Innovative Power Devices for a Sustainable Future

Traction, industrial equipment, building facilities, electric vehicles, renewable energies, home appliances...

Power devices are a key component in power electronics products for contributing to the realization of a low-carbon society. Attracting attention as the most energy-efficient power device is one made using new material, silicon-carbide (SiC). The material characteristics of SiC have led to a dramatic reduction in power loss and significant energy savings for power electronics devices. Mitsubishi Electric began the development of elemental SiC technologies in the early 1990s and has since introduced them to achieve practical energy-saving effects for products manufactured using SiC. Innovative SiC power modules are contributing to the realization of a low-carbon society and more affluent lifestyles.

*SiC: Silicon Carbide-Compound that fuses silicon and carbon at a ratio of one-to-one.

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Merits of Incorporating SiC Power Modules

- **Traction**
  - Size and weight of traction inverters reduced
  - Regenerative performance enhanced
  - Noise reduced

- **Home appliances**
  - Energy savings increased
  - Cooling system more compact
  - Equipment more compact/thinner

- **Industrial equipment**
  - High torque, high speed, size reduced
  - Cooling system more compact
  - Manufacturing productivity enhanced

- **Electric/Hybrid vehicles**
  - Power loss reduced
  - Regenerative power used efficiently

- **Renewable energies**
  - Energy conversion efficiency improved
  - Passive components downsized
  - Quieter high-speed operation

- **Building facilities**
  - Greater layout freedom as the result of smaller equipment

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Traction:
- PSF20L91A6-A
- PSF25S92F6
- PSF15S92F6
- PSH50YA2A6
- CMH600DU-24NFH
- CMH400DU-24NFH
- CMH200DU-24NFH
- CMH150DY-24NFH
- CMH100DY-24NFH
- FMF400BX-24A
- PMH200CS1D060
- BD20060S
- BD20060T

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** terminology**
- MOSFET: Metal Oxide Semiconductor Field Effect Transistor
- IGBT: Insulated Gate Bipolar Transistor
- SBD: Schottky Barrier Diode
- PSF: Power Semiconductor Field-effect Transistors
- CMH: Current-Mismatched Hybrid
- FMF: Fast-Matching Field-effect Transistors
- PMH: Power-Matched Hybrid

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**Diagrams and illustrations**
- Connection States
- Voltage [V]
- Current [A]
- Electric resistance
- Thermal conductivity
- Band gap
- Conduction band
- Valence band
- Junction Barrier Schottky
- Photovoltaics

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**Table of Ratings**
- **Current [A]**
  - 15
  - 20
  - 30
  - 40
  - 50
  - 60
  - 80
  - 100
  - 150
  - 200
  - 300
  - 400
  - 600

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**Graphs and Waveforms**
- Turn-on switching waveform
- Turn-off switching waveform
SiC with superior characteristics

**Power loss reduced**

SiC has approximately 10 times the critical breakdown strength of silicon. Furthermore, the drift layer that is a main cause of electrical resistance is one-tenth of the thickness. This allows a large reduction in electrical resistance and, in turn, reduces power loss. This SiC characteristic enables dramatic reductions in conductivity loss and switching loss in power devices.

**High-speed switching operation**

With SiC, owing to the high dielectric breakdown, power loss is reduced and high-voltage is easier to achieve, it is possible to use Schottky Barrier Diodes (SBDs), which cannot be used with Si. SBDs can realize high-speed switching motion because they don’t have accumulation carriers. As a result, high-speed switching can be realized.

**High-temperature operation**

When the temperature increases, electrons are exited to the conduction band and the leakage current increases. At times, this results in abnormal operation. However, SiC has three times the band gap width of silicon, preventing the flow of leakage current and enabling operation at high temperatures.

**Heat dissipation**

SiC has three times the heat conductivity of silicon, which improves heat dissipation.

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### SiC power modules appropriated by application

<table>
<thead>
<tr>
<th>Application</th>
<th>Product name</th>
<th>Model</th>
<th>Rating</th>
<th>Connection</th>
<th>States</th>
<th>Insert pages</th>
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<tbody>
<tr>
<td>Home appliances</td>
<td>SiC-SBD</td>
<td>BD20060T</td>
<td>600</td>
<td>-</td>
<td>Sample available</td>
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<tr>
<td></td>
<td>Full SiC-IPM</td>
<td>PMF1200C1T1000</td>
<td>600</td>
<td>6 in 1</td>
<td>Commerially available</td>
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<td></td>
<td>Full SiC Power Modules</td>
<td>PMF755C1T120</td>
<td>75</td>
<td>6 in 1</td>
<td>Sample available</td>
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<td></td>
<td>Hybrid SiC Power Modules for High-frequency Switching Applications</td>
<td>FMF8000X-24A</td>
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<td></td>
<td>Large Hybrid SiC DIPPC™ for PV Application</td>
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<td>Commerially available</td>
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<td>Traction</td>
<td>Hybrid SiC Power Modules</td>
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<td></td>
<td>Super-mini Full SiC DIPPC™</td>
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<td></td>
<td>Super-mini Full SiC DIPPC™</td>
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### Terminology

- **SiC** — Silicon Carbide
- **IPM** — Intelligent Power Module
- **DIPPM™** — Dual-In-Line Package Intelligent Power Module
- **DIPPC™** — Dual-In-Line Package Power Factor Correction
- **SBD** — Schottky Barrier Diode
- **MOSFET** — Metal Oxide Semiconductor Field Effect Transistor
- **IGBT** — Insulated Gate Bipolar Transistor
- **Tr** — Transistor
- **FW-SW** — Freewheeling switching loss
- **FW-DC** — Freewheeling DC loss
- **Tr-SW** — Transistor switching loss
- **Tr-DC** — Transistor DC loss
- **IGBT-SW** — IGBT switching loss
- **IGBT-DC** — IGBT DC loss
- **PV** — Photovoltaics
- **CSTBT™** — Mitsubishi Electric’s unique IGBT that makes use of the carrier cumulative effect
- **JBS** — Junction Barrier Schottky
Contribute to reducing power loss and the size of power supply systems for home appliances and industrial equipment

**Features**
- Power loss is reduced by approx. 21% compared to silicon (Si) products, contributing to energy conversion.
- The SiC-SBD allows high frequency switching and contributes to downsizing the reactor, heat sink and other peripheral components.
- JBS structure allows high forward surge capability and contributes to improving reliability.

**Inner circuit**

![Inner circuit diagram](image)

**Power loss comparison**

![Power loss comparison graph](image)

**SiC-SBD incorporated in an IPM with a built-in drive circuit and protection functions**

**Power loss reduction of approx. 20% contributes to enhancing the performance of industrial machinery**

**Features**
- Hybrid combination of SiC-SBD and IGBT with current and temperature sensors implemented for IPM supplies high functionality and low loss enabling high torque and motor speed.
- Recovery loss (Err) reduced by 95% compared to the conventional product*
- Package compatible with the conventional product* making replacement possible.

*Conventional product: Mitsubishi Electric S1 Series PM200SC1D060

**Internal circuit diagram**

![Internal circuit diagram](image)

**Power loss comparison**

![Power loss comparison graph](image)
Built-in drive circuit and protection functions realize high functionality

**Features**
- Incorporates SiC-MOSFET with current sensor and built-in drive circuit and protection functions to deliver high functionality.
- Significant reduction in power loss compared to the conventional product*.
- Package compatible with the conventional product*.

* Conventional product: Mitsubishi Electric IPM L1 Series PM75CL1A120

<table>
<thead>
<tr>
<th>Main specifications</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rating</td>
</tr>
<tr>
<td>Mounted Functions</td>
</tr>
</tbody>
</table>

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**Power loss comparison**

Condition: Vcc=600V, Io=31Arms (assuming a 15kW inverter), fc=15kHz, P.F=0.9, Modulation=1, Three-phase modulation, Tj=125˚C

- Si-IPM: Approx. 25% reduction
- Hybrid SiC-IPM: Approx. 70% reduction
- Full SiC-IPM: Approx. 70% reduction

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1200V/400A • 1200V/800A Full SiC Power Modules for Industrial Equipment

FMF400BX-24A/FMF800DX-24A Commercially available

Contributes to reducing size/weight of industrial-use inverters with the mounting area reduced by approx. 60%

**Features**
- Power loss reduced approx. 70% compared to the conventional product*.
- Low-inductance package adopted to deliver full SiC performance.
- Contributes to realizing smaller/lighter inverter equipment by significantly reducing the package size and realizing a mounting area approx. 60% smaller compared to the conventional product*.

* Conventional product: Mitsubishi Electric CM400DY-24NF(1200V/400A 2in1) 2pcs

<table>
<thead>
<tr>
<th>Product lineup</th>
</tr>
</thead>
<tbody>
<tr>
<td>Applications</td>
</tr>
<tr>
<td>Industrial equipment</td>
</tr>
<tr>
<td>800A</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Comparison with conventional product package</th>
</tr>
</thead>
<tbody>
<tr>
<td>Si power module 1200V/400A(2-in-1) 2pcs</td>
</tr>
<tr>
<td>Full SiC power module 1200V/400A(4-in-1) 1pcs or 1200V/800A(2-in-1) 1pcs</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Power loss comparison</th>
</tr>
</thead>
<tbody>
<tr>
<td>Condition: Vcc=600V, Io=222Arms (assuming a 110kW inverter), fc=15kHz, P.F=0.8, Modulation=1, Three-phase modulation, Tj=125˚C</td>
</tr>
<tr>
<td>IGBT module(Si): Approx. 70% reduction</td>
</tr>
<tr>
<td>Full SiC module: Approx. 70% reduction</td>
</tr>
</tbody>
</table>
Commercially available

For optimal operation of power electronics devices that conduct high-frequency switching

**Features**
- Power loss reduction of approx. 40% contributes to higher efficiency, smaller size and weight reduction of total system
- Suppresses surge voltage by reducing internal inductance
- Package compatible with the conventional product
- Conventional product: Mitsubishi Electric Large DIPIPM

**Product lineup**

<table>
<thead>
<tr>
<th>Applications</th>
<th>Model</th>
<th>Rated voltage</th>
<th>Rated current</th>
<th>Thermal configuration</th>
<th>External size (L x W)</th>
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<tbody>
<tr>
<td>Industrial equipment</td>
<td>CMH1000DY-24NFH</td>
<td>100A</td>
<td>48 x 94mm</td>
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<td></td>
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<tr>
<td></td>
<td>CMH1500DY-24NFH</td>
<td>150A</td>
<td>48 x 94mm</td>
<td></td>
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<tr>
<td></td>
<td>CMH2000DU-24NFH</td>
<td>200A</td>
<td>62 x 108mm</td>
<td></td>
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<td></td>
<td>CMH3000DU-24NFH</td>
<td>300A</td>
<td>62 x 108mm</td>
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<td></td>
<td>CMH4000DU-24NFH</td>
<td>400A</td>
<td>80 x 110mm</td>
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<td></td>
<td>CMH6000DU-24NFH</td>
<td>600A</td>
<td>80 x 110mm</td>
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</tr>
</tbody>
</table>

**Recovery waveform (FWD)**

**Power loss comparison**

Condition: Vcc=600V, Io=600Arms, fc=15kHz, P.F=0.8, Modulation=1, Three-phase modulation, Tj=125˚C

Approx. 40% reduction

More efficient power modules for PV power conditioner applications

**Features**
- Hybrid structure achieved with SiC Schottky barrier diode and 7th-generation IGBT chips
- Power loss reduction of approx. 25% compared to the conventional product
- Helps downsize PV inverter system thanks to modified short-circuit protection scheme

*Conventional product: Mitsubishi Electric Large DIPIPM™ PS61A99

**600V/50A Large Hybrid SiC DIPIPM™ for PV Applications**

PSH50YA2A6 Commercially available

**Internal circuit diagram**

**Power loss comparison**

Condition: Vcc=300V, Io=25Arms, P.F=0.8, fc=10kHz, Tj=125˚C

Approx. 25% reduction
1700V/1200A Hybrid SiC Power Modules for Traction Inverters
CMH1200DC-34S (Commercially available)

High-power/low-loss/highly reliable modules appropriate for use in traction inverters

- **Features**
  - Power loss reduced approximately 30% compared to the conventional product*
  - Highly reliable design appropriate for use in traction
  - Package compatible with the conventional product*

* Conventional product: Mitsubishi Electric Large DIPIPM™ NFH Series IGBT Modules

- **Main specifications**

<table>
<thead>
<tr>
<th>Module</th>
<th>Max. operating temperature</th>
<th>Isolation voltage</th>
<th>Si-IGBT @ 150˚C</th>
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<tbody>
<tr>
<td></td>
<td>150˚C</td>
<td>4000Vrms</td>
<td>Collector-emitter saturation voltage 2.2V</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td>Switching loss 850V/1200V turn-on 144mJ</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td>turn-off 590μJ</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Emitter-collector voltage 2.3V</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Capacitive charge 9.0μC</td>
</tr>
</tbody>
</table>

- **Internal circuit diagram**

- **Power loss comparison**

Contributes to extremely high power-efficiency in air conditioners, and easily applicable to industrial equipment

- **Features**
  - SiC-MOSFET achieves reduction in ON resistance, power loss reduced approx. 70% compared to conventional product*
  - Construct low-noise system by reducing recovery current
  - Numerous built-in functions: Bootstrap diode for power supply to drive P-side, temperature information output, etc.
  - Unnecessary minus-bias gate drive circuit using original high Vth SiC-MOSFET technology
  - As package and pin layout compatibility with conventional products* is ensured, simply replace this product to improve performance

*Conventional product: Mitsubishi Electric Super-mini DIPIPM™ Series

- **Internal block diagram**

- **Power loss comparison**
Utilizing SiC enables high-frequency switching and contributes to reducing the size of peripheral components.

- **Features**
  - Incorporating SiC chip in the Super-mini package widely used in home appliances
  - The SiC chip allows high-frequency switching (up to 40kHz) and contributes to downsizing the reactor, heat sink and other peripheral components
  - Adopts the same package as the Super mini DIPIP™ to eliminate the need for a spacer between the inverter and heat sink, and to facilitate its implementation

- **Internal block diagram (Full SiC DIPPFC™)**

- **Power loss comparison**

- **Interleaved PFC circuit configuration (for Hybrid SiC DIPPFC™)**

- **Merits of combined use of SiC DIPIP™ and DIPPFC™**
  - No need to use spacer for adjusting height when attaching heat sink
  - Integration of PFC circuit and drive IC made it possible to reduce the mounting area and make components more compact such as simplifying the wiring pattern
### SiC Power Module Lineup

#### 600V/200A Hybrid SiC-IPM for Industrial Use
PMH200CS1D060

#### 1200V/75A Hybrid/Full SiC-IPM for Industrial Equipment
PMH75CL1A120/PMF75CL1A120
600V/75A Full SiC-IPM for PV Applications
PMF75B4L1A060

#### 1200V/400A, 1200V/800A Full SiC Power Modules for Industrial Use
FMF400BX-24A
FMF800DX-24A

#### Hybrid SiC Power Modules for High-frequency Switching Applications
- CMH100DY-24NFH
- CMH150DY-24NFH

#### Hybrid SiC Power Modules for High-frequency Switching Applications
- CMH 200DU-24NFH
- CMH 300DU-24NFH

#### Hybrid SiC Power Modules for High-frequency Switching Applications
- CMH 400DU-24NFH
- CMH 800DU-24NFH

#### 600V/50A Large Hybrid SiC DIPIP™ for PV Applications
PSH50YA2A6

#### 1700V/1200A Hybrid SiC Power Modules for Traction Inverters
CMH1200DC-34S

#### SiC-SBD for power supply systems
BD20060T
BD20060S
Development of Mitsubishi Electric SiC Power Devices and Power Electronics Equipment Incorporating Them

Mitsubishi Electric began developing SiC as a new material in the early 1990s. Pursuing special characteristics, we succeeded in developing various elemental technologies.

In 2010, we commercialized the first air conditioner in the world equipped with a SiC power device. Furthermore, substantial energy-saving effects have been achieved for traction and FA machinery.

We will continue to provide competitive SiC power modules with advanced development and achievements from now on.

Development of these modules and applications has been partially supported by Japan's Ministry of Economy, Trade and Industry (METI) and New Energy and Industrial Technology Development Organization (NEDO).
2014
February 2014
Developed EV motor drive system with built-in SiC inverter*2

May 2014
Began shipping samples of hybrid SiC power modules for high-frequency switching applications

November 2014
Launched Large Hybrid SiC DIPIPMTM for PV Applications

2015
January 2015
Launched power conditioner for PV equipped with full SiC-IPM

June 2015
Railcar traction system with full SiC power modules installed in Shinkansen bullet trains

2016
February 2013
Developed SiC for application in elevator control systems*2

February 2013
Developed technologies to increase capacities of SiC power modules*2

May 2013
Launched SiC power modules

December 2013
Launched railcar traction inverter with full SiC power module

March 2013
Delivered auxiliary power supply systems for railcars

2017
March 2017
Launched SiC-SBD

March 2017
Develops World’s smallest SiC Inverter for HEVs.

2013
February 2013
Developed SiC for application in elevator control systems*2

March 2013
Delivered auxiliary power supply systems for railcars

May 2013
Launched SiC power modules

December 2013
Launched railcar traction inverter with full SiC power module

*1 Researched in press releases by Mitsubishi Electric. *2 Currently under development, as of April 2017.
* The year and month listed are based on press releases or information released during the product launch month in Japan.

Contribution to the realization of a low-carbon society and more affluent lifestyles
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