High-Voltage Intelligent Power Devices
Application Note (SSOP30)
# Table of Contents

Table of Contents ............................................................... 2  
1. Products discussed herein.................................................. 3  
  1.1. Product offerings.......................................................... 3  
2. Outline dimensions and marking of the SSOP30 package .................................................. 4  
  2.1. Package outline dimensions.......................................... 5  
  2.2. Marking.......................................................................... 6  
  2.3. PCB land pattern dimensions (Reference) .......................... 6  
  2.4. Soldering........................................................................... 7  
  2.5. Attaching a heatsink....................................................... 8  
3. Pin description ...................................................................... 10  
  3.1. Pin assignment.............................................................. 10  
4. Functional descriptions and usage considerations ........ 11  
  4.1. Protection features....................................................... 11  
  4.2. V\textsubscript{REG} power supply ...................................... 14  
  4.3. Power supply sequencing ............................................. 15  
  4.4. Calculating power losses............................................. 16  
5. Application circuit example .......................................... 17  
  5.1. Application circuit example ....................................... 17  
6. RESTRICTIONS ON PRODUCT USE................................. 19
1. Products discussed herein

1.1. Product offerings

Table 1.1 High-voltage intelligent power devices

<table>
<thead>
<tr>
<th>Part Number</th>
<th>Ratings</th>
<th>Features</th>
<th>Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>TPD4204F</td>
<td>600 V/2.5 A</td>
<td>Y – Y Y Y Y</td>
<td>180°</td>
</tr>
<tr>
<td>TPD4206F</td>
<td>500 V/2.5 A</td>
<td>Y – Y Y Y Y</td>
<td>180°</td>
</tr>
<tr>
<td>TPD4207F</td>
<td>600 V/5 A</td>
<td>Y – Y Y Y Y</td>
<td>180°</td>
</tr>
</tbody>
</table>

Note: In combination with a microcontroller unit (MCU) or a motor controller IC

HVIPDs for sine-wave (180-degree) type

The HVIPDs can be used in combination with Toshiba’s motor controller IC or MCU to drive a motor with sine-wave (180-degree) type so as to reduce its acoustic noise and vibration.

Figure 1.1 Block diagram for an HVIPD for sine-wave (180-degree) type
**Table 1.2.1 Controller IC list sine-wave drive type (Example of products)**

<table>
<thead>
<tr>
<th>Part Number</th>
<th>Package</th>
<th>Vcc / Io</th>
<th>Position Sensing</th>
<th>Features</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Lead Angle Control</td>
</tr>
<tr>
<td>TB6551FAG</td>
<td>SSOP24</td>
<td>12V/2mA</td>
<td>Hall effect IC</td>
<td>External setting</td>
</tr>
<tr>
<td>TB6556FG</td>
<td>SSOP30</td>
<td>12V/2mA</td>
<td></td>
<td>Current Feedback</td>
</tr>
<tr>
<td>TB6584FNG/AFNG</td>
<td>SSOP30</td>
<td>18V/2mA</td>
<td></td>
<td>RPM Feedback</td>
</tr>
<tr>
<td>TB6634FNG</td>
<td>SSOP30</td>
<td>18V/2mA</td>
<td>Hall element or Hall effect IC</td>
<td>RPM Feedback</td>
</tr>
<tr>
<td>TB6631FNG</td>
<td>SSOP30</td>
<td>18V/2mA</td>
<td></td>
<td>RPM Feedback</td>
</tr>
<tr>
<td>TC78B041FNG</td>
<td>SSOP30</td>
<td>18V/2mA</td>
<td></td>
<td>RPM Feedback</td>
</tr>
<tr>
<td>TC78B042FTG</td>
<td>QFN32</td>
<td>18V/2mA</td>
<td></td>
<td>RPM Feedback</td>
</tr>
</tbody>
</table>

**Note 1:** Specifications such as modulation generation method and automatic advance angle mode differ. Refer to the data sheet of each product for details.

**Note 2:** Internal auto lead angle control based on the frequency of the FG signal.

**Note 3:** Toshiba’s original automatic phase adjustment function.

---

**Table 1.2.2 Microcomputer list sine-wave drive type (Example of products)**

<table>
<thead>
<tr>
<th>Part Number</th>
<th>Package</th>
<th>ROM Size (Bytes)</th>
<th>RAM Size (Bytes)</th>
<th>Max. Operating Frequency (MHz)</th>
<th>Operating Voltage (V)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Min</td>
</tr>
<tr>
<td>TMPM375FSDMG</td>
<td>SSOP30</td>
<td>64 K</td>
<td>4 K</td>
<td>40(Note 1)</td>
<td>4.5</td>
</tr>
<tr>
<td>TMPM372FWUG</td>
<td>LQFP64</td>
<td>128 K</td>
<td>6 K</td>
<td>80(Note 2) 32(Note 1)</td>
<td>4.5</td>
</tr>
<tr>
<td>TMPM373FWDUG</td>
<td>LQFP48</td>
<td>256 K</td>
<td>10 K</td>
<td>80(Note 2)</td>
<td>4.5</td>
</tr>
<tr>
<td>TMPM374FWUG</td>
<td>LQFP44</td>
<td>512 K</td>
<td>32 K</td>
<td>80(Note 2)</td>
<td>4.5</td>
</tr>
<tr>
<td>TMPM370FYDFG</td>
<td>QFP100</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>TMPM370FYFG</td>
<td>LQFP100</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>TMPM376FDDFG</td>
<td>QFP100</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>TMPM376FDFG</td>
<td>LQFP100</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Note 1:** Ambient temperature -40℃～105℃

**Note 2:** Ambient temperature -40℃～85℃

---

### 2. Outline dimensions and marking of the SSOP30 package

The SSOP30 package simplifies board trace routing because it has high-voltage and control
pins on opposite sides. In addition, the SSOP30 package is thin and small.

2.1. Package outline dimensions

P-SSOP30-1120-1.00-001

Unit: mm

Figure 2.1 Outline dimensions of the SSOP30 package
2.2. Marking

Figure 2.2 Part marking on the SSOP30 package

2.3. PCB land pattern dimensions (Reference)

(Unit: mm)

Figure 2.3 Land pattern of the SSOP30 (Reference)
2.4. Soldering

Recommended soldering methods

<table>
<thead>
<tr>
<th>Method</th>
<th>Reflow soldering</th>
<th>Flow soldering</th>
<th>Soldering iron</th>
</tr>
</thead>
<tbody>
<tr>
<td>3 times maximum</td>
<td>Not supported</td>
<td></td>
<td>Only once</td>
</tr>
</tbody>
</table>

1) Reflow
   - Peak temperature: Maximum 260°C / a moment
   - Internal device temperature / period: 230°C or more / 30 to 50 seconds
   - Pre-heat temperature / period: 180 to 190°C / 60 to 120 seconds

   Note: Maximum mounting temperature is based on package surface temperature.

   Figure 2.4 shows the temperature profile. This profile represents the maximum device temperature at which device performance can be guaranteed. The preheat temperature and heating temperature will be governed by factors such as the type of solder paste used, but must be within the range shown in Figure 2.4.

   The package is carefully wrapped to be protected against humidity. After unwrapping, the package should be maintained at 30°C and 60% RH until the final reflow stage, and mounting should be completed within 168 hours.

   ![Figure 2.4 Example of a reflow soldering profile](image)

2) Flow
   - This package is not suitable for solder flow mounting.

3) Soldering iron
   - Heating method: Via lead tip of soldering iron
   - Heating condition: 400°C (at tip) for no more than 3sec
   - Repetition: No repetitions (once only per terminal)

• Note:
  - Check solder bonding strength via in-house testing at the substrate mounting stage.
2.5. Attaching a heatsink

A heatsink may be required, depending on the ambient temperature or the heating of the HVIPD or its neighboring devices. Attach a heatsink as described below if necessary.

- Heatsink attachment example
  1) Example of using an insulating sheet

  ![Heatsink attachment example (using an insulating sheet)](image1)

  **Figure 2.5.1 Heatsink attachment example (using an insulating sheet)**

  2) Example of using resin or gelatinous insulating material

  ![Heatsink attachment example (using resin or gelatinous insulating material)](image2)

  **Figure 2.5.2 Heatsink attachment example (using resin or gelatinous insulating material)**

  3) Example of other heatsink attachment method

  ![Heatsink attachment example (other methods)](image3)

  **Figure 2.5.3 Soldering**  **Figure 2.5.4 Pushpin**  **Figure 2.5.5 Adhesion attachment**

---

**Table 2.5.1 Example of parts used**

<table>
<thead>
<tr>
<th>Part</th>
<th>Specification</th>
</tr>
</thead>
<tbody>
<tr>
<td>Screw</td>
<td>M3</td>
</tr>
<tr>
<td>Insulating sheet</td>
<td>Soft material</td>
</tr>
<tr>
<td></td>
<td>t=0.5mm</td>
</tr>
<tr>
<td>Height spacer</td>
<td>t=2.5mm</td>
</tr>
<tr>
<td></td>
<td>Holes:3.2Φ</td>
</tr>
</tbody>
</table>
The result of having measured the case temperature in the substrate for evaluation which attached the radiator plate with soldering is shown in reference.

Evaluation conditions: \( V_{BB}=280\,\text{V}, \, V_{CC}=15\,\text{V} \), motor number of rotations = regularity (1500rpm), \( f_c=16.5\,\text{kHz} \), \( T_a=25^\circ\text{C} \)

In combination with substrate for our company evaluation (TPD4204F+TB6551FAG), Heatsink (three types), Variable of the load of a fan motor is carried out, and case temperature is measured.

![Images of substrate evaluation and temperature survey position]

**Figure 2.5.6 The substrate for evaluation, and a temperature survey position**

<table>
<thead>
<tr>
<th>TYPE-A</th>
<th>TYPE-B</th>
<th>TYPE-C</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image" alt="Image of TYPE-A heatsink" /></td>
<td><img src="image" alt="Image of TYPE-B heatsink" /></td>
<td><img src="image" alt="Image of TYPE-C heatsink" /></td>
</tr>
<tr>
<td>Sankyo Thermo Tech Type:20FSH036-L36-WFL-B</td>
<td>Sankyo Thermo Tech Type:20FSH036-L64-WFL-B</td>
<td>Sankyo Thermo Tech Type:16FSH064-L36-WFL-B</td>
</tr>
<tr>
<td>Length:36 × Width:36 × Height:20mm</td>
<td>Length:36 × Width:64 × Height:20mm</td>
<td>Length:36 × Width:64 × Height:16mm</td>
</tr>
<tr>
<td>Surface area:115cm²</td>
<td>Surface area:202cm²</td>
<td>Surface area:163cm²</td>
</tr>
</tbody>
</table>
Figure 2.5.8 Bent PCB

3. Pin description

3.1. Pin assignment

<table>
<thead>
<tr>
<th>Pin No.</th>
<th>Symbol</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>NC</td>
<td>No-connect pin, which is not connected to the internal chip</td>
</tr>
<tr>
<td>2</td>
<td>NC</td>
<td>No-connect pin, which is not connected to the internal chip</td>
</tr>
<tr>
<td>3</td>
<td>NC</td>
<td>No-connect pin, which is not connected to the internal chip</td>
</tr>
<tr>
<td>4</td>
<td>DIAG</td>
<td>Open-drain diagnostic output. Connect a pull-up resistor to the DIAG pin. The DIAG pin is driven Low in the event of a fault (an overcurrent, overtemperature, or under voltage condition).</td>
</tr>
<tr>
<td>5</td>
<td>VCC</td>
<td>Control power supply pin (15V typical)</td>
</tr>
</tbody>
</table>
4. Functional descriptions and usage considerations

4.1. Protection features

Under voltage protection

The HVIPD incorporates an under voltage protection circuit, which prevents internal MOSFETs from operating in an unsaturated region when the VCC and VBS voltages drop. When VCC drops to VCCUVD (= 11V typical), all the MOSFET outputs shut down regardless of the input states. Under voltage protection has a hysteresis of 0.5V. When VCC rises back to VCCUVR (= 11.5V typical), the MOSFETs return to normal operation and turn on according to the input states. When VCC under voltage protection is tripped, the DIAG output toggles its state. However, the DIAG output might remain unchanged if VCC is lower than 7V. (All the MOSFET outputs shut down when VCC drops below 11V, even if the DIAG output does not toggle.) When VBS drops to
V_{BSUVD} (= 10V typical), all the high-side MOSFET outputs shut down. When V_{BS} rises back to V_{BSUVR} (= 10.5V typical), 0.5V higher than V_{BSUVD}, the high-side MOSFETs return to normal operation and operate according to the control signals. V_{BS} under voltage protection does not cause the DIAG output to toggle.

**Figure 4.1.1 V_{CC} Under voltage protection**

**Figure 4.1.2 V_{BS} Under voltage protection**

**Overcurrent protection**

The HVIPD incorporates a current limiter, which protects itself from excessive current at motor startup or when the rotor is locked. The current limiter senses the voltage across the current-sensing resistor connected to the RS pin. When this voltage exceeds V_{R} (= 0.5V typical), the MOSFET outputs temporarily shut down after a delay of 3μs (typical) to prevent a further
increase in current. Setting the control signals to all-Lows releases the HVIPD from current-limiting mode.

Selecting a current-limiting resistor:

\[ I_O = \frac{V_R}{R_1} \]

\( V_R \): Current-limiting voltage, \( I_O \): Current limit, \( R_1 \): Current-limiting resistor

### Table 4.1 Current-limiting voltage (from the Electrical Characteristics table) Unit: V

<table>
<thead>
<tr>
<th>Characteristics</th>
<th>Symbol</th>
<th>Min</th>
<th>Typ.</th>
<th>Max</th>
</tr>
</thead>
<tbody>
<tr>
<td>Current-limiting voltage</td>
<td>( V_R )</td>
<td>0.46</td>
<td>0.5</td>
<td>0.54</td>
</tr>
</tbody>
</table>

Setting the current-limiting delay time

The HVIPD incorporates a filter shown in Figure 4.1.3 to prevent the current limiter from malfunctioning because of the noise at the current-limiting resistor. The delay time from when the current limiter senses a current exceeding the current limit to when the MOSFETs outputs shut down is determined by the sum of the filtering time (dead time) of the filter and the delay time of the control circuit:

\[ \text{Current-limiting delay time} (D_t) = \text{filtering time} (\text{dead time}) + \text{control circuit delay} \]

If the current-limiting resistor has large noise, the dead time of the internal filter may be insufficient. In that case, an external filter should be added as shown below. Note that an external filter increases the current-limiting delay time (i.e., the time required for the MOSFET outputs to shut down).

### Table 4.2 Current-limiting delay time (from the Electrical Characteristics table) Unit: \( \mu s \)

<table>
<thead>
<tr>
<th>Characteristics</th>
<th>Symbol</th>
<th>Min</th>
<th>Typ.</th>
<th>Max</th>
</tr>
</thead>
<tbody>
<tr>
<td>Current-limiting delay time</td>
<td>( D_t )</td>
<td>1.5</td>
<td>3</td>
<td>5</td>
</tr>
</tbody>
</table>

![Figure 4.1.3 Internal circuit of the RS pin](image)

![Figure 4.1.4 Overcurrent protection operation](image)
Thermal shutdown
The HVIPD incorporates a thermal shutdown circuit to protect itself from excessive temperature. When an external factor or internally generated heat causes the chip temperature to rise to the thermal shutdown temperature (TSD), all the MOSFET outputs shut down regardless of the input states. Thermal shutdown has a hysteresis (ΔTSD) of 50°C typical. When the chip temperature drops below (TSD − ΔTSD), the MOSFETs return to normal operation and turn on according to the input states.

The HVIPD senses its chip temperature at one position. Suppose that MOSFETs are heat sources. The time taken to shut down the MOSFETs differs, depending on the distance between a heat source and the temperature sensor. Therefore, the chip temperature may be higher than the thermal shutdown temperature (TSD) when the thermal shutdown circuit is tripped.

![Figure 4.1.5 Thermal shutdown operation](image)

SD function
An overcurrent condition may be detected by an external circuit. Setting the SD pin Low causes all the MOSFET outputs to shut down after a delay of 2μs (typical). Setting the control signals to all-Lows releases the MOSFETs from shutdown mode.

4.2. VREG power supply
A regulated supply voltage from the VREG pin is generated from the VCC power supply. VREG can be used as a power supply not only for the internal circuit but also for an external control IC or other peripheral ICs.
Add an external capacitor to the VREG pin to prevent oscillation. A capacitor with a value of 0.1
μF to 1μF is recommended. As I\textsubscript{REG} increases, V\textsubscript{REG} becomes more susceptible to oscillation. Adjust the value of the capacitor if V\textsubscript{REG} oscillates under actual usage conditions. Table 4.2 shows the V\textsubscript{REG} output voltage.

### Table 4.2 Regulator voltage (at V\textsubscript{CC}=15V, I\textsubscript{REG}=30mA) Unit: V

<table>
<thead>
<tr>
<th></th>
<th>Min</th>
<th>Typ.</th>
<th>Max</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>6.5</td>
<td>7</td>
<td>7.5</td>
</tr>
</tbody>
</table>

#### 4.3. Power supply sequencing

We do not recommend the following power sequences:

- At power-up: Powering up V\textsubscript{CC} after V\textsubscript{BB} and control signals
- At power-down: Powering down V\textsubscript{CC} before V\textsubscript{BB} and control signals

#### Table 4.3.1 At power-up

<table>
<thead>
<tr>
<th>At power-up</th>
<th>〇/×</th>
</tr>
</thead>
<tbody>
<tr>
<td>V\textsubscript{CC}</td>
<td>V\textsubscript{BB}</td>
</tr>
<tr>
<td>V\textsubscript{BB}</td>
<td>V\textsubscript{CC}</td>
</tr>
<tr>
<td>Control signals</td>
<td>V\textsubscript{BB}</td>
</tr>
</tbody>
</table>

#### Table 4.3.1 At power-down

<table>
<thead>
<tr>
<th>At power-down</th>
<th>〇/×</th>
</tr>
</thead>
<tbody>
<tr>
<td>V\textsubscript{CC}</td>
<td>V\textsubscript{BB}</td>
</tr>
<tr>
<td>V\textsubscript{BB}</td>
<td>V\textsubscript{CC}</td>
</tr>
<tr>
<td>Control signals</td>
<td>V\textsubscript{BB}</td>
</tr>
</tbody>
</table>

〇: Recommended, ×: Unrecommended

Note that even when V\textsubscript{CC} and V\textsubscript{BB} are powered down, the device might be permanently damaged if the V\textsubscript{BB} line is disconnected by a relay or other means while the motor is running because this blocks a current recirculation path to V\textsubscript{BB}.
4.4. Calculating power losses

This section shows how to calculate power losses that occur when the output current is sinusoidal.

\[ P = P_{on} + P_t + P_{BB} + P_{CC} \]

(1) Conduction loss: \( P_{on} \)

\[ P_{on} = P_H + P_L + P_D \ (W) \]

- High-side MOSFET conduction loss: \( P_H = I^2 \times R_{onH} \times (1/8 + D/3\pi \times \cos\theta) \times 3 \)
- Low-side MOSFET conduction loss: \( P_L = I^2 \times R_{onL} \times (1/8 + D/3\pi \times \cos\theta) \times 3 \)
- Flywheel diode conduction loss: \( P_D = I \times V_F \times (1/8 - D/3\pi \times \cos\theta) \times 6 \)

\( I_p \): Peak motor winding current (A)
\( R_{onH}/R_{onL} \): On-resistance of the output MOSFET (Ω)
\( V_F \): Forward voltage drop of the FRD (V)
\( D \): PWM duty cycle (on-duty cycle of the high-side MOSFETs)
\( \theta \): Power factor

(2) MOSFET switching loss: \( P_t \)

\[ P_t = (W_{ton} + W_{toff}) \times f_C / n \times 6 \ (W) \]

- \( W_{ton} \): Turn-on loss (μJ per pulse)
- \( W_{toff} \): Turn-off loss (μJ per pulse)
- \( f_C \): Switching frequency (Hz)

(3) \( V_{BB} \) power loss: \( P_{BB} \)

\[ P_{BB} = V_{BB} \times I_{BB} \ (W) \]

\( I_{BB} \): \( V_{BB} \) supply current (A) * Supply current when all phases are off

(4) Steady-state power loss: \( P_{CC} \)

\[ P_{CC} = V_{CC} \times I_{CC} \ (W) \]

\( I_{CC} \): \( V_{CC} \) supply current (A) * Supply current during normal operation

**Figure 4.4 Motor current waveform for power loss calculation**
5. Application circuit example

5.1. Application circuit example

Figure 5.1 Application circuit example (for tripping the current limiter with an HVIPD)

Figure 5.2 Application circuit example (for tripping the current limiter with a motor controller IC or an MCU)
Table 5.1 shows typical external parts.

### Table 5.1 External parts for the application circuit

<table>
<thead>
<tr>
<th>Part</th>
<th>Recommended Value</th>
<th>Purpose</th>
<th>Note</th>
</tr>
</thead>
<tbody>
<tr>
<td>C\textsubscript{1}, C\textsubscript{2}, C\textsubscript{3}</td>
<td>25V/2.2(\mu)F</td>
<td>Bootstrap capacitors</td>
<td>(Note 1)</td>
</tr>
<tr>
<td>C\textsubscript{4}</td>
<td>25V/10(\mu)F</td>
<td>(V\textsubscript{CC}) voltage stability</td>
<td>(Note 2)</td>
</tr>
<tr>
<td>C\textsubscript{5}</td>
<td>25V/0.1(\mu)F</td>
<td>(V\textsubscript{CC}) surge absorption</td>
<td>(Note 2)</td>
</tr>
<tr>
<td>C\textsubscript{6}</td>
<td>25V/1(\mu)F</td>
<td>(V\textsubscript{REG}) voltage stability</td>
<td>(Note 2)</td>
</tr>
<tr>
<td>C\textsubscript{7}</td>
<td>25V/1000pF</td>
<td>(V\textsubscript{REG}) surge absorption</td>
<td>(Note 2)</td>
</tr>
<tr>
<td>R\textsubscript{1}</td>
<td>5.1k(\Omega)</td>
<td>DIAG pull-up resistor</td>
<td>(Note 3)</td>
</tr>
<tr>
<td>R\textsubscript{2}</td>
<td>10k(\Omega)</td>
<td>SD pull-up resistor</td>
<td>(Note 4)</td>
</tr>
<tr>
<td>R\textsubscript{3}</td>
<td>0.35(\Omega)±1% (1W)</td>
<td>Overcurrent detection</td>
<td>(Note 5)</td>
</tr>
</tbody>
</table>

**Note 1:** The required bootstrap capacitor value varies, depending on the motor drive conditions. The capacitor is biased by \(V\textsubscript{CC}\) and must be sufficiently derated.

Calculating the value of the bootstrap capacitor required:

\[
CB = IB \times \frac{\text{maximum high-side drive period}}{(V\textsubscript{CC} - VF(BSD) + VF(FRD) - 13.5)} \text{ (F)}
\]

- \(CB\): Minimum capacitance of the bootstrap capacitor
- \(IB\): Maximum supply current of the high-side driver
- \(VF\) (BSD): Forward voltage of the bootstrap diode
- \(VF\) (FRD): Forward voltage of the flywheel diode

**Note 2:** The capacitor values should be adjusted if noise occurs under actual usage conditions. Place the capacitors as close as possible to the IC leads to minimize ripple noise.

**Note 3:** The DIAG pin has an open-drain configuration. When unused, the DIAG pin should be connected to GND. The maximum rated current of the DIAG pin is 20mA. Therefore, when it is pulled up to 7V, the minimum resistor value is 350\(\Omega\).

**Note 3 and Note 4:** The recommended pull-up resistor values are:
- \(R\textsubscript{1}\): 1k\(\Omega\) to 10k\(\Omega\)
- \(R\textsubscript{2}\): 5k\(\Omega\) to 15k\(\Omega\)

**Note 5:** The current-sensing level is expressed as: \(I_0 = V\text{_R} \div R\textsubscript{3}\) (\(V\text{_R} = 0.5\text{V}\) typical)

In order that IS1/IS2/IS3 terminals which connects shunt resistance may avoid malfunction and destruction, please wiring length be short and design.

When wiring length becomes long, please attach the diode for surge protection between IS1/IS2/IS3 terminals -GND terminal.
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