Power Semiconductor Devices

MITSUBISHI ELECTRIC
Changes for the Better

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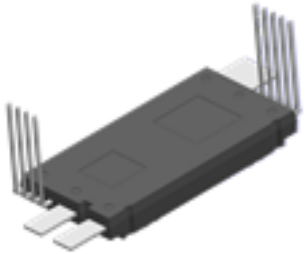

Industry Experience

Eric R. Motto
Chief Engineer
Power Semiconductor Applications
Mitsubishi Electric US Inc.

34 years power semiconductor device Application Engineering

What does an application engineer do?

- Introduce new technology/products to engineers
- Assist with the selection of devices
- Provide advice on care and feeding of power semiconductor devices
- Perform autopsy on the ones that were not cared for
- Assist with troubleshooting problems

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Use of SiC is on the rise

- Mitsubishi currently has more than 20 module types using SiC chips in mass production. Many more in various stages of development.
- Reported reliability concerns with SiC MOSFETs such as bipolar mode degradation and gate oxide integrity have been eliminated or effectively inhibited by screening, improved raw materials and device structure enhancements. Expect reliability at least equal to Si IGBT.

Silicon is not dead yet

- The Silicon IGBT is expected to continue as a reliable, cost-effective power semiconductor device for industrial applications for a decade or more.
- Optimization and Variations such as the RCIGBT offer additional cost and performance advantages for some applications

SiC Investments

Double the previous investment plan*1 to approximately 260 billion yen, including the construction of a new factory building for SiC, in order to drive the growth strategy for Power Device Business.

Capital investment (actual, planned)

Double cumulative capital investment from FY2022 to FY2026

- Continue strategic growth investment for further business expansion in SiC, in addition to the conventional plan

SiC 200mm wafer new factory building

Achieve high production efficiency through cutting-edge energy conservation and high-level automation

- Achieve energy savings of approximately 30%*3 compared to the conventional system by thoroughly recovering waste heat, in addition to adopting a swirl-induced stratified air conditioning system (TCR-SWIT®*2) in clean rooms
- Employ automatic transport system to enable labor saving and equipment operation rate improvement

Startup scheduled in April 2026

What is Driving SiC Investments Today?

(1) xEV Hybrid and Battery Electric vehicles

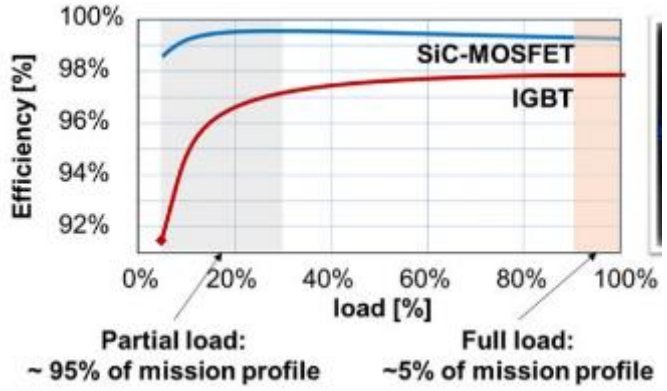
Why?

Increased battery voltages → 900V to 1300V Power Semiconductors Required

Desire to minimize inverter audible noise → 15kHz+ Switching frequency

→ Si IGBT efficiency not good at this condition

SiC Improved mission profile efficiency → Increased range for BEV



(2) **Traction – Subway, Light Rail**

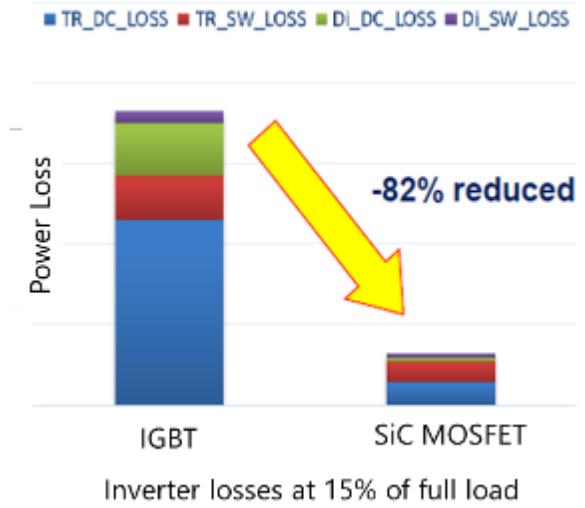
Why?

Low reverse conduction losses due to 3rd quadrant conduction

Increased regenerative braking → Energy Savings

Low switching losses (Especially for 1.7KV and 3.3KV devices) enables

Higher Fsw → Reduced harmonics → Increased motor efficiency → Energy Savings



(3) **High Efficiency HVAC**

Why?

SiC MOSFET has low conduction losses at low current

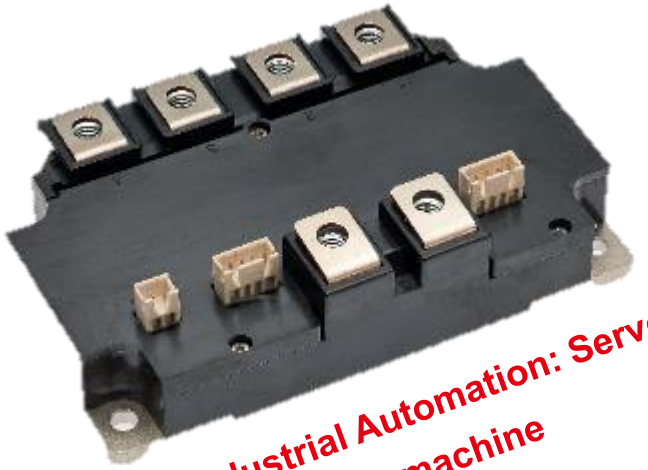
Improved efficiency under light load → High efficiency ratings

Mitsubishi SiC Power Semiconductor Devices

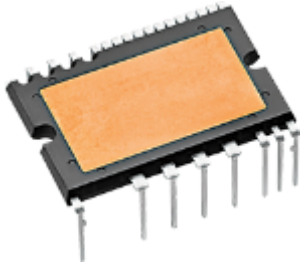
Traction: Subway, Locomotive, Grid-Tie Inverters

Industrial Power Supply, Motor Control

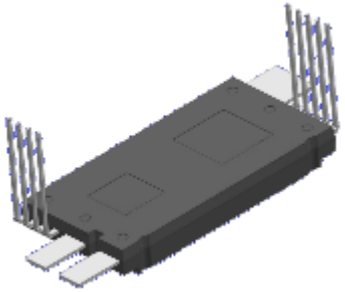
Medical Power Supply



Industrial Automation: Servo Drive, CNC machine



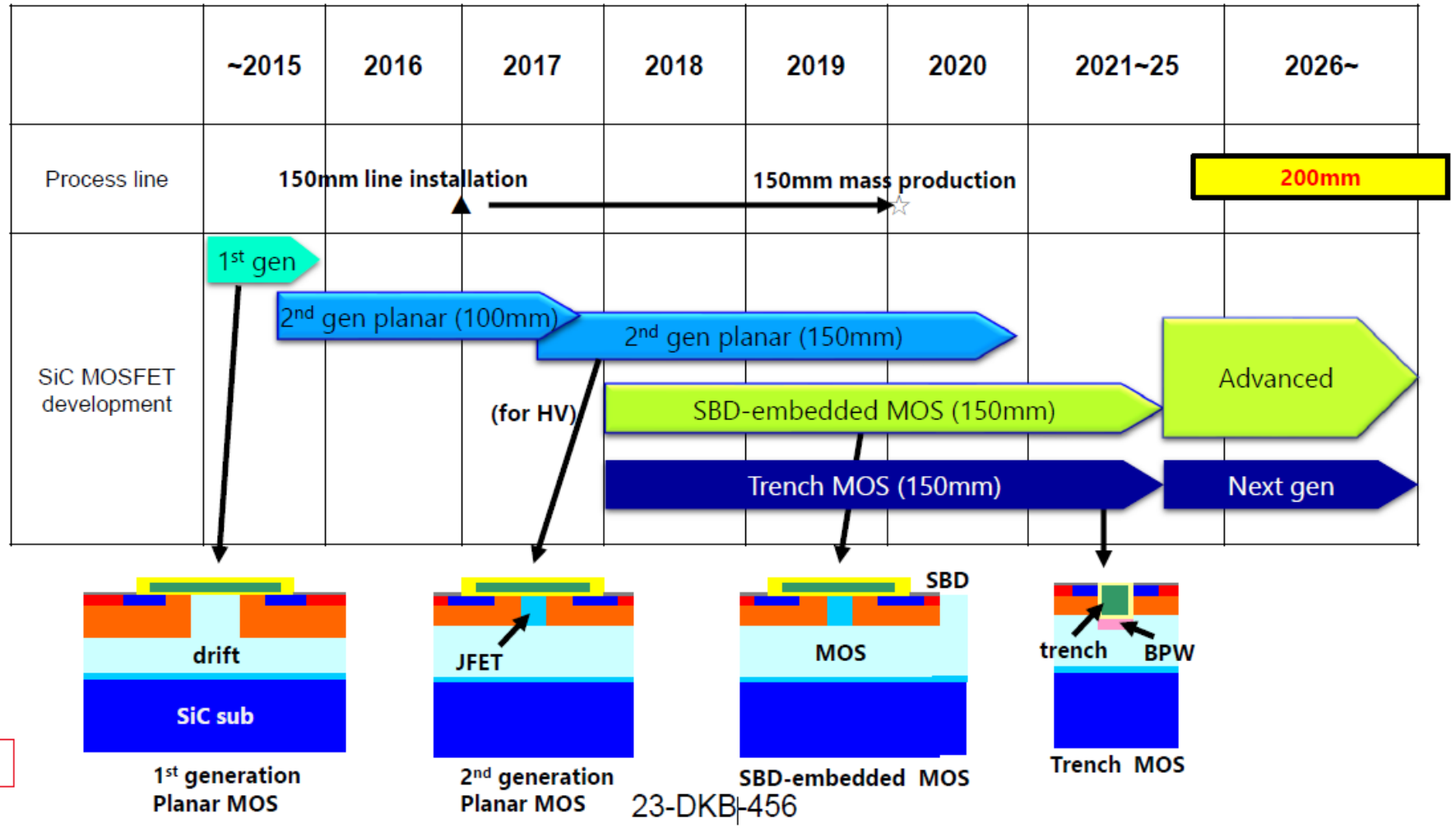
High Efficiency HVAC



EV, HEV

Mitsubishi SiC Development Roadmap

Development of 2nd generation MOSFET chips has been completed. SBD-embedded MOSFET for HV and trench MOSFET for 1200V rating will soon be put on the market.



23-DKB-456

SiC MOSFET Modules with RTC

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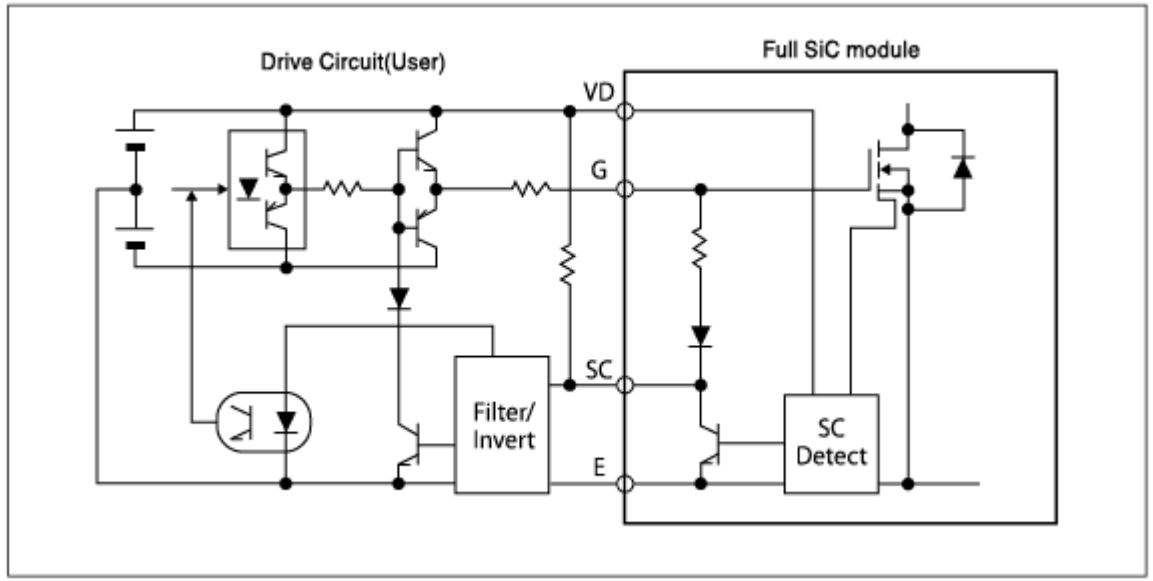
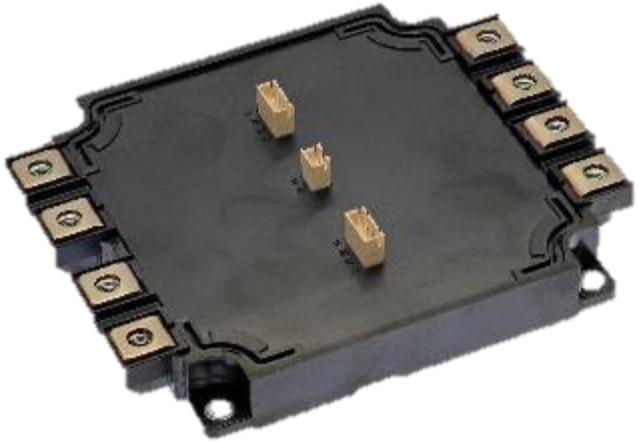
Features

- By using short circuit monitoring circuit in the module it is possible to transfer a short circuit detection signal to the system side
- Power loss reduced approx.70% compared to the conventional product*
- Low- inductance package adopted to deliver full SiC performance

Voltage (V)	Current (A)	Part Number	Topology	Package
1200V	300A	FMF300BXZ-24B	Dual	A
1200V	400A	FMF400BXZ-24B	Four Pack	A
1200V	600A	FMF600DXZA-24B	Dual	A
1200V	800A	FMF800DXZA-24B	Dual	A
1200V	1200A	FMF1200DXZ-24B	Dual	B
1700V	300A	FMF300DXZ-34B	Dual	A
1700V	300A	FMF300E3XZ-34B	Chopper	A

Protection circuit diagram





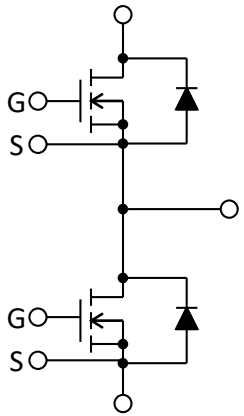
(A) (B)

Low Inductance Packages with RTC

SiC in Industry Standard Packages

Full SiC MOSFET with Anti-Parallel SiC SBD

108mm x 62mm Industry Standard Package

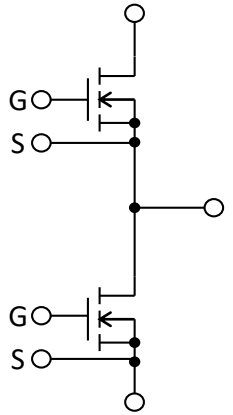


Voltage (V)	Current (A)	Part Number	Topology
1200V	400A	FMF400DY-24B	Dual

Full SiC MOSFET

152mm x 62mm Industry Standard Package (NX)

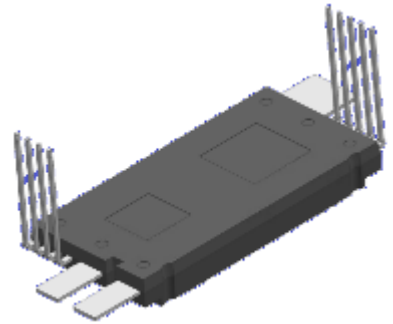
Laminated Internal Electrodes to Achieve 9nH P-N Inductance

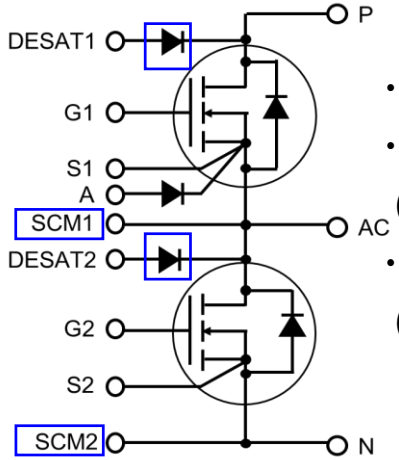
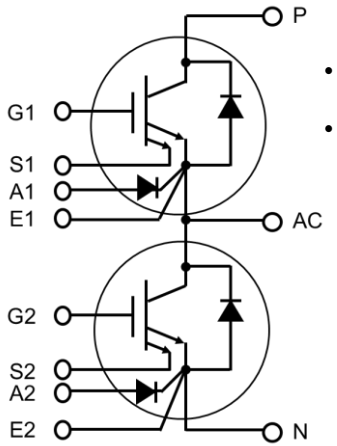


Voltage (V)	Current (A)	Part Number	Topology
1200V	600A	FMF600DXE-24BN	Dual
1700V	600A	FMF600DXE-34BN	Dual

Automotive: J3-T-PM

- ✓ **Cutting-edge power chips:** High current in small package
- ✓ **3rd gen. T-PM:** Compact, high reliability, low thermal impedance
- ✓ **Essential function for SiC:** DESAT with SCM for SC protection
- ✓ **Modular building block:** suitable for 50kW to 250kW Interters



	J3-T-PM (SiC)		J3-T-PM (RC-IGBT)	
Device	SiC MOSFET		Si RC-IGBT	
Rated Current	(230A)*	350A	400A	(560A)*
Rated Voltage	1300V	1300V	750V	750V
Package Size (Resin)	53.9mm × 26.5mm × 6.92mm			
Circuit Configuration Half bridge	 ・DESAT Diode ・Temperature sense (Outside chip) ・SCM terminal (for SC protection)		 ・On-chip temperature sense ・On-chip current sense	

LV100/HV100 New Industry Standard High-Power Packaging

Industrial LV100

4 kV Isolation
1200V to 2000V
100mm x 140mm

Traction LV100

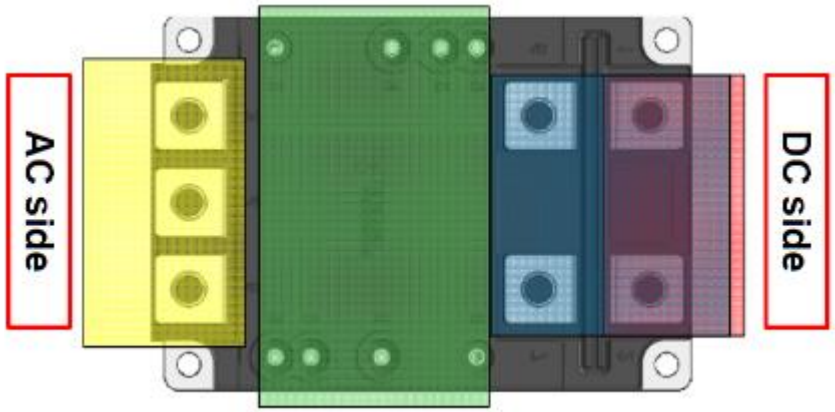
6 kV Isolation
1700V to 3300V
100mm x 140mm

HV100

10.2 kV Isolation
3300V to 6500V
100mm x 140mm

Advantages of LV100 & HV100 Designs

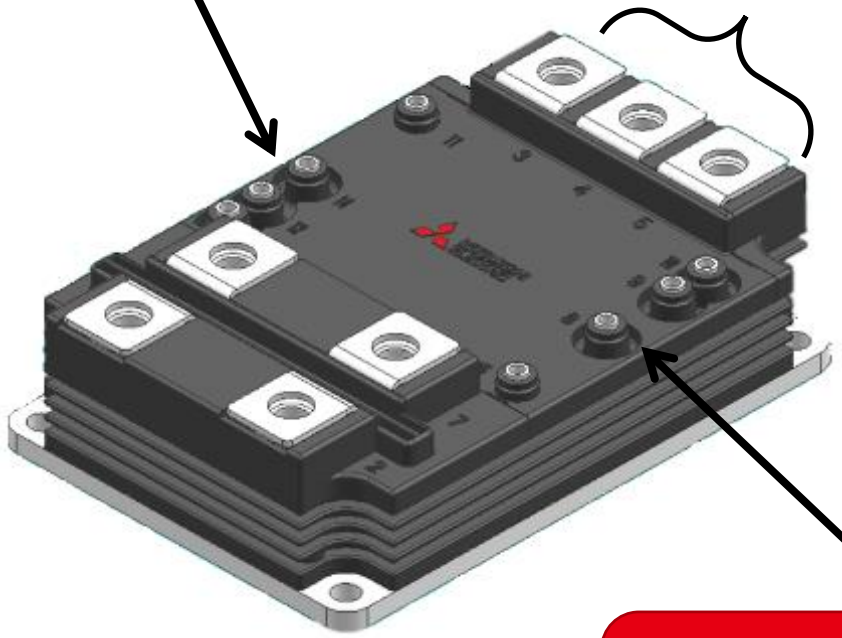
- Industry Standard Package
- Terminal layout allows for simplified DC bus and gate drive design
- Symmetrical layout – Easy to parallel modules
- Raised terminals permit topside and bottom side PCB components
- Extra AC terminals allow for high power density increases like 750A/3.3kV SiC
- Future ready as the low inductance dual topology is SiC compatible

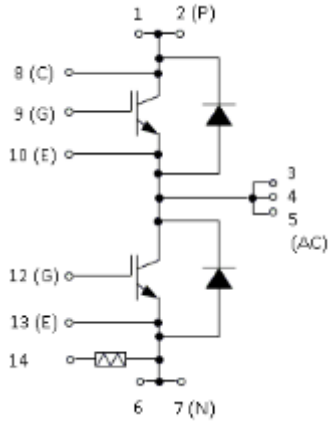


"Flow-Through" Terminal Arrangement

Easy connection to one gate driver, under parallel usage by terminal layout

3 AC terminals for lowering terminal temperature.
Allows for future higher RMS current implementation such as the 750A SiC Module





Low inductance
>10nH

Terminals raised to allow space for top/bottom side mounted PCB of Gate Driver

LV100/HV100 Silicon IGBT Module Line-Up

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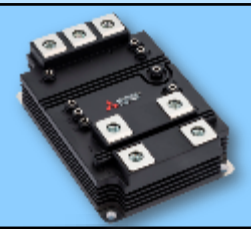
	Part Number	Voltage	Current	Package
Si module				
LV100 Industrial Viso=4KV	CM1200DW-24T	1200V	1200A	
	CM1800DW-24?	1200V	1800A (Under Development)	
	CM800DW-34T	1700V	800A	
	CM800DW-34TA	1700V	800A IGBT, 1200A FWDi	
	CM1200DW-34T	1700V	1200A	
	CM1200DW-40T	2000V	1200A	
	CM1200DW-50T	2500V	1200A (Under development)	
LV100 Viso=6KV (Traction Use)	CM1200DA-34X	1700V	1200A	
	CM450DA-66X	3300V	450A	
	CM600E1A-66X	3300V	600A (Chopper)	
	CM600DA-66X	3300V	600A	
HV100 Viso=10.2KV (Traction & Medium Voltage Drives)	CM450DE-66X	3300V	450A	
	CM600DE-66X	3300V	600A	
	CM450DE-90X	4500V	450A (Under Development)	
	CM300DE-130X	6500V	300A	

LV100 SiC MOSFET module Line-Up

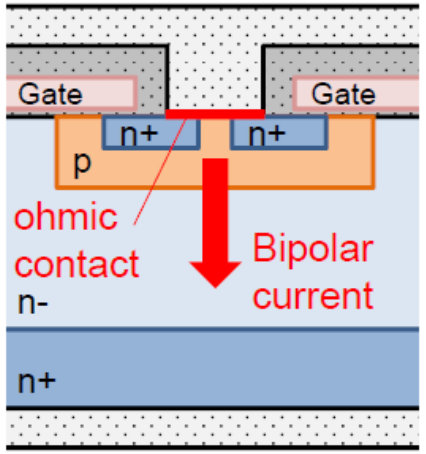
	Part Number	Voltage	Current	Package
SiC module				
SiC LV100 Viso=6KV	CMH1200DA-34X	1700V	1200A (Hybrid-Si IGBT+SiC Schottky)	
	CMH600DA-66X	3300V	600A (Hybrid-Si IGBT+SiC Schottky)	
	FMF185DC-66A	3300V	185A	
	FMF375DC-66A	3300V	375A	
	FMF750DC-66A	3300V	750A	
	FMF200DC-66BE*	3300V	200A (NEW)	
	FMF400DC-66BEW*	3300V	400A (NEW)	
	FMF800DC-66BEW*	3300V	800A (NEW)	

*** Unifull™** Embedded Schottky Technology

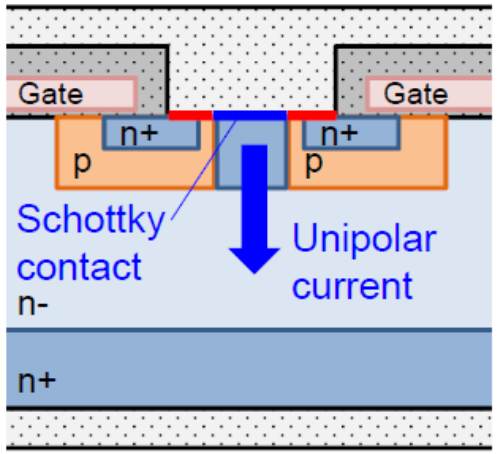
Advantages of **Unifull™** SBD-embedded MOSFETs

- ✓ Anytime unipolar current operation both in forward and reverse direction, leading to fast switching and reduced losses
- ✓ Free from bipolar degradation caused by body diode current
- ✓ Realizing SBD-free power modules, leading to smaller size and cost reduction

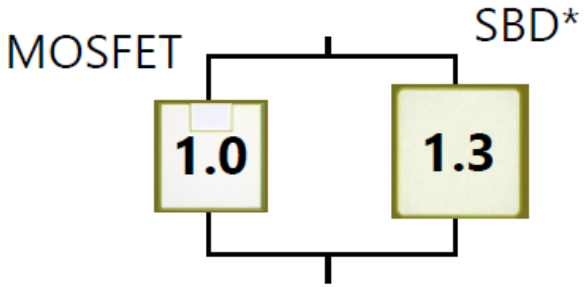
Conventional MOS structure



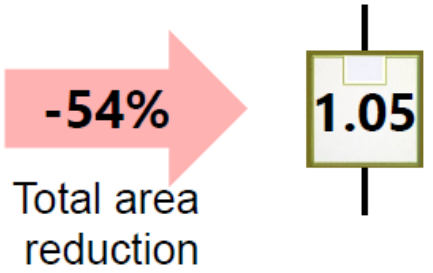
SBD-embedded MOS structure



SiC-MOSFET + external SiC-SBD (3.3kV)



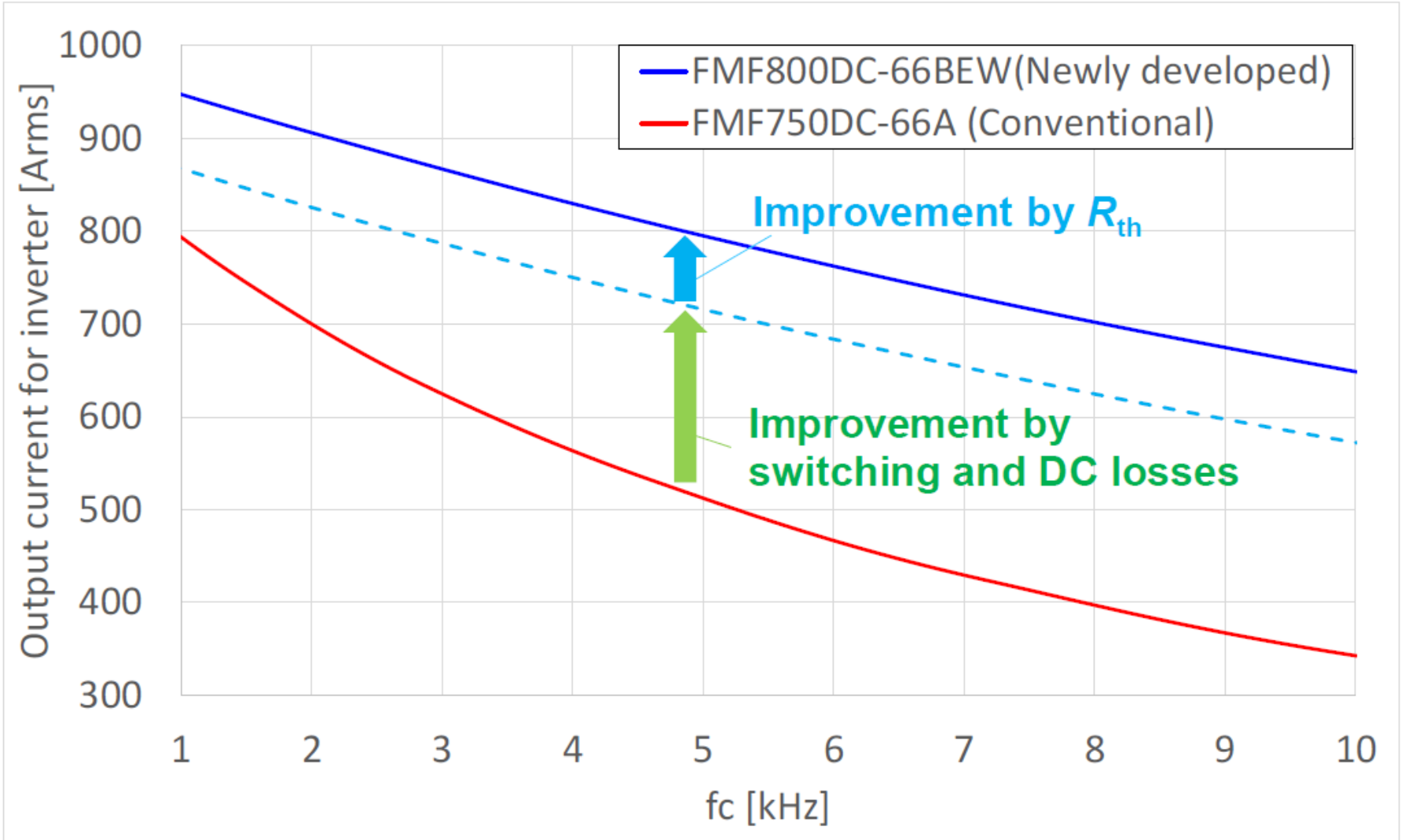
SBD-embedded SiC-MOSFET (3.3kV)



*SBD area is estimated with no bipolar current (body-diode current) under normal operations

Performance of Unifull™ SBD-embedded SiC-MOSFET

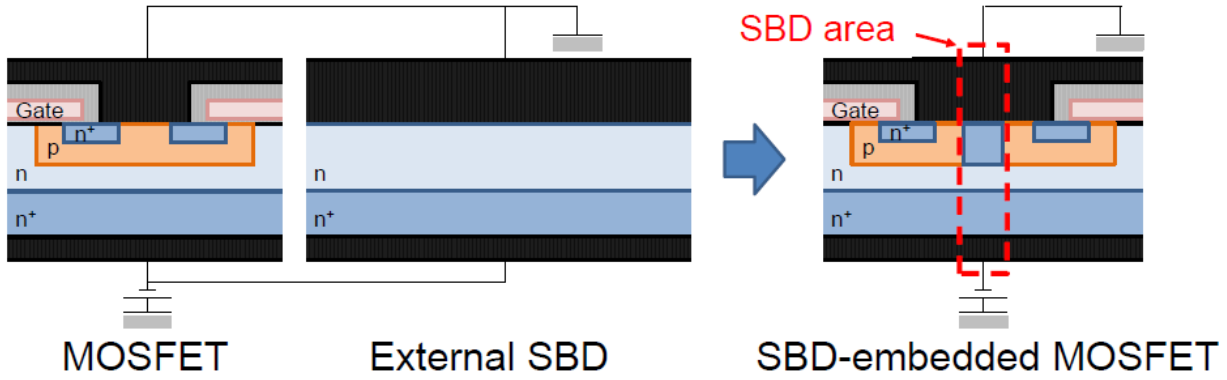
Condition: V_{DD}=1800V, Modulation raio=1, f_o=50Hz, P.F=0.85, T_s=80℃, T_{jave}=T_{jmax}

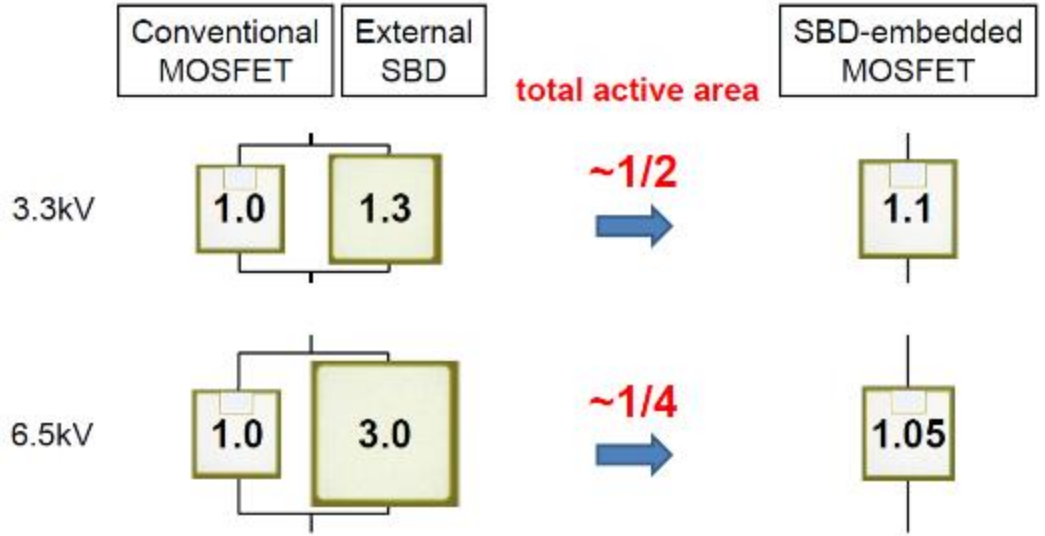


UnifulI™ Technology for 6.5 kV SiC MOSFETs

To remove large external SBD keeping body diode inactive

➡ Embedding SBD into each unit cell of MOSFET

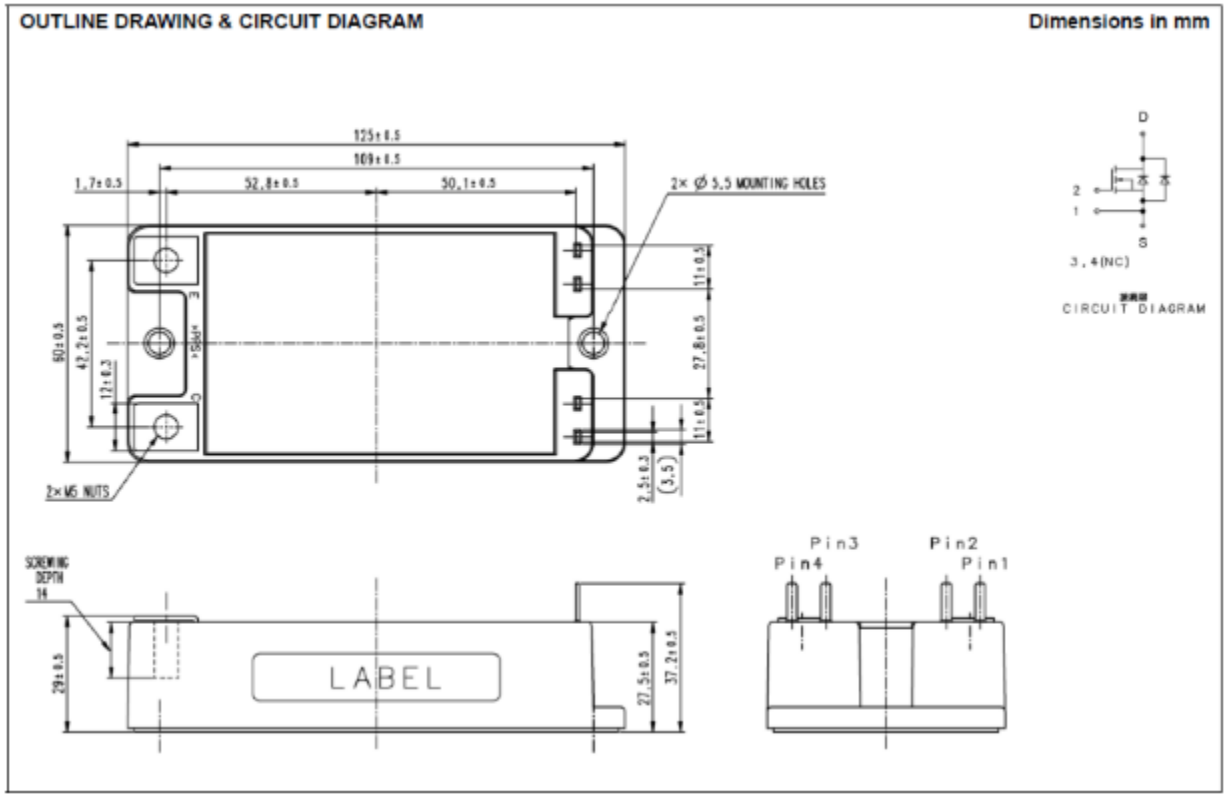




Reduction of chip area = Lower Cost

Market Study - 6.5kV, 25A SiC Module

Unifull™ Technology



Main Characteristics	
Type Number	FMF25HB-1340BE
Technology	SiC MOSFET Embeded Schottky Technology
Package	125mm X 60mm
Off-State Blocking Voltage	6500V
Nominal Current Rating	25A
On-State Forward Voltage 25A, 150C	6.3V
Reverse Voltage 600A, 150C	5.9V
Turn-On Switching Energy 1800V, 600A, 150C	37.5mJ
Turn-Off Switching Energy 1800V, 600A, 150C	25mJ
Reverse Recovery Energy 1800V, 600A, 150C	0.75mJ

Target application: EV charger direct from 4160VAC

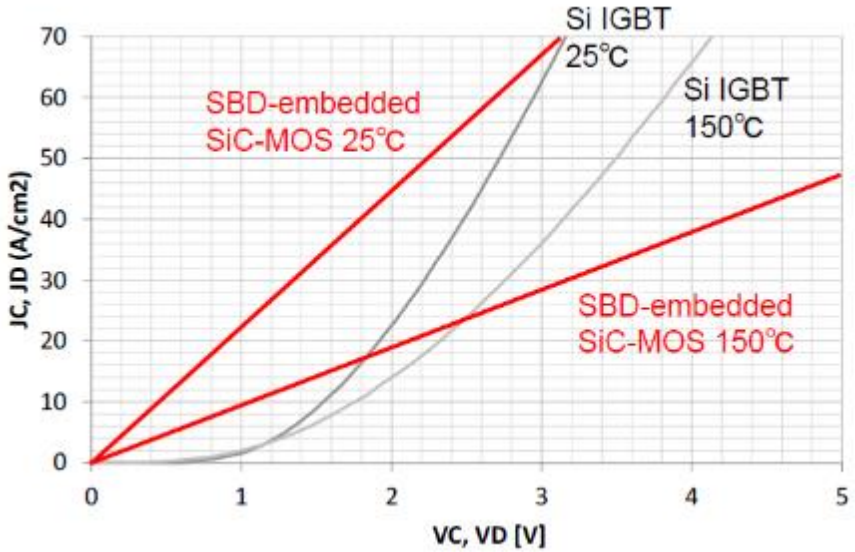
Under R&D*: 6.5kV Full SiC Power Module

Package:

- HV100 (2 in 1) module as the standardized package design
- Easy connection for both serial and/or parallel connections for the wide voltage and/or current range
- High flexibility and scalability for system configuration

SiC MOSFET Module Target Specifications:

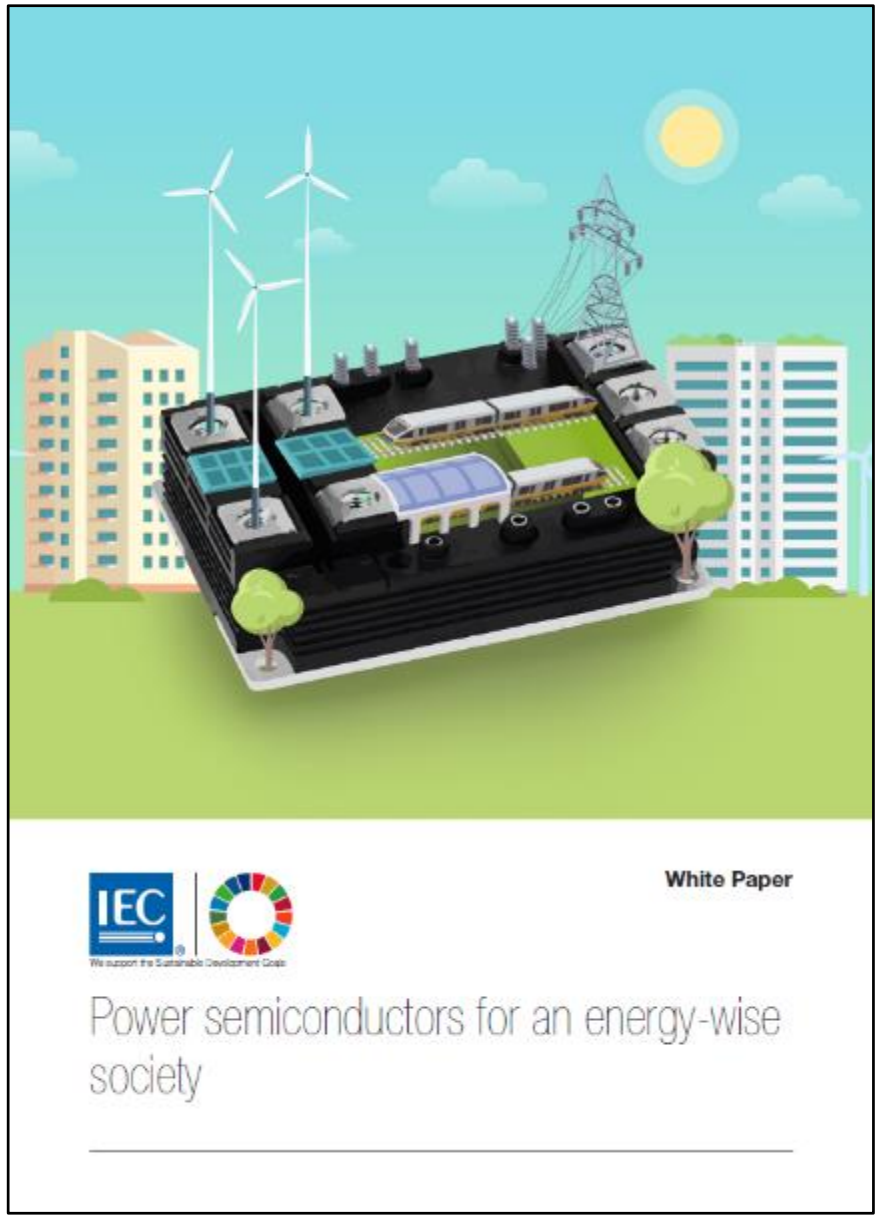
- 6.5kV SBD-embedded SiC-MOSFETs
- Vdd= 6.5 kV, Id = 400 A
- Tjmax= 175 ℃
- Low inductance
- Low thermal resistance
- High P/C and H/C endurances



SiC MOSFETs markedly reduce DC loss compered to Si IGBTs when forward current is low.

** Mass Production Release Not Set*

IEC White Paper: Power semiconductors for an energy-wise society



- To identify how power semiconductors contribute to demanding applications for an energy-wise society
- To examine the readiness and potential markets for WBG devices based on application-specific developments
- To evaluate at a high level the impact on energy, technologies, supply chains, policies and relevant standards;
- To provide an outline of how future standardization could be conducted with collaboration between power semiconductor device manufacturers and power electronics industry members.

Acknowledgments: *This white paper has been prepared by a project team of 61 members representing a variety of organizations, working under the IEC Market Strategy Board.*

Download Here:

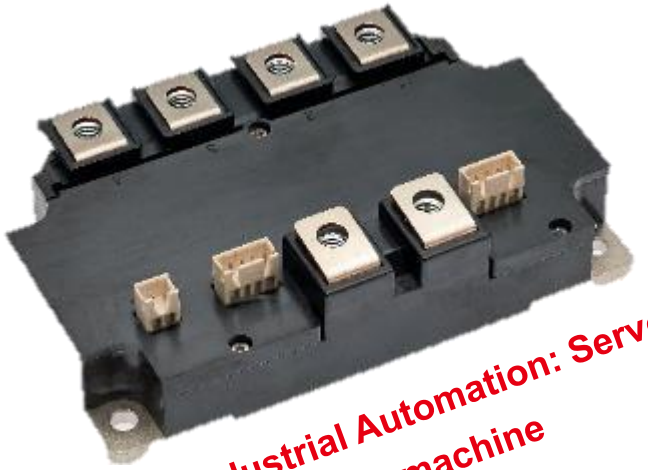
https://www.iec.ch/basecamp/power-semiconductors-energy-wise-society

Thank you for your attention….

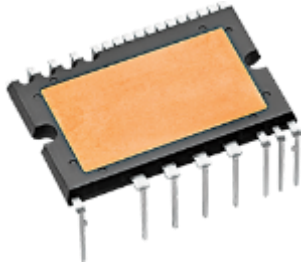
Traction: Subway, Locomotive, Grid-Tie Inverters

Industrial Power Supply, Motor Control

Medical Power Supply



Industrial Automation: Servo Drive, CNC machine



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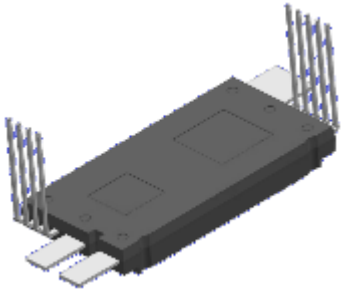

EV, HEV