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 conduction 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 the use of a small drift region of the same thickness as the carrier cumulative carriers. As a result, high-speed switching can be realized.

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

SiC power modules appropriately by application

<table>
<thead>
<tr>
<th>Application</th>
<th>Product name</th>
<th>Model</th>
<th>Voltage(V)</th>
<th>Current(A)</th>
<th>Connection</th>
<th>Status</th>
<th>Insert page</th>
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<tbody>
<tr>
<td>Home appliances</td>
<td>SiC-SBD</td>
<td>BD10120S</td>
<td>1200</td>
<td>20</td>
<td>-</td>
<td>Sample available</td>
<td>P5</td>
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<tr>
<td>Industrial equipment</td>
<td>Full SiC Power Modules</td>
<td>BD10120P</td>
<td>1200</td>
<td>30</td>
<td>2 in 1</td>
<td>User development</td>
<td>P4</td>
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<tr>
<td>Traction</td>
<td>Hybrid SiC Power Modules</td>
<td>BD10120S</td>
<td>1200</td>
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<td>2 in 1</td>
<td>Commercial available</td>
<td>P5</td>
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<td>Industrial equipment</td>
<td>Full SiC Power Modules for High-frequency Switching Applications</td>
<td>BD10120P</td>
<td>1200</td>
<td>30</td>
<td>2 in 1</td>
<td>Sample available</td>
<td>P5</td>
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<tr>
<td>Home appliances</td>
<td>Large Hybrid SiC DIPIPMTM for PV Application</td>
<td>BD10120P</td>
<td>1200</td>
<td>30</td>
<td>6 in 1</td>
<td>Commercially available</td>
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<td>Home appliances</td>
<td>Super-mini Full SiC DIPFM™</td>
<td>BD10120P</td>
<td>1200</td>
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<td>Sample available</td>
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Terminology

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<th>Term</th>
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<tr>
<td>SIC</td>
<td>Silicon Carbide</td>
</tr>
<tr>
<td>IPM</td>
<td>Intelligent Power Module</td>
</tr>
<tr>
<td>DIPP™</td>
<td>DIPP™ Power Module of the mold package type with protection circuits</td>
</tr>
<tr>
<td>DIPPDC™</td>
<td>DIPP™ Power Module of the mold package type with power factor circuits</td>
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<tr>
<td>SBD</td>
<td>Schottky Barrier Diode</td>
</tr>
<tr>
<td>MOSFET</td>
<td>Metal Oxide Semiconductor Field Effect Transistor</td>
</tr>
<tr>
<td>IGBT</td>
<td>Insulated Gate Bipolar Transistor</td>
</tr>
<tr>
<td>Tr</td>
<td>Transistor</td>
</tr>
<tr>
<td>FW-SW</td>
<td>Freewheeling switching loss</td>
</tr>
<tr>
<td>FW-DC</td>
<td>Freewheeling conduction loss</td>
</tr>
<tr>
<td>Tr-SW</td>
<td>Transistor switching loss</td>
</tr>
<tr>
<td>IGBT-SW</td>
<td>IGBT switching loss</td>
</tr>
<tr>
<td>IGBT-DC</td>
<td>IGBT conduction loss</td>
</tr>
<tr>
<td>PV</td>
<td>Photovoltaics</td>
</tr>
<tr>
<td>CSTB™</td>
<td>Mitsubishi Electric’s unique IGBT that makes use of the carrier cumulative effect</td>
</tr>
<tr>
<td>JBS</td>
<td>Junction Barrier Schottky</td>
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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.

SC: Silicon Carbide—Compound that fuses silicon and carbon at a ratio of one-to-one.
SiC-SBD (Schottky Barrier Diode) for power supply systems
600V series 1200V series
Sample available after June 2019

Contribute to reducing power loss and the size of power supply systems

- Power loss is reduced by approx. 21%* compared to the conventional 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.

* Conventional Si product: S1 series which is equipped with Mitsubishi Electric DIPFDC®.

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

- Suitable chip set realize high speed switching
- Power loss is reduced by compared to Silicon (Si) product*
- Low inductance package adopted to deliver Full SiC performance

* Si product: Mitsubishi Electric HVTGBT, CM600DC-66X

Full/Hybrid SiC Power Modules for Traction Inverters and HVDC system
FMF750DC-66A Commercially available / FMF375DC-66A Under development
CMH1200DC-34X/CMH600DC-66X Under development

Contributes to energy saving and downsizing for inverters in traction motors, DC-power transmitters, large industrial machinery

- Suitable chip set realize high speed switching
- Power loss is reduced by compared to Silicon (Si) product*
- Low inductance package adopted to deliver Full SiC performance

* Conventional Si product: Mitsubishi Electric HVTGBT, CM600DC-66X

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
- Contributing to reducing power loss and the size of power supply systems
- Power loss comparison

- Contributes to energy saving and downsizing for inverters in traction motors, DC-power transmitters, large industrial machinery
- Suitable chip set realize high speed switching
- Power loss is reduced by compared to Silicon (Si) product*
- Low inductance package adopted to deliver Full SiC performance

- Conventional Si product: Mitsubishi Electric HVTGBT, CM600DC-66X

600V/200A Hybrid SiC-IPM for Industrial Equipment
PMH200CS1D060 Sample available

- Contributing to energy saving and downsizing for inverters in traction motors, DC-power transmitters, large industrial machinery
- Suitable chip set realize high speed switching
- Power loss is reduced by compared to Silicon (Si) product*
- Low inductance package adopted to deliver Full SiC performance

- Conventional Si product: Mitsubishi Electric HVTGBT, CM600DC-66X
Contributes to reducing size/weight of industrial-use inverters with the mounting area reduced by approx. 60%.

- Power loss reduced approx. 70% compared to the conventional product*
- Low-inductance packaging adopted to deliver full SiC performance
- Contributing 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 CSM60DY-24HF (1200V/400A 2in1 2pcs)

1200V/400A • 1200V/800A Fill SiC Power Modules for Industrial Equipment FMF600DX2-24A/FMF800DX2-24A [Sample available]

Contributes to enhancing the performance of industrial-use inverters thanks to built-in protection function for short circuit.

- 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 packaging adopted to deliver full SiC performance

*Conventional product: Mitsubishi Electric CSM60DY-24HF (1200V/400A 2in1 2pcs)

**Product lineup**

<table>
<thead>
<tr>
<th>Model</th>
<th>Rated voltage</th>
<th>Rated current</th>
<th>Circuit configuration</th>
<th>Package size (D x W)</th>
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<tr>
<td>FMF600DX2-24A</td>
<td>1200V</td>
<td>600A</td>
<td>4in1</td>
<td>92.3 x 121.7mm</td>
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<tr>
<td>FMF800DX2-24A</td>
<td>1200V</td>
<td>800A</td>
<td>2in1</td>
<td>92.3 x 121.7mm</td>
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**Power loss comparison**

<table>
<thead>
<tr>
<th>Model</th>
<th>Power loss [W]</th>
<th>Condition</th>
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<tbody>
<tr>
<td>IGBT module</td>
<td>Approx. 70% reduction</td>
<td></td>
</tr>
<tr>
<td>Full SiC module</td>
<td>Approx. 70% reduction</td>
<td></td>
</tr>
</tbody>
</table>

Condition: Vcc=600V, Io=600A (assuming a 55kW inverter), fc=15kHz, P.F=0.8, Modulation=1, Three-phase modulation, TJ=100˚C

**Recovery waveform (FWD)**

600V/50A Large Hybrid SiC DIPIPM™ for PV Applications PSH50YA2A6 [Commercially available]

More efficient power modules for PV power conditioner applications.

- 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

**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

**Power loss comparison**

<table>
<thead>
<tr>
<th>Model</th>
<th>Power loss [W]</th>
<th>Condition</th>
</tr>
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<tbody>
<tr>
<td>SI DIPIPM</td>
<td>Approx. 70% reduction</td>
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</tr>
<tr>
<td>Hybrid SiC DIPIPM</td>
<td>Approx. 70% reduction</td>
<td></td>
</tr>
</tbody>
</table>

Condition: Vcc=300V, Io=25A (assuming a 110kW inverter), fc=10kHz, P.F=0.8, Tj=125˚C

**Internal circuit diagram**

**Power loss comparison**

<table>
<thead>
<tr>
<th>Model</th>
<th>Power loss [W]</th>
<th>Condition</th>
</tr>
</thead>
<tbody>
<tr>
<td>S DPPM™</td>
<td>Approx. 70% reduction</td>
<td></td>
</tr>
<tr>
<td>Hybrid SiC DPPM™</td>
<td>Approx. 70% reduction</td>
<td></td>
</tr>
</tbody>
</table>

Condition: Vcc=300V, Io=25A (assuming a 110kW inverter), fc=10kHz, P.F=0.8, Tj=125˚C

Hybrid SiC Power Modules for High-frequency Switching Applications [Commercially available]

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

Internal block diagram

Power loss comparison

Super-mini Hybrid / Full SiC DIPPFCTM for Home Appliances
PSH20L91A6-A / PSF20L91A6-A Commercially available

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 DIPIPMTM to eliminate the need for a spacer between the inverter and heat sink, and to facilitate its implementation

Internal block diagram (Full SiC DIPPFCTM)

Power loss comparison

SiC Power Module Lineup
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 Mitsubishi Electric SiC Power Devices and Power Electronics Equipment Incorporating Them**

- **1990s**
  - Developed new material, silicon-carbide (SiC) power semiconductor, maintaining a lead over other companies.

- **2000s**
  - Developed various elemental technologies.

- **2006**
  - January 2006
    - Successfully developed SiC inverter for driving motor rated at 3.7kW.
  - October 2010
    - Launched "Kirigamine" inverter air conditioner.

- **2009**
  - February 2009
    - Developed 116kW SiC inverter, world’s highest value* with approx. 70% reduction in power loss.
  - November 2009
    - Developed 20kW SiC inverter, world’s highest value* with approx. 90% reduction in power loss.

- **2010**
  - January 2010
    - Developed large-capacity power module equipped with SiC diode.
  - February 2010
    - Launched "Kirigamine" inverter air conditioner.
  - October 2010
    - Launched "Kirigamine" inverter air conditioner.
  - October 2011
    - Launched SiC inverter for use in railcars.

- **2011**
  - January 2011
    - Verified highest power conversion efficiency* for solar power generation system power conditioner (domestic industry).
  - October 2011
    - Commercialized SiC inverter for use in railcars.

- **2012**
  - March 2012
    - Developed motor system with built-in SiC inverter*.
  - September 2012
    - Verified in main circuit system for railcars.
  - December 2012
    - Delivered auxiliary power supply systems for railcars.

- **2013**
  - February 2013
    - Developed SiC for application in elevator control systems*.
  - March 2013
    - Launched CNC drive unit equipped with SiC power module.
  - December 2013
    - Launched traction inverter with full SiC power module.

- **2014**
  - February 2014
    - Developed EV motor drive system with built-in SiC inverter*.
  - May 2014
    - Began shipping samples of hybrid SiC power modules for high-frequency switching 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**
  - March 2016
    - Launched SiC-SBD.
  - April 2016
    - Launched Super-mini Full SiC DIPIPM™.
  - October 2016
    - Launched packaging air conditioners with full SiC DIPIPM™ in Japan.

- **2017**
  - March 2017
    - Developed World’s smallest SiC Inverter for HEVs.
  - June 2017
    - Developed SiC Power Device with Record Power Efficiency.
  - December 2017
    - Mitsubishi Electric and the University of Tokyo Reveal New Mechanism for Enhancing Reliability of SiC Power Semiconductor Devices.

- **2018**
  - January 2018
    - New 8kV SiC Power Semiconductor Module Achieves World’s Highest Power Density.
  - December 2018
    - Mitsubishi Electric and the University of Tokyo Reveal New Mechanism for Enhancing Reliability of SiC Power Semiconductor Devices.

- **2019**
  - June 2019
    - Began shipping samples of 1200V SiC-SBD.
  - February 2019
    - Developed Super Compact Power Unit for Hybrid Electric Vehicle.
  - May 2019
    - Developed Super Compact Power Unit for Hybrid Electric Vehicle.

- **2020**
  - June 2020
    - Launched Super-mini Full SiC DIPIPM™.
  - October 2020
    - Launched packaging air conditioners with full SiC DIPIPM™ in Japan.

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

- January 2010
  - Developed large-capacity power module equipped with SiC diode.
- October 2010
  - Launched "Kirigamine" inverter air conditioner.
- January 2011
  - Verified highest power conversion efficiency* for solar power generation system power conditioner (domestic industry).
- February 2013
  - Developed SiC for application in elevator control systems*.
- March 2013
  - Developed technologies to increase capacities of 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 2019.
*3 The year and month listed are based on press releases or information released during the product launch month in Japan.
<table>
<thead>
<tr>
<th>Country</th>
<th>Company</th>
<th>Address</th>
<th>Contact Information</th>
</tr>
</thead>
</table>
| Austria                 | GLYN AUSTRIA                                 | Campus 21 / Businesspark Wien Süd, Liebermannstr. A02/301, A-2345 Brunn am Gebirge | Email: sales@glyn.at  
www.glyn.at                                                      |
|                         | HY-LINE COMPONENTS GMBH                      | Inselkammerstr. 10, D-82008 Unterhaching                                  | Email: power@hy-line.de  
www.hy-line.de                                                      |
| Baltic countries        | ELGERTA UAB                                  | Visorius st. 2, LT-08300 Vilnius, Lithuania                              | Email: lithuania@elgerta.com  
www.elgerta.com                                                      |
| Belarus                 | SYMMETRON MINSK                              | V. Khoruzhiev str. 1a, 220005, Minsk, Belarus                            | Email: minsk@symmetron.ru                              |
| Benelux                 | GLYN GMBH & CO KG, Benelux Division          | Ringstr. 88, D-41334 Nettetal                                             | Email: benelux@glyn.com  
www.glyn.com                                                      |
| Bulgaria                | OHM BG EOOD                                  | Svetlina Street No. 11, 8800 Sliven, Bulgaria                           | Email: teokay@ohm.com.tr  
www.ohm.com.tr                                                      |
| Czech Republic          | STARMAN ELECTRONICS, S.R.O.                 | V Zahradák 8362/4, 180 00 Praha 8, Czech Republic                        | Email: components@starmans.cz  
www.starmans.net                                                      |
| Denmark                 | GLYN DENMARK                                 | Slotsmarken 18, DK-2970 Hørsholm                                         | Email: sales@glyn-nordic.dk  
www.glyn-nordic.dk                                                      |
| France                  | ARCEL                                        | ZI le tronchon – 2 rue des auines, F-69410 Champagne Au Mont D’or       | Email: info@arcel.eu  
www.arcel.eu                                                      |
|                         | COMPELEC                                     | MultiParc du Jubin, Bâtiment A 27, chemin des Peupliers, 69 570 Dardilly, France | Email: yfouletier@compelec.com  
www.compelec.com                                                      |
| Germany                 | GLYN GMBH & CO KG, Vertriebs GMBH           | Am Wörtzgarten 8, D-65510 Idstein/Ts.                                    | Email: power@glyn.de  
www.glyn.de                                                      |
|                         | HY-LINE POWER COMPONENTS VERTRIEBS GMBH     | Inselkammerstr. 10, D-82008 Unterhaching                                  | Email: power@hy-line.de  
www.hy-line.de                                                      |
|                         | INELTRON GMBH                                | Hugenottenstr. 30, D-61381 Friedrichsdorf                                | Email: info@ineltron.de  
www.ineltron.de                                                      |
| Hungary                 | INELTRON HUNGARY                             | Fecskes 16, H-1194 Budapest                                               | Email: l.laszlo@ineltron.hu                           |
| Israel                  | RAM N.S TECHNOLOGIES LTD                     | 1, Harnasger St., Raanana 43653, Israel                                   | Email: nati@ram-tech.co.il  
www.ram-tech.co.il                                                      |
| Italy                   | MELCHIONI SPA                                | Via P. Colletta 37, 20135 Milano (Italy)                                  | Email: G.Morelli@melchioni.it  
www.melchioni.it                                                      |
|                         | SPECIAL IND PRODOTTI SPECIALI PER L INDUSTRIA S.P.A. | Piazza Spotorno, 3 - 20159 Milano                                      | Email: specialind@specialind.it  
www.specialind.it                                                      |
<table>
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<th>Country</th>
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<th>Phone</th>
<th>Fax</th>
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<tbody>
<tr>
<td>Poland</td>
<td>DACPOL</td>
<td>Ul. Pulawska 34, PL-05500 Plaseczno</td>
<td>+48 22 7035 100</td>
<td>+48 22 7035 101</td>
<td><a href="mailto:dacpol@dacpol.com.pl">dacpol@dacpol.com.pl</a></td>
<td><a href="http://www.dacpol.com.pl">www.dacpol.com.pl</a></td>
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<td></td>
<td>ELEKTRON POLSKA Sp. z o.o.</td>
<td>ul. Wroclawska 33 D PL-55-090 Dlugolęka</td>
<td></td>
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<td><a href="mailto:power@elektron-polska.pl">power@elektron-polska.pl</a></td>
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<tr>
<td>Romania</td>
<td>INELTRON ROMANIA</td>
<td>Str. Lunetii 4, RO-400504 Cluj – Napoca</td>
<td>+36 70 366 60 55</td>
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<td><a href="mailto:i.laszlo@ineltron.hu">i.laszlo@ineltron.hu</a></td>
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<tr>
<td>Russia</td>
<td>EFO LTD</td>
<td>St. Petersburg, 194100, Novotikovskaya St. 15 lit. A, Business-center Akvilon, office 441</td>
<td>+7 (812) 327-8654</td>
<td>+7 (812) 320-1819</td>
<td></td>
<td>efo-power.ru</td>
</tr>
<tr>
<td></td>
<td>PLATAN COMPONENTS</td>
<td>40-1, Bld. 2, Ivana Franko Str., RU-121351 Moscow</td>
<td></td>
<td></td>
<td><a href="mailto:platan@aha.ru">platan@aha.ru</a></td>
<td><a href="http://www.platan.ru">www.platan.ru</a></td>
</tr>
<tr>
<td></td>
<td>SYMMETRON ELECTRONIC COMPONENTS</td>
<td>Tallinskaya St. 7, RU-195196 St. Petersburg</td>
<td>+7 (812) 449 40 00</td>
<td></td>
<td><a href="mailto:npo@symmetron.ru">npo@symmetron.ru</a></td>
<td><a href="http://www.symmetron.ru">www.symmetron.ru</a></td>
</tr>
<tr>
<td>Spain and Portugal</td>
<td>AICOX SOLUCIONES SA</td>
<td>Avda. Somosierra, 12, 1ºA, E-28703 San Sebastián de los Reyes</td>
<td>+34 91 65 92 970</td>
<td></td>
<td><a href="mailto:informa@aicox.com">informa@aicox.com</a></td>
<td><a href="http://www.aicox.com">www.aicox.com</a></td>
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<tr>
<td>Portugal</td>
<td>INELEC SA</td>
<td>Bocangel, 38, E-28028 Madrid</td>
<td>+34 91 726 35 00</td>
<td></td>
<td><a href="mailto:inelec@inelec.net">inelec@inelec.net</a></td>
<td><a href="http://www.inelec.net">www.inelec.net</a></td>
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<td>Sweden</td>
<td>GLYN SWEDEN</td>
<td>Tammsväg 13, SE-81576 Söderfors</td>
<td>+46 (0) 293 300 84</td>
<td></td>
<td><a href="mailto:sales@glyn.se">sales@glyn.se</a></td>
<td><a href="http://www.glyn.se">www.glyn.se</a></td>
</tr>
<tr>
<td>Switzerland</td>
<td>ELEKTRON AG</td>
<td>Riedhofstr. 11, CH-8804 Au (Zürich)</td>
<td>+41 (0) 44 781 01 11</td>
<td></td>
<td><a href="mailto:info@elektron.ch">info@elektron.ch</a></td>
<td><a href="http://www.elektron.ch">www.elektron.ch</a></td>
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<tr>
<td>Turkey</td>
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