Power Devices Business Briefing

— Providing crucial energy-saving devices as a global top-level power devices manufacturer —

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In charge of Semiconductor & Device

MITSUBISHI ELECTRIC CORPORATION
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1. Introduction

Embodiment of the Corporate Mission

Corporate Mission
The Mitsubishi Electric Group will continually improve its technologies and services by applying creativity to all aspects of its business. By doing so, we enhance the quality of life in our society.

【Contemporary Social Issues】
- Environmental issues
- Resource/Energy issues

【Initiatives of Mitsubishi Electric Group】
- Global Development of Products, Systems, and Services
- Make Strong Businesses Stronger
- Technology Synergies/Business Synergies
- Realize a Sustainable Society
- Provide Safety, Security, and Comfort

【Embodiment of the Corporate Mission in the Context of the Current Environment】
- Growth Targets to be Achieved by FY2020
  Net Sales 5 trillion yen or more
  OPM 8% or more
- "Global, Leading Green Company"
  Contribute to the realization of a prosperous society
1. Introduction

Embodiment of the Power device Business Mission

Corporate Mission

The Mitsubishi Electric Group will continually improve its technologies and services by applying creativity to all aspects of its business. By doing so, we enhance the quality of life in our society.

【Contemporary Social Issues】

Environmental issues
Resource/ Energy issues

【Initiatives of Mitsubishi Electric Group】

Global Development of Products, Systems, and Services
Make Strong Businesses Stronger
Technology Synergies/ Business Synergies

Realize a Sustainable Society
Provide Safety, Security, and Comfort

【Embodiment of the Corporate Mission in the Context of the Current Environment】

Growth Targets to be Achieved by FY2022
Net Sales 200 billion yen
OPM 10%

“Global, Leading Green Company” Contribute to the realization of a prosperous society
2. Positioning and Features of Business

Power devices are crucial for low-carbon societies

➢ Semiconductor devices that efficiently control electric power by converting electricity from DC to AC, DC to AC, or by raising or lowering voltage
➢ Key energy saving devices used in a wide range of sectors including power control for industrial machinery, traction, electric vehicles (EV\*), home appliances, photovoltaic power generation, wind power generation, motor control, and more.

* EV: Electric Vehicle
2. Positioning and Features of Business

Positioned as a business to drive corporate growth

- **Energy & Electric Systems**
  - **Power Systems**
    - Power generation systems,
      Transmission & distribution systems,
      Power distribution systems,
      Particle therapy systems, etc.
  - **Transportation Systems**
    - Inverters, main motors and
      air conditioning systems for railcars,
      Train Vision, Train control and
      management systems,
      Railcar operation management systems,
      Signaling systems, etc.
  - **Building Systems**
    - Elevators, Escalators,
      Building management systems, etc.
  - **Public Systems**
    - Water treatment systems,
      Disaster prevention systems, etc.
- **Industrial Automation Systems**
  - **Factory Automation (FA) Systems**
    - PLCs, AC servomotors,
      CNCs, Industrial robots,
      Laser processing machines, etc.
  - **Automotive Equipment**
    - Starters, Alternators, Car multimedia,
      EPS system products,
      Electric powertrain system, etc.
- **Transportation Systems**
  - **Inverters**, main motors and
    air conditioning systems for railcars,
    Train Vision, Train control and
    management systems,
    Railcar operation management systems,
    Signaling systems, etc.
- **Building Systems**
  - Elevators, Escalators,
    Building management systems, etc.
- **Public Systems**
  - Water treatment systems,
    Disaster prevention systems, etc.
- **Information & Communication Systems**
  - **Space Systems**
    - Satellites, Ground systems for
      satellite control, etc.
  - **Defense Systems**
    - Radar equipment, Antennas, etc.
  - **Communication Systems**
    - Optical, wireless and satellite
      communications systems, etc.
  - **Video Monitoring Systems**
    - Network camera systems
  - **IT Solution**
  - **Electronic Devices**
    - **SiC** modules, IGBT modules, etc.
    - High Frequency and
      Optical Devices
      High frequency devices (GaN and
      GaAs), Optical devices, etc.
  - **TFT** LCD Modules
- **Home Appliances**
- **Air-Conditioning & Refrigeration Systems**
  - Room and package air conditioners,
    Multiple AC units for buildings, Lossnay
    ventilation systems, Chillers, etc.
  - **Housing Equipment**
    - Smart appliances, Lighting, HEMS, etc.
  - **Kitchen and Other Household Appliances**

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1. **SiC**: Silicon carbide  
2. **IGBT**: Insulated gate bipolar transistor  
3. **GaN**: Gallium nitride  
4. **GaAs**: Gallium arsenide  
5. **TFT**: Thin film transistor

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2. Positioning and Features of Business

Strengths are in-house business and technology synergies, and global innovation

Mitsubishi Electric

Business segments

- Industrial Automation Systems
- Energy & Electric Systems
- Home Appliances

Electronic devices (power devices)

Technology/business synergies (make strong businesses even stronger)

Open & global innovation

- Advanced Technology R&D Center
- Information Technology R&D Center

Government & foundations (national projects)
Standardizing body forums, etc.
Universities
Companies
Research-related independent administrative agencies (AIST, etc.)
2. Positioning and Features of Business

Our Focus: IGBTs and Modules

IGBT and MOSFET*

Application range for power devices

Device output capacity [VA]

Switching frequency [Hz]

100M
10M
1M
100k
10k
1k
100

IGBT
MOSFET

IGBT module

Compound power devices with multiple IGBTs and diodes in a single package

Discrete

IGBT
Diode

* MOSFET: Metal oxide semiconductor field effect transistor
2. Positioning and Features of Business

Focus on maintaining world’s top share\(^1\) in IPM\(^2\)

- **Control IC**
  - Drive circuit
  - Short-circuit-monitoring Protection circuit

- **IGBT module**

- **Package**
  - Case type

- **IPM**
  - Drive circuit
  - Short-circuit-monitoring Protection circuit

- **Package**
  - Case type
  - DIP type (Dual In-line Package)

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1 As of November 2017, surveyed by Mitsubishi Electric  
2 IPM: Intelligent power module
2. Positioning and Features of Business

Focused on Four Segments: Meeting Diverse Needs

<table>
<thead>
<tr>
<th>Application segment</th>
<th>Application examples</th>
<th>IGBT module</th>
<th>IPM</th>
<th>Discrete</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Case type</td>
<td></td>
<td>DIP type</td>
</tr>
<tr>
<td></td>
<td></td>
<td>General</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>HV¹</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

- **Home appliances**
  - Air conditioners
  - Washing machines
  - Refrigerators
  - Fan motors

- **Industry (Incl. renewable energy)**
  - AC motors
  - Inverters
  - Photovoltaic power generation
  - Power conditioner
  - Robots
  - Wind power generation

- **Traction/Electric power**
  - Traction
  - DC power transmission

- **Automotive**
  - EV・HEV

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1. HV: High voltage
2. HEV: Hybrid electric vehicle

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### Background of power devices market expansion

**Home appliances:** Growth due to expansion of market for major appliances (air conditioners, refrigerators, washing machines, etc.) and progress in shift to inverters.

**Automotive:** High growth due to accelerated shift to EVs due to more stringent environmental regulations.

**Industry:** Expansion, mainly in FA market, due to investment in factory automation, power efficiency improvements, and strengthened environmental regulations for motors (incl. renewable energy). Growth will accompany expansion of renewable energy (solar and wind) markets around the world.

**Traction/Electric power:** Moderate growth in electric railway rolling stock market in line with population growth, urbanization, etc.

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**Annual market growth rate of about 6%**

Global market scale by IGBT module segment

(Mitsubishi Electric estimate)

- **Traction /Electric power**
- **Industry** (incl. renewable energy)
- **Automobile**
- **Home appliances**

<table>
<thead>
<tr>
<th>Year</th>
<th>FY2016</th>
<th>FY2017</th>
<th>FY2018</th>
<th>FY2019</th>
<th>FY2020</th>
<th>FY2021</th>
<th>FY2022</th>
</tr>
</thead>
<tbody>
<tr>
<td>(US$ million)</td>
<td>3,000</td>
<td>3,500</td>
<td>4,000</td>
<td>4,500</td>
<td>5,000</td>
<td>5,500</td>
<td>6,000</td>
</tr>
</tbody>
</table>

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4. Growth Targets

**FY2022: Net sales of 200 billion yen and OPM of 10%**

**Growth strategy: 10% growth in focus segments (exceed market growth of 6%)**

- **Home appliances:** Enhance product lineup balanced with market demands (higher functionality, lower power loss, and lower costs), aiming to become the undisputed market leader
- **Automotive:** Capture opportunities in the shift to electric-power automobiles and grow strongly worldwide
- **Industry (incl. renewable energy):** Introduce competitive products to increase share in major markets for power device business
- **Traction/Electric power:** Pursue greater added value in infrastructure segment where growth is not high but demands for quality and reliability are high, to maintain the position as a top supplier

**Power devices business sales targets**

- **FY2016:** 130 billion yen
- **FY2017:** 200 billion yen
- **FY2022:** 200 billion yen

Annual growth rate of 10% (annual market growth rate of about 6%)
5. Differentiation Strategy

Developing high-efficiency power devices (chip)s and packages that match market needs are inseparable for differentiation.

**Power capacity**
- Large: Traction/DC power transmission
- SiC

**Carrier frequency**
- Low: Si*
- SiC
- EV, etc.
- Switching power source, etc.
- High: SiC

**Si**: Balance performance and cost
- Low power loss
- Wide application range
- High reliability

**SiC**: High performance for value-added applications
- Lower power loss (70% less than Si)
- High-frequency switching (100kHz class)
- High temp. operation (200 °C class)

**High performance**
- Miniaturization
- High-current-density packages
- High-heat-dissipation substrates

**Longer life**
- Low-stress structure at heat cycle
- Low-thermal-resistance materials (bonding materials & encapsulants)

**Higher functionality**
- Integrated radiators
- Incorporation of peripheral circuits

**Home appliances**
- Smaller packages
- Less peripheral circuits
- Lower losses for energy savings

**Industry / Renewable energy**
- Easy installation
- Industry-standard package
- Incorporation of peripheral functions

**Automotive**
- Miniaturization & High power density
- Incorporation of cooling functions
- Operation in high-temp environments

**Traction / Electric power**
- Large current
- High reliability
- Industry-standard packages

**5. Differentiation Strategy**

Developing high-efficiency power devices (chip)s and packages that match market needs are inseparable for differentiation.
5. Differentiation Strategy: Si IGBT chips

Evolution of Si IGBT chips

IGBT chip (1200V industrial use)
6th generation

7th generation

Next generation

Optimization of structure
Make ultra-thin
(Ultra-thin device
(higher performance
& easier to use)

Combine IGBT and diode onto one chip to improve manufacturability and module power density
(Merge functions)

RC-IGBT*

Make ultra-thin
(Ultra-thin device
(higher performance
& easier to use)

Next-generation RC-IGBT

* RC-IGBT: Reverse conducting-IGBT
5. Differentiation Strategy: SiC

Become No.1 in many SiC applications¹

➢ Pursue advanced achievements through synergy among strong power electronics business units within company
➢ Introduce SiC power modules from the start, applying SiC to product groups for all applications

- **Traction**
  - Installs Railcar Traction System with All-SiC Power Modules on Shinkansen Bullet Trains (Announced in June 2015)
  - Commercialized SiC inverter for use in railcars (October 2011)

- **Industry**
  - Launched Computer numerical control (CNC) drive unit equipped with SiC power module (Released in December 2012)
  - Develops SiC for application in elevator control systems (Announced in February 2013)

- **Automotive**
  - Under Development
  - Develops world’s smallest SiC Inverter for HEVs (Announced in March 2017)
  - Equipped for first time in industry

- **Home Appliances**
  - Equipped for first time in industry
  - Launched “Kirigamine” inverter air conditioner (Released in October 2010)
  - Launched package air conditioners with full SiC DIPIPM² in Japan (Released in May 2016)

- **Energy**
  - Verified highest power conversion efficiency for photovoltaic power conditioner (domestic industry) (Announced in January 2011)
  - Launched power conditioner for photovoltaic equipped with full SiC-IPM (Released in January 2015)

¹ The year and month listed are based on press releases or information released during the product launch month in Japan.
² DIPIPM: Registered trademark of Mitsubishi Electric Corporation

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).
5. Differentiation Strategy: SiC chips

Continuous development of SiC to lower costs and improve performance

Features of SiC chips

<table>
<thead>
<tr>
<th>Item</th>
<th>Si</th>
<th>SiC</th>
<th>Customer benefits</th>
<th>Combined uses</th>
</tr>
</thead>
<tbody>
<tr>
<td>Power loss</td>
<td>1</td>
<td>1/3</td>
<td>High efficiency, higher output and energy savings</td>
<td>EVs, air conditioner, railways, and DC power transmission</td>
</tr>
<tr>
<td>High temp. operation</td>
<td>175℃</td>
<td>Tj&gt;200℃</td>
<td>Reduced heat-dissipation fins</td>
<td>EVs and special inverters</td>
</tr>
<tr>
<td>High-speed switch</td>
<td>30KHz</td>
<td>Fc&gt;100KHz</td>
<td>High efficiency and smaller size</td>
<td>Power sources and non-contact power supply</td>
</tr>
</tbody>
</table>

Advancement of SiC chips

➢ Trench MOSFET ⇒ Smaller size/Low loss/High reliability

- Gate placed on wall of trench formed downward and cell density improved/refined with aim of lowest loss in the industry
- Original field alleviating structure employed to improve reliability

➢ MOSFET with built-in SBD* ⇒ Smaller size/Low cost

- Mitsubishi Electric original technology where chip is miniaturized by building SBD in to MOS Effective especially for high-voltage devices and has approx. 60% surface area for 3.3kV

Forward-looking R&D is pursuing new-material power devices, such as vertical GaN and gallium oxide, in addition to SiC-IGBT (current MOSFET)

MOSFET structure comparison

* SBD: Schottky barrier diode

**Our strengths and features**

- **DIPIPIM utilizing transfer mold technology**
- **High-quality and diverse product lineup**
- **Application technology and customer support capability for top share in segment**
- **World's top production capacity and stable supply support capabilities**

**Growth strategy**

Enhance product lineup balanced with market demands (higher functionality, lower power loss, and lower costs) with the goal of being the undisputed market leader.

- Capture more share where inverter use is expected to grow:
  - Washing machines
    - (2017: 19% → 2022: 62%)
  - Refrigerators
    - (2017: 18% → 2022: 40%)
  - Lower costs

- Enter small-capacity fan-motor market
  - Lower costs

- For existing RAC/PAC*, gradually develop new markets in developing economies where switch to inverters is progressing (roughly double from 2017 to 2022)
  - Lower costs

- Introduce SiC products in luxury device market
  - Energy savings and higher functionality

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*RAC: Room air conditioner, PAC: Package air conditioner*

Product strategy

➢ Higher functionality: More products equipped with SiC and reduce loss
➢ Lower costs: Apply RC-IGBT chips and low-cost packages

**Luxury room air conditioners**
- Full SiC DIPIPM
- Hybrid SiC DIPIPM
- SJMOS¹ equipped ultracompact DIPIPM
- Ultracompact DIPIPM

**Mainstream room air conditioners**
- RC-IGBT equipped SLIMDIP²

**Washing machines & Refrigerators**
- RC-IGBT equipped Small-capacity IPM

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1 SJMOS: Super Junction MOSFET 2 SLIMDIP: Registered trademark of Mitsubishi Electric Corporation

Our strengths and features

- Ability to offer diverse solutions according to customer demands (chips & modules)
- High quality, strong technical application
- Support, and customer-support abilities
- Abundant know-how and good market performance from start of EV market

Cumulative xEV* equipped with our power devices

Growth strategy
Capture opportunities in shift to electric-power automobiles and grow strongly worldwide

- Shift focus from Japan to overseas markets
- Shift development and delivery from customized to standardized products
- Deploy standardized modules (J/J1 series) globally
- Raise chip performance
  - Si: Raise IGBT and RC-IGBT performance
  - SiC: Shift to 6-inch and trench type

* xEV: General term for electric vehicles

Abundant know-how and good market performance from start of EV market

Standard module product strategy
➢ Expand product lineup according to market demands (high voltage, large current)

<table>
<thead>
<tr>
<th>Motor capacity [kW]</th>
<th>10</th>
<th>20</th>
<th>30</th>
<th>40</th>
<th>50</th>
<th>60</th>
<th>70</th>
<th>80</th>
<th>90～150</th>
</tr>
</thead>
<tbody>
<tr>
<td>Target xEV models</td>
<td>ULV²</td>
<td>Mild Hybrid (except 48V)</td>
<td>PHEV³</td>
<td>BEV⁴ / FCEV⁵</td>
<td>Full Hybrid</td>
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</table>

Advantages of J1 series
- Compact (footprint approx. 30% smaller than other makes)
- Light weight (approx. 30% lighter than other makes)
- High heat dissipation
- High efficiency

For small-capacity (J series) 1200V
For medium-capacity (J1A series)
For large-capacity (J1B series)

Further performance increase with SiC-equipped products

1 As of November 2017: Mitsubishi Electric  2 Ultra-light vehicles  3 Plug-in hybrid electric vehicles  4 Electric vehicles  5 Fuel-cell electric vehicle

Know-how accumulated serving Japanese users over many decades and market performance

Our strengths and features

Products offering competitive advantages based on 7th generation chips and new package technologies

High quality, strong technical application support and customer support abilities

Growth strategy

Increase share in major markets for power devices business with competitive products

➢ Focus on business in European and Chinese markets while maintaining high market share in Japan
➢ Focus on energy storage, charging, and EV buses as new markets
➢ Increased strategic original packages in addition to industrial-standard packages
➢ Increased intelligent products (for IoT*)
➢ Develop products and synergies with Vincotech (German)

* IoT: Internet of Things

Product strategy

- **Medium- and large-capacity products:** Enhance industry-standard packages and increase capacities.
- **Small-capacity products:** Enhance lineup of DIPIPM original packages (No.1 among home appliances) and pursue lower costs and higher quality.
- **Transfer medium- and large-capacity technologies to Vincotech to capture custom products market.**
6. Business Strategy by Segment: Traction and Electric power

Our strengths and features

- High reliability for infrastructure
- Unmatched record and know-how in high-voltage segment
- Top record* in mass production of high-voltage SiC module products

Growth strategy
Pursue greater added value in infrastructure segment, where growth is not high but high quality/reliability are demanded, to maintain position as a top supplier

➢ Deploy products that utilize latest Si technologies (X series: equipped with first 7th generation 8-inch chips and employs latest packaging technology)

➢ Deploy high-voltage, low-loss SiC module products (3.3kV and 1.7kV)

➢ Continue to develop Chinese and Indian markets, where solid demand is expected for railways.

➢ Focus on DC power transmission, where future expansion is anticipated in Europe, North America and China

* As of November 2017, surveyed by Mitsubishi Electric

Product strategy
➢ Expand applications in traction and electric-power market by introducing products with current densities exceeding those of other makes

Current density [A/cm²]

Traction

Electric power

SiC-equipped products

- X series (LV100 and HV100 package)
- X series (Standard package)
- R series
- H series

2015 2025

12 9 6 3

FY2017 FY2022

Expand applications in traction and electric-power market by introducing products with current densities exceeding those of other makes.
7. Production Strategy: Wafer Production

- Maintain highly added-value processes that are key to differentiation at company factories and continue to make investments (Si wafer back side processing and SiC wafers)
- Maximize production subcontracting (fabrication outsourcing) for Si wafer surface processing involving mainly general technologies and expand capacity while minimizing investments
- Utilize IoT and promote thorough productivity improvements
- Promote transition to multiple production lines to fortify BCP*

* BCP: Business continuity plan

Surface processing

Fukuoka (Fukuoka City): Mother factory
SiC wafer (4-inch) surface and back-side processing (including SiC)

Kumamoto (Koshi City): Mother factory
Wafer-surface and back-side processing

Hyogo (Itami City)
Si-wafer back-side processing

Japan production outsourcing
Si-wafer surface processing

Overseas production outsourcing (to be decided)
Si-wafer surface processing

Wafer process

Back side processing*

*Process specific to power wafers where electrodes, etc. are formed after grinding back side of wafer
7. Production Strategy (assembly/inspection)

- Establish global system based on local production and consumption
- Utilize IoT for thorough productivity improvements
- Transition to multiple production lines to fortify BCP
- Internalize inspection technologies as know-how and advance them

Fukuoka (Fukuoka City/Itoshima City): Mother factory
Automotive/Traction/ Home appliances products

Hyogo (Itami City/Toyooka City)
Industrial products

China (Hefei City/Shanghai City*)
Home appliances products

Hungary (Vincotech)
Industrial products

*Outsourcing in Shanghai
8. Summary

Growth target for “FY2022”
Net Sales 200 billion yen
OPM 10%
Overseas sales ratio 60%