energy loss decreases significantly using SiC. To put in numbers, compared to Si, the switching energy loss reduces for Hybrid SiC and Full SiC by 50% and 80% respectively at 600 A.

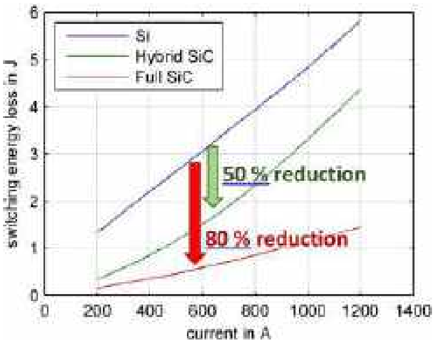


Figure 5: Switching losses (E_{on}+E_{off}+E_{rr}) for each 3.3 kV semiconductor technology (V_{cc} = 1800 V, T_j = 150 °C, L_s = 65 nH)

Due to the lower switching energy loss, SiC technology allows higher switching frequencies. Figure 6 shows the ratio of switching frequency achieved by SiC versus Si considering same switching losses. Consequently, Hybrid SiC achieves about twice as high switching frequencies (at nominal current) compared to Si. Furthermore, Full SiC reaches about 5-times higher switching frequencies at the same switching current. Reflecting this to a PWM application and considering the conduction loss, 5 – 9 times higher switching frequency can be expected [3].

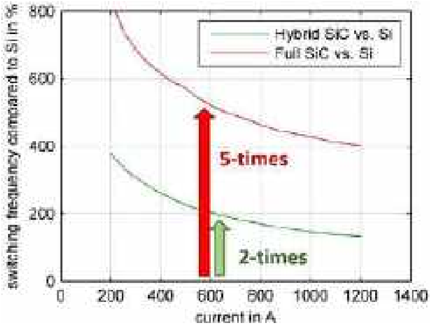


Figure 6: Switching frequency compared to Si device for equal switching losses (V_{cc} = 1800 V, T_j = 150 °C, L_s = 65 nH)

The higher switching frequency brings advances in many applications. Often filters, transformers or machines can be design more compact, which again increases the system efficiency and reduces costs.

Finally, it is worth mentioning, that these modules are intended for critical applications, which have highest quality and reliability requirements; like railway traction drives. The development of the 3.3 kV Full SiC module is finished and same or higher reliability is achieved compared to classical Si traction modules. Moreover, Mitsubishi Electric holds many years of field experience with 3.3 kV SiC technology in railway applications. Therefore, 3.3 kV SiC has become a major and reliable technology.

Future Technology

A well-known effect in SiC semiconductors is the so-called “bipolar degradation” or “stacking fault expansion”. These terms describe a dislocation of the SiC lattice evoked by the recombination of electron-hole pairs as a result of bipolar currents [4] [5]. Ultimately, this effect leads to an irreversible degradation causing increasing forward voltage drop. The SBD freewheeling diode, connected in anti-parallel to the MOSFET, prevents the SiC MOFET from bipolar current and bipolar degradation respectively.

Today’s 3.3 kV SiC modules successfully use separate SBD chips, connected inside the module next to the MOSFET chips. Nevertheless, considering even higher voltage levels like 6.5 kV Full SiC MOSFETs, this approach is no longer economical. Therefore, Mitsubishi Electric has developed a technology to embed the SBD diode inside the MOSFET chip, instead of using separate chips [6]. Figure 7 illustrates the conventional and the enhanced MOSFET chip structure.

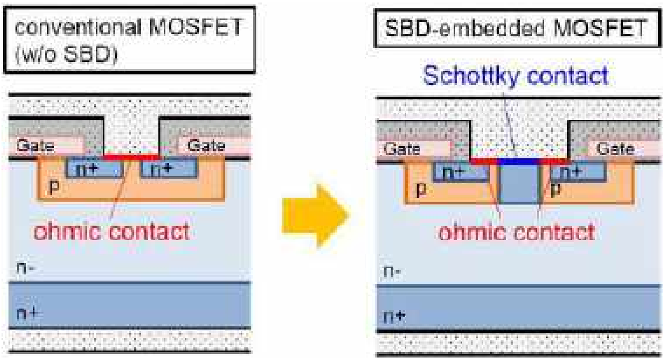


Figure 7: SBD-embedded MOSFET structure to optimize protection against bipolar degradation for 6.5 kV SiC MOSFETS

This technology is able to shrink the totally required SiC chip area to make SiC technology more efficient and more economical at voltage ratings above 3.3 kV [7].

Conclusion

This article has shown the switching characteristics of state-of-the-art 3.3 kV Full SiC and Hybrid SiC power modules. It has been explained that due to the nature of unipolar SiC devices, switching losses reduce by 50 – 80 %. As a result, Full SiC can operate at 5-times higher switching frequency.

In today’s 3.3 kV SiC technology, the SBD diode chips inside the power module effectively protects the MOSFET from bipolar degradation. Now, Mitsubishi Electric has developed the SBD-embedded MOSFET, which is a key-enabling technology for efficient and economical higher-voltage SiC technology.

References

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