Introduction of Smart Power Module
for Low-Power Motor Drives Applications

Sep 2004

HP SPM & System Engineering Group
Fairchild Semiconductor
2. Motion Control Technology Trends
- Power Module technology Trend
- Motor technology Trend
- Technology Trend by Applications
- Motion Control Market Needs
 & Technology Challenges
History of Power Modules.. and **NOW**
In Half-bridge, Full-bridge and 3-phase Inverter Applications

1970 - Now
**Discrete Solutions**
- Isolation
- Completed Main Power Circuit

1979 - Now
**SPM Solutions**

1981
**Transistor Modules**
- High Speed Control
- Low Power Losses

1987 - Now
**IGBT Modules**
- Included Drive Circuit
- Protection Circuit

1991 - Now
**IPM Solutions**
(Intelligent Power Modules)
- System Module Solutions
  (Built-in BLDC controller & advanced gate driver)
- Cost-effectiveness

1994 - Now
**Application Specific IPM**

1999 - Now
**STPM Solutions**
- Higher Performance
- Cost-effectiveness

1999 - Now
**Future**

• Creating new market in both of Industrial and Home Appliances (Very huge customers)
• Because providing higher performance and higher efficiency system keeping cost-effectiveness

Future
- System Module Solutions
  (Built-in BLDC controller & advanced gate driver)
- Cost-effectiveness

Only High Power Industrial Applications due to bad cost-effectiveness (not huge market)

Appendix
# Category & Trend of Motor Technology

<table>
<thead>
<tr>
<th>Motor</th>
<th>Induction Motor</th>
<th>SynRM</th>
<th>SMPMM</th>
<th>PMA-SynRM</th>
</tr>
</thead>
<tbody>
<tr>
<td>Efficiency*1</td>
<td>Low (89%)</td>
<td>Medium (91%)</td>
<td>High (94%)</td>
<td>Excellent (95%)</td>
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<td>Material Cost*1</td>
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<td>Mechanical</td>
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<td>Medium</td>
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<tr>
<td>Torque</td>
<td>Good</td>
<td>Good</td>
<td>Good</td>
<td>Excellent</td>
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<tr>
<td>High-speed</td>
<td>Good</td>
<td>Good</td>
<td>Poor</td>
<td>Excellent</td>
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<table>
<thead>
<tr>
<th>Drive</th>
<th>Complexity</th>
<th>High-speed</th>
<th>Position-Sensorless</th>
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</thead>
<tbody>
<tr>
<td>Efficiency</td>
<td>Simple</td>
<td>Medium</td>
<td>Easy</td>
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<tr>
<td>Mechanical</td>
<td>Complex</td>
<td>Poor</td>
<td>Complex</td>
</tr>
<tr>
<td>Torque</td>
<td>Medium</td>
<td>Excellent</td>
<td>Medium</td>
</tr>
</tbody>
</table>

*1: Data based on research result of Matsushita Electric Industrial Co.
Technology Trend of Air conditioner and Refrigerator
(Compressor Driving Unit)

• Efficiency
  - High speed operation
  - High efficiency of motor and inverter
  - Adoption of permanent magnet motor (BLDC)
  - Saving Energy by more 60% compared with conventional ON/OFF controller

• Performance
  - Adjustable speed drive using Sensorless Field Orientation Control
  - Vibration control due to compressor’s salient structure
  - Calm and precise operation

• Engineering Challenge
  - How to reduce the EMI
  - How to reduce the leakage current
  - How to reduce the acoustic noise
  - How to increase the efficiency
Technology Trend of Cloth Washer

- **Efficiency**
  - Adoption of permanent magnet motor

- **Performance**
  - Wide speed operation
    - High torque @ Washing
    - High speed @ Drying
  - Sensorless Field Orientation Control
  - Silent operation

- **Engineering Challenge**
  - Control considering large variation of the load (Control Performance)
  - How to reduce the acoustic noise
  - How to increase the efficiency

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1φ Induction Motor with Clutch (Conventional)
BLDC-DD Motor (SMPMM) (Current inverter Trend)
BLDC-DD Motor (PMA-SynRM) (Future Trend)

Motion Control Segment - SBP  Confidential  Smart Power Module
Technology Trend of Fan Motor

- **Efficiency**
  - Adoption of permanent magnet motor (BLDC)
  - Saving Energy by more 60% compared with conventional 1φ Induction motor

- **Performance**
  - Ease of control (Square-wave Control) due to simple & cost-effectiveness
  - Variable speed drive
  - Silent operation

- **Engineering Challenge**
  - How to reduce the EMI
  - How to reduce the acoustic noise
  - How to increase the efficiency

1φ Induction Motor (Conventional)  BLDC Motor (SMPMM) (Current inverter Trend)
Motion Control Market Needs & Technology Challenges

### Market Needs

- **Downsizing, Cost reduction**
- **Higher Efficiency** (Energy Saving)
- Environment-friendly improvement
  - Low harmonics
  - Low acoustic noise
  - Low EMI
- **Higher Reliability**

### Technology Challenges

- **Device loss/size reduction**
  - New device technology
- **Higher switching frequency** and lower dV/dt
  - Filter downsizing
  - Soft switching
- **Elimination of electrolytic capacitors**
  - Matrix converter
- **Advanced Package & Chip Technology**
  - Flip-chip, Ribbon bonding
  - New packaging material
3. Competitor’s Status & Information
## Competitors Status and Fairchild

### MITSUBISHI

#### STATUS
- World champion (Now) and leading company
- Creating new building concept of end-system
- Long Development and Business experience of over 15 years
- DIP-IPM experience of over 7 years
- Acquisition of Toshiba Module / IPM Biz.
- Spin-off all discrete Biz. to form Renesas
  - Focus & concentration on IPM/Module Biz.

#### TECHNOLOGY
- Considered as the top-level in every fields
  - IGBT, FRD and HVIC Technology for motor drives (5thGen. 1.2KV_Trench)
  - PKG Technology
    - TMT PKG expands to high module (2-pack 300A/600V)
  - System Technology
    - Inverter-driven motor driving
    - Product Concept and Design
  - Mass Production
    - Testing technology
    - Much and Huge experience
  - Fast change to new version of IPM concept
  - Very big size and high technology market in Japan

#### MARKET
- Sales volume of DIP-IPM
  - Now, 12M pcs/y
  - ’04 Sep, increase capa to 18M pcs/y
  - Upto 30M pcs/y 3years later
- In Japan (Appliances)
  - 70% share in inverter use
- In Japan (Other applications)
  - 70% share
- In Korea
  - 70% share in inverter use
- In China
  - Almost 100% share
- In Europe/US, Not much

#### Competing Devices
- Large DIP-IPM (SPM2)
- Mini DIP-IPM (SPM3)
- SIP-IPM (SPM4)
- Large-DIP PFCM (SPM3-V)
Competitors Status and Fairchild - Continued

**STATUS**
- Newly started the Development and Biz.
- IR changes the IR’s strategy to focus wafer business.
- Doing cooperative development and Biz. with Sanyo (but, not going well)
- Already released the System Module last year… but it seems to be just for technical point, not for Biz. One
  - Establish IR-Sanyo joint Venture..but almost giving-up the module Biz.

**TECHNOLOGY**
- Looks excellent technology in Semiconductors: NPT-IGBTs, FRD and particularly, HVIC technology for motor drives
- She has no new idea of PKG
  - The big weak point
- So, Design concept strongly depends on the existing PKG
  - Sanyo is doing M/P (IMS)
- Releasing 6 types of PKG and 2 kinds of IPM

**MARKET**
- Now.. No result.. But doing very strong Promotions
- But, considered that it is very difficult to meet the market price due to the PKG problem and no value proposition

**Competing Devices**
- About IMDS Series SPM2, SPM3, SPM4
Competitors Status and Fairchild - Continued

**SANYO**

**STATUS**
- Started the business from 1999
- Now releasing new series of IPM
- She has her own PKG technology of IMST
- Recently, she is doing very close cooperating work with IR
- She does do much focusing on PDP module also

**TECHNOLOGY**
- Has the excellent IMS PKG technology
- But, there is no semiconductor technology (out-sourcing)
- So, The characteristics of the IPM are not so good due to old chips

**MARKET**
- Sanyo makes various customized modules for Audio, Video, PDP and Power AMP
- Almost only selling to Sanyo company such as Sanyo washing machines and Air-conditioners
- But, recently Sanyo Air-conditioners are using SPM2, and also she plan to use ver.2 of SPM3 for the next project

**Competing Devices**

(SPM2)
(SPM3)
TOKYO (Nikkei)--Mitsubishi Electric Corp. (6503) this fall intends to raise its monthly output of power semiconductors used in home appliances and hybrid cars by 50% to 1.5 million units, The Nihon Keizai Shimbun learned Monday.

The increase comes amid the growing popularity of energy-saving home appliances equipped with power chips. If Chinese demand for inverter-equipped home appliances grows, the company will boost its monthly output capacity to 2-3 million units next year or later, according to the head of the Fukuoka plant. It will consider launching production in China as well.

Mitsubishi Electric has earmarked roughly 5 billion yen to beef up the final assembly lines at a plant in Fukuoka as well as install new facilities capable of producing wafers with larger diameters at a factory in Kumamoto Prefecture.

The firm expects its power chip segment, which includes devices used for hybrid cars and industrial machines, to generate sales of 70 billion yen this fiscal year, up 13% on the year.

Mitsubishi Electric, which commands more than 60% of the market for power chips used in inverter-equipped home appliances, plans to buy part of Toshiba Corp.'s (6502) power chip operations as of Oct. 1.

The firm now supplies power semiconductors to Toyota Motor Corp. (7203), Honda Motor Co. (7267) and Ford Motor Co. for use in their hybrid cars.

Source: The Nihon Keizai Shimbun Tuesday morning edition
TOKYO, June 17th, 2004 – Mitsubishi Electric Corporation (President and CEO: Tamotsu Nomakuchi; hereafter “Mitsubishi Electric”) and Toshiba Corporation (President and CEO: Tadashi Okamura; hereafter “Toshiba”) announced today that they have agreed in principle to transfer a majority of Toshiba’s high capacity power module business, which accounts for a small portion of its power transistor business, over to Mitsubishi Electric. The business transfer will include product development, design, manufacturing and the marketing of high capacity power module products, but will not include products for automotive use, high voltage modules or other related products. Discussions about the exact details of the business transfer are ongoing. A final agreement is expected to be concluded by October 1st, 2004.

1 High voltage modules to be used by Toshiba’s Industrial and Power Systems & Services Company will continue to be supplied by Toshiba.

As a result of its “Focus and Concentration” strategy, Mitsubishi Electric has previously spun-off its system LSI and system memory businesses to form a new joint venture with Hitachi Corporation, called Renesas Technology Corporation. Mitsubishi Electric now concentrates its own resources on power semiconductors and high frequency optical devices, capable of achieving synergies within the company’s business. Mitsubishi Electric has been concentrating on its IGBT module business in inverter controller equipment for consumer products and industrial equipment, and in new areas such as hybrid cars. Mitsubishi Electric believes that this business transfer will enable it to accelerate the strength of its module business by combining both companies’ technology.

2 IGBT: Insulated Gate Bipolar Transistor

Toshiba’s semiconductor business is focused on three key industry sectors— discrete semiconductors, system LSIs and memories—and the ability to offer solutions as an integrated device manufacturer (IDM) with market-leading capabilities in the integration of design, development and production. In the discrete business, where Toshiba is the world’s number one in market share with total sales of approximately 220 billion yen in the fiscal year 2003, the company is fine-tuning its strategic direction and has decided to focus resources on power transistors, which account for approximately 40% of Toshiba’s total discrete business, for use in hybrid car and electric vehicle applications and for use in PCs and digital consumer electronics, all areas that are expected to see consistent growth. In pursuit of this strategy, Toshiba reached agreement with Mitsubishi Electric on the transfer to Mitsubishi Electric of the majority of the high capacity power module segment of Toshiba’s power transistor business, of which consists only a few percent of Toshiba’s total discrete business.

The worldwide demand for power semiconductors looks set to increase, on the back of greater demand for products reflecting a greater concern for energy saving, such as hybrid cars, solar-power generators, wind-power generators, and inverter control devices for consumer electronics and industrial equipment. However, worldwide market conditions are becoming increasingly severe as specialist manufacturers from Europe and North America become more competitive. In order to survive in these conditions, the strengthening and acceleration of the “Focus and Concentration” strategy is vital.

Both companies had been developing their power semiconductor businesses independently up until now. However, both concurred that concentrating on their specialist areas would further both companies’ competitiveness, and therefore came to an agreement at this time.
## SPM2 Family

### Key Features

<table>
<thead>
<tr>
<th>SPM Series</th>
<th>Rating (Motor rating)</th>
<th>Features</th>
<th>Main Applications</th>
</tr>
</thead>
<tbody>
<tr>
<td>SPM2</td>
<td>600V 10<del>30A (0.8k</del>2.4kW)</td>
<td>3-phase IGBT inverter with - 3 divided N-terminal for current sensing - Built-in HVIC with UVP - Built-in LVIC with UVP, OCP - Sense IGBT for low-side - Built-in Thermistor</td>
<td>Air conditioner Washing machine Treadmill Industrial inverter</td>
</tr>
</tbody>
</table>

- Air conditioner
- Washing machine
- Treadmill
- Industrial inverter
SPM2 Series

- Line-up:
  - 600V/10A, 15A, 20A, 30A

- Target Applications:
  - Low cost consumer appliance inverters
    (Air conditioner, Washing machine, Water pump, Treadmill)
  - Low cost industrial inverters

- Feature:
  - Optional built-in thermistor (NTC)
  - Short-circuit protection with soft shut-down control using sense-IGBTs
  - Good thermal resistance and isolation capacity with ceramic substrate
  - 3 N-terminals for low-cost current sensing
# Line up of DIP-SPM (SPM2)

- Status : Mass production

<table>
<thead>
<tr>
<th>Products</th>
<th>BVCES (Min) (V)</th>
<th>IC(A)</th>
<th>Frequency Typ(kHz)</th>
<th>Motor Rating</th>
<th>Built in Thermistor</th>
<th>Major App.</th>
</tr>
</thead>
<tbody>
<tr>
<td>FSAM10SH60A</td>
<td>600</td>
<td>10</td>
<td>15</td>
<td>1.0</td>
<td>Yes</td>
<td>Washing machine</td>
</tr>
<tr>
<td>FSBM10SH60A</td>
<td>600</td>
<td>10</td>
<td>15</td>
<td>1.0</td>
<td>No</td>
<td>Washing machine</td>
</tr>
<tr>
<td>FSAM10SM60A</td>
<td>600</td>
<td>10</td>
<td>5</td>
<td>1.0</td>
<td>Yes</td>
<td>Airconditioner</td>
</tr>
<tr>
<td>FSBM10SM60A</td>
<td>600</td>
<td>10</td>
<td>5</td>
<td>1.0</td>
<td>No</td>
<td>Airconditioner</td>
</tr>
<tr>
<td>FSAM15SH60A</td>
<td>600</td>
<td>15</td>
<td>15</td>
<td>1.5</td>
<td>Yes</td>
<td>Washing machine</td>
</tr>
<tr>
<td>FSBM15SH60A</td>
<td>600</td>
<td>15</td>
<td>15</td>
<td>1.5</td>
<td>No</td>
<td>Washing machine</td>
</tr>
<tr>
<td>FSAM15SM60A</td>
<td>600</td>
<td>15</td>
<td>5</td>
<td>1.5</td>
<td>Yes</td>
<td>Airconditioner</td>
</tr>
<tr>
<td>FSBM15SM60A</td>
<td>600</td>
<td>15</td>
<td>5</td>
<td>1.5</td>
<td>No</td>
<td>Airconditioner</td>
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<tr>
<td>FSAM20SH60A</td>
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<td>20</td>
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<tr>
<td>FSBM20SH60A</td>
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<td>20</td>
<td>15</td>
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<tr>
<td>FSAM20SM60A</td>
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<td>20</td>
<td>5</td>
<td>2.2</td>
<td>Yes</td>
<td>Airconditioner</td>
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<tr>
<td>FSBM20SM60A</td>
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<td>5</td>
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<tr>
<td>FSAM30SM60A</td>
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<td>30</td>
<td>5</td>
<td>3.0</td>
<td>Yes</td>
<td>Airconditioner</td>
</tr>
<tr>
<td>FSBM30SM60A</td>
<td>600</td>
<td>30</td>
<td>5</td>
<td>3.0</td>
<td>No</td>
<td>Airconditioner</td>
</tr>
</tbody>
</table>
# SPM2 and SPM3 Family

## Key Features

<table>
<thead>
<tr>
<th>SPM Series</th>
<th>Rating (Motor rating)</th>
<th>Features</th>
<th>Main Applications</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>SPM2</strong></td>
<td>600V 10<del>30A (0.8k</del>2.4kW)</td>
<td>3-phase IGBT inverter with - 3 divided N-terminal for current sensing - Built-in HVIC with UVP - Built-in LVIC with UVP, OCP - Sense IGBT for low-side - Built-in Thermistor</td>
<td>Air conditioner Washing machine Treadmill Industrial inverter</td>
</tr>
<tr>
<td><strong>SPM3</strong></td>
<td>600V 3<del>30A (0.25k</del>2.4kW)</td>
<td>3-phase IGBT inverter with - 3 divided N-terminal for current sensing - Built-in HVIC with UVP - Built-in LVIC with UVP, OCP - Small Footprint</td>
<td>Air conditioner Washing machine Refrigerator Industrial inverter</td>
</tr>
</tbody>
</table>
### SPM3 Series

**Line-up:**
- 600V/3A, 5A, 7A, 10A, 15A (for Ceramic-SPM3)
- 600V/15A, 20A, 30A (for DBC-SPM3)

**Target Applications:**
- Low cost consumer/industrial appliance inverters (Air conditioner, Washing machine, Refrigerator, Water pump, Treadmill, servo)

**Feature:**
- Good thermal resistance
- Small size & Large pin-to-pin spacing with zigzag package structure
- Controllable switching speed with external gate resistor
- 3 N-terminals for low-cost current sensing
## Line up of Mini-SPM (SPM3)
- **Status**: under development, **Mass production**: Aug, 2004

<table>
<thead>
<tr>
<th>Products</th>
<th>BVCES (Min) (V)</th>
<th>IC (A)</th>
<th>Motor Rating</th>
<th>Major App.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mini-SPM (SPM3)</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>FSBS3CH60</td>
<td>600</td>
<td>3</td>
<td>0.3</td>
<td>220 Refrigerator, Fan motor</td>
</tr>
<tr>
<td>FSBS5CH60</td>
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<td>0.45</td>
<td>220 Refrigerator, W/M</td>
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<td>FSBS7CH60</td>
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<td>0.75</td>
<td>220 W/M</td>
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<td>220 A/C, W/M</td>
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<td>15</td>
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<td>220 A/C, W/M</td>
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<td>30</td>
<td>2.2</td>
<td>220 A/C, W/M</td>
</tr>
</tbody>
</table>
Controller Platform Strategy

SPM3-based Control Engine Platform

- Can do more reduction in total system cost
- Can do more reduction in the development time
- Can do more easy management
- Can achieve optimized control flexibility
- Can achieve higher reliability

Current Rating (A)

Thermal resistance, IGBT (Degree/W)

DBC BASE

FSBS3CH60
FSBS5CH60
FSBS7CH60
FSBS10CH60
FSBS15CH60
FSBB15CH60
FSBB20CH60
FSBB30CH60
SRM: FCAS50SN60
SPM3 Series
System Connection Diagram

Input Signal for Short Circuit Protection

Phase Current Monitoring

Switching Speed Control
SPM3 Series
- Switching speed control

- High side switching speed control
  - External impedance cell can be used
- Low side switching speed control
  - 2 kinds of LVIC for high/low on-dv/dt are provided optionally

<table>
<thead>
<tr>
<th>Type</th>
<th>Impedance cell</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td></td>
<td>On/off dv/dt control</td>
</tr>
<tr>
<td>B</td>
<td></td>
<td>Off dv/dt control</td>
</tr>
<tr>
<td>C</td>
<td></td>
<td>On dv/dt control</td>
</tr>
<tr>
<td>D</td>
<td></td>
<td>Separate on/off dv/dt control</td>
</tr>
</tbody>
</table>
Development of DBC PKG is on-going for 15/20A SPM3
Merits: 20A Chips can be used by utilization of fine patterning
Very Low Thermal Resistance Possible by using DBC
Exactly Same in External Structure (Pin-to-Pin Compatibility to existing one)

<table>
<thead>
<tr>
<th>Max. R $\theta_{jc}$</th>
<th>R$\theta_{jc}$ [°C/W] _ IGBT</th>
<th>R$\theta_{jc}$ [°C/W] _ FRD</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Ceramic</td>
<td>DBC</td>
</tr>
<tr>
<td>10A SPM3</td>
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<td>-</td>
</tr>
<tr>
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<tr>
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<td>1.51</td>
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</tbody>
</table>
SPM Key Customers

Air Conditioner

Refrigerator

Cloth Washer

Motion Control Segment - SBP  Confidential  Smart Power Module