High Voltage Intelligent Power Device 【HV-IPD】
Application note

Outline
This is application note of TOSHIBA High voltage intelligent power device that explains for specification, function, characteristic, package outside dimension and the notes of use of TPD414 series products.
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1. Outline

1.1. High voltage intelligent power device

This is a single chip inverter IC and TOSHIBA original SOI(Silicon on insulator) process device. As shown in the following figure, it has control circuit of IGBT gate drive circuit, Bootstrap circuit used for high side gate drive power supply, Various protection circuits, Level shift circuit, Logic circuit. And it has also six IGBT and FRD in single chip devise. It has function of direct drive three phase brushless DC motor. It is the optimal product for motor control of home appliance.

Figure 1.1 High voltage intelligent power device

※Brushless DC motor

As shown in the following(left) figure, DC motor with Brash has to exchange brash periodically because brash controls the current which flows mechanically and it will wear in out. On the other hand, as shown in the following (right) figure, DC brushless motor can change the polarity of driving current by feeding back position detection signals, such as Hall device and Hall IC, to an inverter(IPD). It can drive a motor. Therefore, a brushless DC motor brush becomes unnecessary and the motor life is characterized by a long time compared with DC motor with a brush.

Figure 1.2 DC motor with brush / brushless outline
1.2. SOI

SOI is the symbol of Silicon On Insulator. SOI is a process technology in which the semiconductor chip is constructed on an insulator such that the high voltage output element and the logic/drive circuits of fine patterning can be realized on a single device.

![SOI POWER IC CROSS SECTION](image)

**Figure 1.3** SOI power IC cross section

**Feature**
- Achieved simple process by using our own wafer direct-bonding technology.
- Trench isolation enables minimization of isolation area.
- High voltage (~500V) IC. It can make inverter circuit directly from utility power.
- This is the IC that high voltage output portion and logic/drive circuits of fine patterning are realized on one chip.
- Each device in IC are completely separated by dielectric material. It is possible to make high reliability system by avoiding effect of parasitic device.

![DEVICE SEPARATED STRUCTURE](image)

**Figure 1.4** SOI device cross section
1.3. Wave control method

There are two type wave control methods. They are square control type(120 degree control type) and sine-wave control type(180 degree control type) which drive six IGBT switches for controlling a three phase brushless DC motor.

The square control type(120 degree control type) motor winding current is controlled to square form from making a middle class U phase, V phase, and W phase turn on electricity so that the turning-on-electricity period of each phase will be 120 degrees. The square control type of Toshiba high voltage intelligent power device adapts 120 degree control type. And, It can drive square control by using position detection signals, such as Hall device and Hall IC and speed control Vs input for high side PWM control by 1PKG(1chip).

The sine wave control type(180 degree control type) motor winding current is controlled to sine wave form from making a middle class U phase, V phase, and W phase turn on electricity so that the using with the Microcontroller or Motor control IC(show you the P10).

<table>
<thead>
<tr>
<th>Condition: V_{BB}=280V/V_{CC}=15V/V_{S}=4V</th>
</tr>
</thead>
<tbody>
<tr>
<td>V_U [200V/div]</td>
</tr>
<tr>
<td>V_V [200V/div]</td>
</tr>
<tr>
<td>V_W [200V/div]</td>
</tr>
<tr>
<td>I_U [0.5A/div]</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Condition: V_{BB}=280V/V_{CC}=15V</th>
</tr>
</thead>
<tbody>
<tr>
<td>V_U [200V/div]</td>
</tr>
<tr>
<td>V_V [200V/div]</td>
</tr>
<tr>
<td>V_W [200V/div]</td>
</tr>
<tr>
<td>I_U [0.5A/div]</td>
</tr>
</tbody>
</table>

**Figure 1.5  Square-wave control type and Sine-wave type wave form**

The features of Square-wave control type(120 degree control type) and Sine-wave control type(180 degree control type) are shown in a bottom table.

| Table1.1 The features of Square-wave control type and Sine-wave control type |
|-----------------------------------------------|-----------------------------------------------|
| Square-wave control type (120 degree control) | Sine-wave control type (180 degree control) |
| Noise/Vibration                               | △                                             |
| Efficiency                                    | △                                             |
| Load change                                   | ○                                             |
| Total cost                                    | △                                             |
| Others                                        | Easy control circuit, Components mounting area: small |
|                                              | Complicated control circuit, Components mounting area: large |
2. Product information

2.1. Product list

<table>
<thead>
<tr>
<th>Product name</th>
<th>Rating</th>
<th>Hall sensor input signal</th>
<th>3 phase matrix logic</th>
<th>Level shift &amp; Driver</th>
<th>Over current</th>
<th>Over temp</th>
<th>Under voltage</th>
<th>Control type</th>
<th>Motor output (Note:1)</th>
</tr>
</thead>
<tbody>
<tr>
<td>TPD4151K</td>
<td>250V/1A</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>120°~40W</td>
<td></td>
</tr>
<tr>
<td>TPD4142K/TPD4146K (Note:2)</td>
<td>500V/1A</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>120°~40W</td>
<td></td>
</tr>
<tr>
<td>TPD4123K</td>
<td>500V/1A</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>180°~40W</td>
<td></td>
</tr>
<tr>
<td>TPD4123AK</td>
<td>500V/1A</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>180°~40W</td>
<td></td>
</tr>
<tr>
<td>TPD4144K</td>
<td>500V/2A</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>180°~80W</td>
<td></td>
</tr>
<tr>
<td>TPD4144AK</td>
<td>500V/2A</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>180°~80W</td>
<td></td>
</tr>
<tr>
<td>TPD4135K</td>
<td>500V/3A</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>180°~120W</td>
<td></td>
</tr>
<tr>
<td>TPD4135AK</td>
<td>500V/3A</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>180°~120W</td>
<td></td>
</tr>
</tbody>
</table>

Note 1: The motor output is reference value and is different depending on the drive operating and temperature condition.

Note 2: TPD4142K・・・FR pin can control forward/reverse rotation(rotation pulse output:3 pulse)
TPD4146K・・・FGC pin can control rotation pulse output 1pulse/3pulse(reverse rotation)

Note 3: It is controlled by Microcontroller or Control IC.(Refer to Toshiba recommendation products:P10)

Square-wave control type (120 degree control) _TPD4151K/TPD4142K/TPD4146K_

It can drive square-wave control by using position detection signals, such as Hall device and Hall IC and microcontroller’s speed control signal for high side PWM control.

---

Figure 2.1  Square-wave control type (120 degree control)  Brock diagram
Sine-wave control type (180 degree control)

It can drive sine-wave control which controls low noise / low vibration motor with microcontroller or motor control IC (Refer to Toshiba recommendation products: P10).

**TPD4123K/TPD4144K/TPD4135K**

The over current protection is built in.

**Figure 2.2 Sine-wave control type (180 degree control)_K type Brock diagram**

**TPD4123AK/TPD4144AK/TPD4135AK**

The over current protection is deleted and the SD (shut down) function is added.

**Figure 2.3 Sine-wave control type (180 degree control)_AK type Brock diagram**
### Table 2.2 Toshiba motor control IC product list_Sine-wave control type(recommendation)

<table>
<thead>
<tr>
<th>Product name</th>
<th>PKG</th>
<th>Vcc / Io</th>
<th>Position detection</th>
<th>機能</th>
<th>Auto lead angle control</th>
<th>OSC circuit</th>
<th>Current limit</th>
<th>Gate block</th>
<th>Unusual position detection</th>
<th>Vcc Under voltage</th>
</tr>
</thead>
<tbody>
<tr>
<td>TB6551FAG</td>
<td>SSOP24</td>
<td>12V/2mA</td>
<td>Hall IC</td>
<td></td>
<td>External</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>TB6556FG</td>
<td>SSOP30</td>
<td>12V/2mA</td>
<td>Hall IC</td>
<td></td>
<td>○</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>TB6584FNG/AFNG</td>
<td>SSOP30</td>
<td>18V/2mA</td>
<td>Hall device/IC</td>
<td></td>
<td>○</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>TB6631FNG</td>
<td>SSOP30</td>
<td>18V/2mA</td>
<td>Hall device/IC</td>
<td>○※</td>
<td>○</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

※Internal automatic lead angle control by frequency of FG signal.
2.2. Absolute Maximum Ratings

It is a detail description about the absolute maximum rating written in specifications. Absolute maximum rating shows the rated value which must not exceed on any operating conditions.

**Square-wave control type (120 degree type) (Example: TPD4142K)**

### Absolute Maximum Ratings (Ta = 25°C)

<table>
<thead>
<tr>
<th>Characteristics</th>
<th>Symbol</th>
<th>Rating</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Power supply voltage</td>
<td>V_BB</td>
<td>500</td>
<td>V</td>
</tr>
<tr>
<td></td>
<td>V_CC</td>
<td>20</td>
<td>V</td>
</tr>
<tr>
<td>Output current (DC)</td>
<td>I_out</td>
<td>2</td>
<td>A</td>
</tr>
<tr>
<td>Output current (pulse)</td>
<td>I_{outp}</td>
<td>2</td>
<td>A</td>
</tr>
<tr>
<td>Input voltage (except V_S)</td>
<td>V_IN</td>
<td>-0.5 to V_{REG} + 0.5</td>
<td>V</td>
</tr>
<tr>
<td>Input voltage (only V_S)</td>
<td>V_{VS}</td>
<td>8.2</td>
<td>V</td>
</tr>
<tr>
<td>V_{REG} current</td>
<td>I_{REG}</td>
<td>50</td>
<td>mA</td>
</tr>
<tr>
<td>FG voltage</td>
<td>V_{FG}</td>
<td>20</td>
<td>V</td>
</tr>
<tr>
<td>FG current</td>
<td>I_{FG}</td>
<td>20</td>
<td>mA</td>
</tr>
<tr>
<td>Power dissipation (Ta = 25°C)</td>
<td>P_C</td>
<td>23</td>
<td>W</td>
</tr>
<tr>
<td>Operating junction temperature</td>
<td>T_{jopr}</td>
<td>-40 to 135</td>
<td>°C</td>
</tr>
<tr>
<td>Junction temperature</td>
<td>T_{j}</td>
<td>150</td>
<td>°C</td>
</tr>
<tr>
<td>Storage temperature</td>
<td>T_{stg}</td>
<td>-55 to 150</td>
<td>°C</td>
</tr>
</tbody>
</table>

Please implement the measure against a noise, and against surge so that power supply voltage does not exceed rated value at the time of stillness and operation. Refer to the P36 for the measure method.

If I_{REG} increases, it will become easy to oscillate V_{REG} voltage. Please use I_{REG} in 50mA or less.

From power dissipation, the heat thermal resistance R_{th(j-c)} is set to about 4.8 °C/W. (135°C-25°C)/23W@T_{a}=25°C

---

**Sine-wave control type (180degree type) (Example: TPD4144K)**

### Absolute Maximum Ratings (Ta = 25°C)

<table>
<thead>
<tr>
<th>Characteristics</th>
<th>Symbol</th>
<th>Rating</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Power supply voltage</td>
<td>V_BB</td>
<td>500</td>
<td>V</td>
</tr>
<tr>
<td></td>
<td>V_CC</td>
<td>18</td>
<td>V</td>
</tr>
<tr>
<td>Output current (DC)</td>
<td>I_out</td>
<td>2</td>
<td>A</td>
</tr>
<tr>
<td>Output current (pulse 1ms)</td>
<td>I_{outp}</td>
<td>3</td>
<td>A</td>
</tr>
<tr>
<td>Input voltage</td>
<td>V_IN</td>
<td>-0.5 to 7</td>
<td>V</td>
</tr>
<tr>
<td>V_{REG} current</td>
<td>I_{REG}</td>
<td>50</td>
<td>mA</td>
</tr>
<tr>
<td>DIAG voltage</td>
<td>V_{DIAG}</td>
<td>20</td>
<td>V</td>
</tr>
<tr>
<td>DIAG current</td>
<td>I_{DIAG}</td>
<td>20</td>
<td>mA</td>
</tr>
<tr>
<td>Power dissipation (IGBT1 phase (Ta = 25°C))</td>
<td>P_C(IGBT)</td>
<td>36</td>
<td>W</td>
</tr>
<tr>
<td>Power dissipation (FRD1 phase (Ta = 25°C))</td>
<td>P_C(FRD)</td>
<td>22</td>
<td>W</td>
</tr>
<tr>
<td>Operating junction temperature</td>
<td>T_{jopr}</td>
<td>-40 to 135</td>
<td>°C</td>
</tr>
<tr>
<td>Junction temperature</td>
<td>T_{j}</td>
<td>150</td>
<td>°C</td>
</tr>
<tr>
<td>Storage temperature</td>
<td>T_{stg}</td>
<td>-55 to 150</td>
<td>°C</td>
</tr>
</tbody>
</table>

Please implement the measure against a noise, and against surge so that power supply voltage does not exceed rated value at the time of stillness and operation. Refer to the P40 for the measure method.

If I_{REG} increases, it will become easy to oscillate V_{REG} voltage. Please use I_{REG} in 50mA or less.

From power dissipation, the heat thermal resistance R_{th(j-c)(IGBT)} is set to about 3.1 °C/W and R_{th(j-c)(FRD)} is set to about 5.0 °C/W.  
(135°C-25°C)/36W@T_{a}=25°C(IGBT1phase)  
(135°C-25°C)/22W@T_{a}=25°C(FRD1phase)
3. Feature/Size/Display of DIP26 package

3.1. Feature of DIP26 package

It can be easy for design of PCB because High voltage power pin and control pin is separated into the both side of package. And, The thin package and high voltage pin to pin clearance is wide. Moreover, this package can secure high heat dissipation nature because it has a metal heat dissipation side in the package surface.

![DIP26 package](image)

Figure 3.1 DIP26 package

3.2. Size of DIP26 package

Mass: 3.8g

Unit: mm

![DIP26 package size](image)

Figure 3.2 DIP26 package size
3.3. Display of DIP26 package

![DIP26 package display](image)

**Figure 3.3** DIP26 package display

The view of Part №

TPD 4144AK

A series name is expressed.

Toshiba high voltage intelligent power device is expressed.

The view of Lot code

3 05

A manufacture week (till 53 weeks) is expressed according to circumference of two characters.

One character shows the single figure end of a year of manufacture (A.D.).

When Lot code is 『 305 』, it expressed that having been manufactured at the 5th week in 2013.
## 4. Pin explanation

### 4.1. Pins arrangement for every product

#### Table 4.1  Pins arrangement list for every product

<table>
<thead>
<tr>
<th>Pin No.</th>
<th>Square-wave control type</th>
<th>Sine-wave control type</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>TPD4151K TPD4142K</td>
<td>TPD4146K</td>
</tr>
<tr>
<td>1</td>
<td>GND</td>
<td>GND</td>
</tr>
<tr>
<td>2</td>
<td>HU+</td>
<td>NC※</td>
</tr>
<tr>
<td>3</td>
<td>HU-</td>
<td>NC※</td>
</tr>
<tr>
<td>4</td>
<td>HV+</td>
<td>HU</td>
</tr>
<tr>
<td>5</td>
<td>HV-</td>
<td>HV</td>
</tr>
<tr>
<td>6</td>
<td>HW+</td>
<td>HW</td>
</tr>
<tr>
<td>7</td>
<td>HW-</td>
<td>LU</td>
</tr>
<tr>
<td>8</td>
<td>FR</td>
<td>FGC</td>
</tr>
<tr>
<td>9</td>
<td>FG</td>
<td>LW</td>
</tr>
<tr>
<td>10</td>
<td>$V_{REG}$</td>
<td>RS</td>
</tr>
<tr>
<td>11</td>
<td>$V_{CC}$</td>
<td>DIAG</td>
</tr>
<tr>
<td>12</td>
<td>OS</td>
<td>NC※</td>
</tr>
<tr>
<td>13</td>
<td>$R_{REF}$</td>
<td>$V_{REG}$</td>
</tr>
<tr>
<td>1</td>
<td>$V_{S}$</td>
<td>NC※</td>
</tr>
<tr>
<td>15</td>
<td>RS</td>
<td>$V_{CC}$</td>
</tr>
<tr>
<td>16</td>
<td>GND</td>
<td>GND</td>
</tr>
<tr>
<td>17</td>
<td>BSU</td>
<td>U</td>
</tr>
<tr>
<td>18</td>
<td>U</td>
<td>BSU</td>
</tr>
<tr>
<td>19</td>
<td>NC※</td>
<td>IS1</td>
</tr>
<tr>
<td>20</td>
<td>IS1</td>
<td>IS2</td>
</tr>
<tr>
<td>21</td>
<td>V</td>
<td>BSV</td>
</tr>
<tr>
<td>22</td>
<td>BSV</td>
<td>V</td>
</tr>
<tr>
<td>23</td>
<td>$V_{BB}$</td>
<td>$V_{BB}$</td>
</tr>
<tr>
<td>24</td>
<td>BSW</td>
<td>BSW</td>
</tr>
<tr>
<td>25</td>
<td>W</td>
<td>W</td>
</tr>
<tr>
<td>26</td>
<td>IS2</td>
<td>IS3</td>
</tr>
</tbody>
</table>

※NC is an intact pin and it is not connected to the internal chip. Even when the NC pin is open, an electrical property is not affected, but it recommends soldering to a substrate.
## 4.2. The function of each pins

1. A pin function list common to all the pins

**Table 4.2  A pin function list common to all the pins.**

<table>
<thead>
<tr>
<th>№</th>
<th>Pin</th>
<th>Item</th>
<th>Function</th>
<th>Pertinent details</th>
<th>Remarks</th>
</tr>
</thead>
</table>
| 1 | VCC | Control supply pin | ・VCC supplies for a low side driver, the bootstrap capacitor for a high side driver and a $V_{REG}$ circuit, etc.  
・If you prevent a malfunction by the noise and a power supply ripple, please connect the capacitor between GND and VCC that has a sufficient frequency characteristic. | $V_{CC}$ under Voltage protection function  
Application circuit example | |
| 2 | VBB | High voltage power supply pin | ・It is connected to the collector of a high side IGBT switch.  
・When surge voltage occurs by the inductor ingredient of a pattern, please connect the capacitor between GND and VBB that has a sufficient frequency characteristic. | Application circuit example | High voltage pin |
| 3 | VREG | Regulator Output pin | ・It is an output pin of the regulator generated by $V_{CC}$.  
・If you prevent a malfunction by the noise and a power supply ripple, please connect the capacitor between GND and $V_{REG}$ that has a sufficient frequency characteristic. | $V_{REG}$ power supply  
Application circuit example | |
| 4 | BSU BSV BSW | Boot strap capacitor Connect pin | ・It supplies a power supply to a high side driver.  
・Please connect a bootstrap capacitor between U, V, and W, respectively.  
・The stress voltage of a bootstrap capacitor becomes a VCC voltage value. Please take derating into consideration enough. | $V_{BS}$ under voltage protection  
Boot strap circuit  
Application circuit example | High voltage pin |
| 5 | GND | GND pin | ・It is an earth pin of a power supply. | — | — |
| 6 | IS1 IS2 IS3 | IGBT emitter/FRD anode pin | ・It is connected to the emitter of the low side IGBT and the anode of FRD.  
・Please let IS1, IS2, and IS3 short near the IC pin. When one or two pins are open, IC may be broken. | — | Square-wave control type has only IS1(U,V) and IS2(W). |
| 7 | U V W | Output pin | ・It is an output terminal of the three phase inverter constituted from six IGBT(s) and FRD(s). | — | High voltage pin |
### A different pin function for every product

#### Table 4.3 A different pin function list for every product

<table>
<thead>
<tr>
<th>№</th>
<th>Pin</th>
<th>Item</th>
<th>Product</th>
<th>Function</th>
<th>Pertinent details</th>
</tr>
</thead>
</table>
| 1 | RS  | Current limit detection pin | TPD4151K  
TPD4142K  
TPD4146K  
TPD4123K  
TPD4144K  
TPD4135K | • Please connect current detection resistance between GND.  
• It monitors the voltage value of over-current detection resistance, judges exceed $V_R=0.5V\, (\text{typ})$ with an over-current state, and protects an output element. | Current limiting / Over current protection  
Application circuit example |
| 2 | VS  | Speed control signal input pin | TPD4151K  
TPD4142K  
TPD4146K  
TPD4123K  
TPD4144K  
TPD4135K | • A rate control signal is inputted. Duty of a PWM signal can be changed with this signal.  
• When there is fear of malfunction by a noise, please connect the filter circuit by resistor and capacitor. | Speed control PWM  
Application circuit example |
| 3 | RREF/OS | PWM triangular wave oscillation frequency setup pin | TPD4151K  
TPD4142K  
TPD4146K  
TPD4123K  
TPD4144K  
TPD4135K | • PWM (clock) frequency can be set up by connecting resistance to a $R_{\text{REF}}$ pin and connecting a capacitor to OS pin.  
• The PWM (clock) frequency $f_C$ is decided by the following formula.  
\[ f_C = \frac{0.65}{C_{\text{OS}} \times (R_{\text{REF}} + 4.25k\Omega)} \] | Application circuit example |
| 4 | FG  | Rotation pulse output pin | TPD4151K  
TPD4142K  
TPD4146K  
TPD4123K  
TPD4144K  
TPD4135K | • A pulse is outputted according to the hall device input signal HU, HV, and HW.  
• Motor number of rotations can be monitored by measuring the output frequency of FG. | |
| 5 | DIAG | Anomaly diagnosis output pin | TPD4123K  
TPD4123AK  
TPD4144K  
TPD4144AK  
TPD4135K  
TPD4135AK | • The diagnostic output terminal of open Drain structure is turned on at the time of abnormalities (Over current / Thermal shutdown / Under voltage of $V_{\text{CC}}$ / SD function).  
• When you use it, please carry out a pull up by resistor.  
DIAG output voltage $= 0.5V(\text{max})$  
$\text{I}_{\text{DIAG}} = 5mA$ | $V_{\text{CC}}$ under voltage protection / Thermal shutdown function / Over current protection / SD function |

- **Input resistor/capacitor**  
TPD4151K: $202k\Omega$, 5pF  
TPD4142K: $158k\Omega$, 10pF  
TPD4146K: $158k\Omega$, 10pF  
TPD4123K/TPD4144K/TPD4144AK: $200k\Omega$, 5pF  
TPD4135K/TPD4135AK: $442k\Omega$, 5pF
<table>
<thead>
<tr>
<th>№</th>
<th>Pin</th>
<th>Item</th>
<th>Product</th>
<th>Function</th>
<th>Pertinent details</th>
</tr>
</thead>
</table>
| 6 | FR  | Forward/Reverse Selection pin | TPD4151K, TPD4142K | • If a H/L level is inputted into FR pin, forward/reverse can be changed.  
• When you change the forward/reverse of a motor with FR terminal, please change at the time of a motor stop. | — |
| 7 | FGC | FG pulse Count select pin | TPD4146K | • If a H/L level is inputted into FGC pin, number of FG pin output pulses 3 pulse/1 pulse can be changed. (Forward) | — |
| 8 | SD  | Input pin of external protection | TPD4123AK, TPD4144AK, TPD4135AK | • If a H/L level is inputted into SD pin, All off/Active of U/V/W high side and low side each IGBT can be changed.  
• SD: Judge a H/L level for 2.5V to a threshold value (with no hysteresis). | — |
| 9 | HU+ HU− HV+ HV− HW+ HW− | Hall amp signal input (Hall IC can be used) pin | TPD4151K, TPD4142K, TPD4146K | • The high side and low side each IGBT of U, V, and W are controlled ON and OFF by the input state (H/L) of hole amplifier (hole IC).  
• The input state of hole amplifier (hole IC)  
  High level: H※+ > H※−  
  Low level: H※+ < H※− | Application circuit example |
| 10 | HU HV HW LU LV LW | The control pin of IGBT | TPD4123K, TPD4123AK, TPD4144AK, TPD4135K, TPD4135AK | • The high side and low side each IGBT of U, V, and W are controlled ON and OFF by the input state (H/L) of signal HU~LW.  
• HU~LW input signal level  
  High level (2.5V~): IGBT ON  
  Low level (~1.5V): IGBT OFF | — |
5. Description of function, Handling precaution

5.1. Protection function

- Square-wave control type (TPD4151K/TPD4142K/TPD4146K)

**VCC Under voltage protection**

> The time of low side operation

![Diagram showing VCC under voltage protection timing chart](image1)

This product incorporates under voltage protection circuits to prevent the IGBT from operating in unsaturated mode when the VCC voltage drops. When the VCC power supply falls to this product internal setting VCC_UVD (= 11 V typ.), all IGBT outputs shut down regardless of the input. This protection function has hysteresis. When the VCC power supply reaches 0.5V higher than the shutdown voltage VCC_UVR (= 11.5 V typ.), this product is automatically restored and the IGBT is turned on again by the input signal.

- TPD4142K Condition: VCC=15V ⇒ 7V/VBB=280V/Vs=4V

![Figure 5.2 VCC Under voltage protection waveform of operation(Square-wave control type)](image2)
Under voltage protection

This product incorporates under voltage protection circuits to prevent the IGBT from operating in unsaturated mode when the $V_{BS}$ voltage drops. When the $V_{BS}$ power supply falls to this product internal setting $V_{BS UVD}$ (= 10 V typ.), high side IGBT outputs shut down. When the $V_{CC}$ power supply reaches 0.5V higher than the shutdown voltage $V_{BS UVR}$ (= 10.5 V typ.), the IGBT is turned on again by the input signal.

Thermal shutdown

This product incorporates a thermal shutdown circuit to protect itself against excessive rise in temperature. When the temperature of this chip rises to the internal setting $TSD$ due to external causes or internal heat generation, all IGBT outputs shut down regardless of the input. This protection function has hysteresis $\Delta TSD$ (= 50°C typ.). When the chip temperature falls to $TSD - \Delta TSD$, the chip is automatically restored and the IGBT is turned on again by the input. Because the chip contains just one temperature-detection location, when the chip heats up due to the IGBT for example, the distance between the detection location and the IGBT (the source of the heat) can cause differences in the time taken for shutdown to occur. Therefore, the temperature of the chip may raise higher than the initial thermal shutdown temperature.

Figure 5.3 $V_{BS}$ Under voltage protection timing chart (Square-wave control type)

Figure 5.4 Thermal shutdown timing chart (Square-wave control type)
> Thermal shutdown waveform of real operation

TPD4142K  Condition: $V_{CC}=15V$, $V_{BB}=280V$, $V_S=4V$, $R_S=0.8\Omega$

● Before detect the thermal shutdown (the time of over load).

● Detecting the thermal shutdown (the time of over load)

● Restoring the thermal shutdown (the time of current limit)

Figure 5.5 Thermal shutdown waveform of operation (Square-wave control type)
Current limit function

The product incorporates a current limit function to protect itself against over current at startup or when a motor is locked. The current limit function detects voltage generated in the current limiting resistor connected to the RS pin. When this voltage exceeds $V_R(=0.5V_{typ})$, the high side IGBT output, which is on, temporarily shuts down after a mask period, preventing any additional current from flowing to the IC. The next PWM ON signal releases the shut down state.

>$\text{Set up of current limiting resistance}$

$\text{Io} = \frac{V_R}{R_1}$

$V_R$: Current control voltage, $\text{Io}$: Current limiting value, $R_1$: Current limiting resistance

<table>
<thead>
<tr>
<th>Characteristics</th>
<th>Symbol</th>
<th>min</th>
<th>typ</th>
<th>max</th>
</tr>
</thead>
<tbody>
<tr>
<td>Current control voltage</td>
<td>$V_R$</td>
<td>0.46</td>
<td>0.5</td>
<td>0.54</td>
</tr>
</tbody>
</table>

In a current limiting value setup, it is necessary to take into consideration the variation of the current limiting resistance $R_1$ other than $V_R$ variation as shown in the above figure. A current limiting value ($\text{Io} =1A$ typ setup) in case current limiting resistance variations are $\pm1\%$ and $\pm5\%$ temporarily is compared with the following figure. Since the setting variation of a current limiting value will also become large if the variation in current limiting resistance is large, please choose small resistance of variation as much as possible.

<table>
<thead>
<tr>
<th>Characteristics</th>
<th>Symbol</th>
<th>min</th>
<th>typ</th>
<th>max</th>
</tr>
</thead>
<tbody>
<tr>
<td>$R_1$($0.5\Omega$)$\pm1%$</td>
<td>$\text{Io1}$</td>
<td>0.91</td>
<td>1.00</td>
<td>1.09</td>
</tr>
<tr>
<td>$R_1$($0.5\Omega$)$\pm5%$</td>
<td>$\text{Io2}$</td>
<td>0.88</td>
<td>1.00</td>
<td>1.14</td>
</tr>
</tbody>
</table>

![Diagram of High voltage intelligent power device](image)

**Figure 5.6 Description of Current limit function (Square-wave control type)**
Set up of current control delay time

This product has a filter circuit as shown in the following figure, in order that the noise which occurs in current limiting resistance may prevent a current limiting circuit from malfunctioning. Current limiting delay time from detecting the current exceeding a current limiting value to shut down the high side IGBT is determined by the sum of filter time (dead time) and the delay time of a control circuit.

Current control delay time \( D_t = \text{Filter time(dead time)} + \text{Control circuit delay time} \)

Refer to P16 for the filter circuit constant of each product.

When the noise level which occurs in current limiting resistance is large and filter time is short, please add an external filter, as shown in the following figure. However, keep in mind that time until IGBT turns off will increase if an external filter will be added.

<table>
<thead>
<tr>
<th>Characteristics</th>
<th>Symbol</th>
<th>min</th>
<th>typ</th>
<th>max</th>
</tr>
</thead>
<tbody>
<tr>
<td>Current control delay time</td>
<td>( D_t )</td>
<td>—</td>
<td>4.5</td>
<td>6.5</td>
</tr>
</tbody>
</table>

Handling precaution about a current limiting function

- This function is not effective to reflux current or regeneration current which do not flow through a current limiting resistor in the positive direction.
- Please use short wire current limiting resistance as much as possible.
- Please connect IS1 and IS2 pin as much as possible in a near position. If the wiring resistance from IS1 and IS2 pin to current limiting resistance has a difference, the current limiting value of each phase may not become equal.

Current limit function operation waveform

TPD4142K  Condition: \( V_{CC}=15V/V_{BB}=280V/V_s=4V(\text{Duty operator}) \)

- Current limiting (\( R_S=1\ \Omega \))
- Non-Current limiting (\( R_S=0\ \Omega \))

Figure 5.7 Current limit waveform of operation@\( V_s=4V(\text{Square-wave control type}) \)
>Current limit waveform of operation
TPD4142K  Condition: $V_{CC}=15\text{V}/V_{BB}=280\text{V}/V_{S}=6\text{V}(100\%\text{Duty})$

- Current limiting ($R_S=1\ \Omega$)

- Non-Current limiting ($R_S=0\ \Omega$)

Figure 5.8 Current limit waveform of operation@$V_S=6\text{V}$ (Square-wave control type)
Sine-wave control type (TPD4123K/TPD4144K/TPD4135K/TPD4123AK/TPD4144AK/TPD4135AK)

**Vcc Under voltage protection**

- The time of low side operation

> [Diagram]

- The time of high side operation

> [Diagram]

**Figure 5.9 Vcc Under voltage protection timing chart (Sine-wave control type)**

This product incorporates under voltage protection circuits to prevent the IGBT from operating in unsaturated mode when the Vcc voltage drops. When the Vcc power supply falls to this product internal setting VccUVD (= 11 V typ.), all IGBT outputs shut down regardless of the input. This protection function has hysteresis. When the Vcc power supply reaches 0.5V higher than the shutdown voltage VccUVR (= 11.5 V typ.), this product is automatically restored and the IGBT is turned on again by the input signal. At this time DIAG output is reversed simultaneously with detection of the under voltage protection of Vcc.

**Figure 5.10 Vcc Under voltage protection waveform of operation (Sine-wave control type)**
This product incorporates under voltage protection circuits to prevent the IGBT from operating in unsaturated mode when the $V_{BS}$ voltage drops. When the $V_{BS}$ power supply falls to this product internal setting $V_{BS\text{UVD}}$ (= 9V typ.), high side IGBT outputs shut down. When the $V_{CC}$ power supply reaches 0.5V higher than the shutdown voltage $V_{BS\text{UVR}}$ (= 9.5 V typ.), the IGBT is turned on again by the input signal. At this time DIAG output is not reversed.

**Figure 5.11 $V_{BS}$ Under voltage protection timing chart (Sine-wave control type)**

This product incorporates a thermal shutdown circuit to protect itself against excessive rise in temperature. When the temperature of this chip rises to the internal setting $TSD$ due to external causes or internal heat generation, all IGBT outputs shut down regardless of the input. This protection function has hysteresis $\Delta TSD$ (= 50°C typ.). When the chip temperature falls to $TSD - \Delta TSD$, the chip is automatically restored and the IGBT is turned on again by the input. Because the chip contains just one temperature-detection location, when the chip heats up due to the IGBT for example, the distance between the detection location and the IGBT (the source of the heat) can cause differences in the time taken for shutdown to occur. Therefore, the temperature of the chip may raise higher than the initial thermal shutdown temperature.

**Figure 5.12 Thermal shutdown timing chart (Sine-wave control type)**
Over current protection

The product incorporates a over current protection circuit to protect itself against over current at startup or when a motor is locked. This protection function detects voltage generated in the current detection resistor connected to the RS pin. When this voltage exceeds \( V_R = 0.5 \text{Vtyp.} \), the IGBT output, which is on, temporarily shuts down after a mask period, preventing any additional current from flowing to this product. The next all “L” signal releases the shutdown state. At this time DIAG output is reversed simultaneously with detection of the over current protection.

> Set up of current detection resistor

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

\( V_R \): Current detection voltage, \( I_O \):Over current value , \( R_1 \): Current detection resister

<table>
<thead>
<tr>
<th>Table 5.4 Standard value of Current detection voltage</th>
<th>Unit: V</th>
</tr>
</thead>
<tbody>
<tr>
<td>Characteristics</td>
<td>Symbol</td>
</tr>
<tr>
<td>Current detection voltage</td>
<td>( V_R )</td>
</tr>
</tbody>
</table>

> Set up of current control delay time

This product has a filter circuit as shown in the following figure, in order that the noise which occurs in current detection resistance may prevent a current detection circuit from malfunctioning. Current control delay time from detecting the current exceeding a over current value to shut down IGBT is determined by the sum of filter time (dead time) and the delay time of a control circuit.

Current control delay time \( D_t = \text{Filter time(dead time)} + \text{Control circuit delay time} \)

Refer to P16 for the filter circuit constant of each product.

When the noise level which occurs in current detection resistance is large and filter time is short, please add an external filter, as shown in the following figure. However, keep in mind that time until IGBT turns off will increase if an external filter will be added.

<table>
<thead>
<tr>
<th>Table 5.5 Standard value of Current control delay time</th>
<th>Unit: ( \mu s )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Characteristics</td>
<td>Symbol</td>
</tr>
<tr>
<td>Current limiting delay time</td>
<td>( D_t )</td>
</tr>
</tbody>
</table>

Figure 5.13 Description of Over current protection(Sine-wave control type)
> Thermal shutdown waveform of operation
TPD4144K Condition : \(V_{CC}=15V/V_{BB}=280V/V_S=3V/RS=0.5\Omega\)

- Detecting the thermal shutdown

- Restoring the thermal shutdown

Figure 5.14 Thermal shutdown waveform of operation (Sine-wave control type)

> Over current protection waveform of operation
TPD4144K Condition : \(V_{CC}=15V/V_{BB}=280V/V_S=3V/RS=1\Omega\)

Figure 5.15 Over current protection waveform of operation (Sine-wave control type)
5.2. Boot strap circuit/Speed control PWM operation (TPD4151K/TPD4142K/TPD4146K)

This product uses boot strap circuit for high side drivers power supply. Charge/discharge operation of a bootstrap capacitor is explained below with PWM operation of speed control voltage \( V_S \).

### Table 5.6 The output state and the bootstrap capacitor charge method for \( V_S \)

<table>
<thead>
<tr>
<th>( V_S ) input voltage</th>
<th>High side IGBT</th>
<th>Low side IGBT</th>
<th>Bootstrap capacitor Charge operation</th>
</tr>
</thead>
<tbody>
<tr>
<td>( 0 \leq V_S &lt; 1.3V )</td>
<td>All phase OFF</td>
<td>All phase OFF</td>
<td>—</td>
</tr>
<tr>
<td>( 1.3 \leq V_S &lt; 2.1V )</td>
<td>All phase OFF</td>
<td>1/5section(Duty:20%)ON</td>
<td>Low side IGBT ON section</td>
</tr>
<tr>
<td>( 2.1 \leq V_S &lt; 3.8V )</td>
<td>ON</td>
<td>1/5section(Duty:20%)ON</td>
<td>Low side IGBT ON section</td>
</tr>
<tr>
<td>( 3.8 \leq V_S \leq 5.4V )</td>
<td>ON</td>
<td>OFF</td>
<td>Low side FRD Regeneration section</td>
</tr>
</tbody>
</table>

(1) \( V_S = 0V \sim 2.1V \)

**Figure 5.16 Description of \( V_S \) and PWM operation(\( V_S = 0V \sim 2.1V \))**

On \( V_S \geq 1.3V \) condition, a bootstrap capacitor is charged in the course of the following figure by carrying out 1/5 section (Duty: 20%) ON of the low side IGBT. As shown in the above figure, the high side IGBT turns on by comparison of a triangle wave and \( V_S \) voltage in \( V_S = 2.1V \). If the high side IGBT turns on, the electric charged by the bootstrap capacitor in the course of the following figure will discharge.

**Figure 5.17 Description of Charging/Discharging boot strap capacitor(\( V_S = 1.3V \sim 2.1V \))**
(2) $V_S = 2.1V \sim 3.8V$

**Figure 5.18 Description of $V_S$ and PWM operation ($V_S = 2.1V \sim 3.8V$)**

On $2.1V \leq V_S \leq 3.8V$ condition, as shown in the above figure, high side IGBT ON period is decided by comparison of a triangle wave and $V_S$ voltage. The low side IGBT is carrying out 1/5 section (Duty: 20%) ON, and charges a bootstrap capacitor in the same course as $1.3V \leq V_S \leq 2.1V$.

(3) $V_S = 3.8V \sim 5.4V$

**Figure 5.19 Description of $V_S$ and PWM operation ($V_S = 3.8V \sim 5.4V$)**

On $3.8V \leq V_S \leq 5.4V$ condition, as shown in the above figure, high side IGBT ON period is decided by comparison of a triangle wave and $V_S$ voltage. Although the low side IGBT is All OFF in $3.8V \leq V_S$ (Duty: 55% or more) condition, PWM control is performed on the high side IGBT, diode regeneration current flows into the low side FRD by which PWM control is carried out, and a bootstrap capacitor is charged in the course of the following figure.

- Charging the boot strap capacitor (High side: OFF / Low side: OFF)

**Figure 5.20 Description of Charging/Discharging boot strap capacitor ($V_S = 3.8V \sim 5.4V$)**
In addition, on $V_S>5.4\,\text{V}$ conditions, since it becomes 100% duty operation, compared with $V_S<5.4\,\text{V}$ conditions, high side IGBT continuation drive time becomes extremely long. When especially motor revolving speed is slow, it needs to be cautious of the amount of electric charges of a bootstrap capacitor. Please check that capacity value is secured in the bootstrap minimum capacitance type (P35 reference), and fully use it after evaluation and examination.

5.3 $V_{\text{REG}}$ power supply

$V_{\text{REG}}$ power supply is generated from a $V_{\text{CC}}$ power supply. $V_{\text{REG}}$ power supply can be used as a power supply of not only the power supply of IC internal circuit but external controller IC, or other circumference IC. Please add a capacitor to a VREG terminal as prevention from an oscillation. Capacity recommends about $0.1\,\mu\text{F}~\sim~1\,\mu\text{F}$.

$V_{\text{REG}}$ voltage may be oscillated if $I_{\text{REG}}$ increases. Please adjust according to actual usage environment. Moreover, as shown in the following table, the output voltage values of a $V_{\text{REG}}$ power supply differ for every product.

| Table 5.7 Regulator voltage (Condition: $V_{\text{CC}}=15\,\text{V}$, $I_{\text{REG}}=30\,\text{mA}$) | Unit: V |
|---|---|---|
| Product name | min | typ | max |
| TPD4151K/TPD4142K/TPD4146K | 5 | 6 | 7 |
| TPD4123K/TPD4144K/TPD4135K/TPD4123AK/TPD4144AK/TPD4135AK | 6.5 | 7 | 7.5 |

5.4 Power supply sequence

● Square-wave control type (TPD4151K/TPD4142K/TPD4146K)

When the power supply starts up or stops down, ensures that $V_S<1.3\,\text{V}$ (all IGBT output OFF). Please follow the following table when the power supply starts up or stops down.

> Start up the power supply

<table>
<thead>
<tr>
<th>Power supply start up</th>
<th>①</th>
<th>②</th>
<th>③</th>
<th>O/X</th>
</tr>
</thead>
<tbody>
<tr>
<td>$V_{\text{CC}}$</td>
<td>$V_{\text{BB}}$</td>
<td>$V_S$</td>
<td>O</td>
<td></td>
</tr>
<tr>
<td>$V_{\text{CC}}$</td>
<td>$V_S$</td>
<td>$V_{\text{BB}}$</td>
<td>O</td>
<td></td>
</tr>
<tr>
<td>$V_{\text{BB}}$</td>
<td>$V_{\text{CC}}$</td>
<td>$V_S$</td>
<td>O</td>
<td></td>
</tr>
<tr>
<td>$V_{\text{BB}}$</td>
<td>$V_S$</td>
<td>$V_{\text{CC}}$</td>
<td>×</td>
<td></td>
</tr>
<tr>
<td>$V_S$</td>
<td>$V_{\text{CC}}$</td>
<td>$V_{\text{BB}}$</td>
<td>O</td>
<td></td>
</tr>
<tr>
<td>$V_S$</td>
<td>$V_{\text{BB}}$</td>
<td>$V_{\text{CC}}$</td>
<td>×</td>
<td></td>
</tr>
</tbody>
</table>

> Stop down the power supply

<table>
<thead>
<tr>
<th>Power supply stop down</th>
<th>①</th>
<th>②</th>
<th>③</th>
<th>O/X</th>
</tr>
</thead>
<tbody>
<tr>
<td>$V_{\text{CC}}$</td>
<td>$V_{\text{BB}}$</td>
<td>$V_S$</td>
<td>×</td>
<td></td>
</tr>
<tr>
<td>$V_{\text{CC}}$</td>
<td>$V_S$</td>
<td>$V_{\text{BB}}$</td>
<td>×</td>
<td></td>
</tr>
<tr>
<td>$V_{\text{BB}}$</td>
<td>$V_{\text{CC}}$</td>
<td>$V_S$</td>
<td>O</td>
<td></td>
</tr>
<tr>
<td>$V_{\text{BB}}$</td>
<td>$V_S$</td>
<td>$V_{\text{CC}}$</td>
<td>O</td>
<td></td>
</tr>
<tr>
<td>$V_S$</td>
<td>$V_{\text{CC}}$</td>
<td>$V_{\text{BB}}$</td>
<td>O</td>
<td></td>
</tr>
<tr>
<td>$V_S$</td>
<td>$V_{\text{BB}}$</td>
<td>$V_{\text{CC}}$</td>
<td>O</td>
<td></td>
</tr>
</tbody>
</table>

● Sine-wave control type (TPD4123K/TPD4144K/TPD4135K/TPD4123AK/TPD4144AK/TPD4135AK)

When the power supply starts up or stops down, ensures that control input is low level (all IGBT output OFF). Please follow the following table when the power supply starts up or stops down.

> Start up the power supply

<table>
<thead>
<tr>
<th>Power supply start up</th>
<th>①</th>
<th>②</th>
<th>③</th>
<th>O/X</th>
</tr>
</thead>
<tbody>
<tr>
<td>$V_{\text{CC}}$</td>
<td>$V_{\text{BB}}$</td>
<td>Control input</td>
<td>O</td>
<td></td>
</tr>
<tr>
<td>$V_{\text{CC}}$</td>
<td>Control input</td>
<td>$V_{\text{BB}}$</td>
<td>O</td>
<td></td>
</tr>
<tr>
<td>$V_{\text{BB}}$</td>
<td>Control input</td>
<td>$V_{\text{CC}}$</td>
<td>×</td>
<td></td>
</tr>
<tr>
<td>Control input</td>
<td>$V_{\text{CC}}$</td>
<td>$V_{\text{BB}}$</td>
<td>O</td>
<td></td>
</tr>
<tr>
<td>Control input</td>
<td>$V_{\text{BB}}$</td>
<td>$V_{\text{CC}}$</td>
<td>×</td>
<td></td>
</tr>
</tbody>
</table>

> Stop down the power supply

<table>
<thead>
<tr>
<th>Power supply stop down</th>
<th>①</th>
<th>②</th>
<th>③</th>
<th>O/X</th>
</tr>
</thead>
<tbody>
<tr>
<td>$V_{\text{CC}}$</td>
<td>$V_{\text{BB}}$</td>
<td>Control input</td>
<td>×</td>
<td></td>
</tr>
<tr>
<td>$V_{\text{CC}}$</td>
<td>Control input</td>
<td>$V_{\text{BB}}$</td>
<td>×</td>
<td></td>
</tr>
<tr>
<td>$V_{\text{BB}}$</td>
<td>Control input</td>
<td>$V_{\text{CC}}$</td>
<td>O</td>
<td></td>
</tr>
<tr>
<td>Control input</td>
<td>$V_{\text{CC}}$</td>
<td>$V_{\text{BB}}$</td>
<td>O</td>
<td></td>
</tr>
<tr>
<td>Control input</td>
<td>$V_{\text{BB}}$</td>
<td>$V_{\text{CC}}$</td>
<td>O</td>
<td></td>
</tr>
</tbody>
</table>

Note that if the power supply is switched off as described above, the IC may be destroyed if the current regeneration route to the $V_{\text{BB}}$ power supply is blocked when the $V_{\text{BB}}$ line is disconnected by a relay or similar while the motor is still running.
5.5. Loss calculation

The formula of square-wave control type and sine-wave control generating loss is shown below.

- **Square-wave control type (120 degree control)**
  - TPD4151K/TPD4142K/TPD4146K

\[
P = P_{on} + P_t + P_{iBB} + P_{iCC}
\]

(1) Output regular loss: \(P_{on}\)

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

- High side IGBT regular loss: \(P_H = I_{ave} \times V_{satH} \times D (W)\)
- Low side IGBT On loss: \(P_L = I_{ave} \times V_{satL} (W)\)
- Di regular loss: \(P_D = I_{ave} \times V_F \times (1-D) (W)\)

\[
I_{ave} = \text{Motor current (ave) (A)}
\]

\[
V_{satH} / V_{satL} = \text{Output IGBT Saturation voltage (V)}
\]

\[
V_F = \text{FRD forward voltage (V)}
\]

\[
D = \text{PWM Duty (High side IGBT ON Duty)}
\]

(2) Output IGBT switching loss: \(P_t\)

\[
P_t = (W_{on} + W_{off}) \times f_C (W)
\]

- \(W_{on}\) = Turn-on loss (μJ/pulse) (W)
- \(W_{off}\) = Turn-off loss (μJ/pulse) (W)
- \(f_C\) = PWM switching frequency (Hz)

(3) \(V_{BB}\) Current dissipation: \(P_{iBB}\) (W)

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

\[
I_{BB} = V_{BB} \text{dissipation (A)} \times \text{Dissipation current @ALL phase OFF}
\]

(4) \(V_{CC}\) Current dissipation: \(P_{iCC}\)

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

\[
I_{CC} = V_{CC} \text{dissipation (A)} \times \text{Dissipation current @operation}
\]

Figure 5.21  Motor current waveform image for loss calculation (square-wave control type)
Square wave control type (120 degree control) example of loss calculation (TPD4142K)

Operation condition: \( V_{BB} = 280 \text{V}, V_{CC} = 15 \text{V}, \text{Duty} = 60\% \)

![Image](image_url)

**Figure 5.22** Motor operation waveform of loss calculation (square-wave control)

1. Output regular loss: \( P_{on} \)
   \[
   P_{on} = P_H + P_L + P_D \text{(W)}
   \]
   Show the following figure which is electrical characteristic graph.
   - High side IGBT output regular loss: \( P_H = I_{ave} \times V_{satH} \times D \text{(W)} \)
     \[
     = 300 \text{mA} \times 1.7 \text{V} \times 0.6 = 0.306 \text{W}
     \]
   - Low side IGBT ON loss: \( P_L = I_{ave} \times V_{satL} \text{(W)} \)
     \[
     = 300 \text{mA} \times 1.7 \text{V} = 0.51 \text{W}
     \]
   - Di regular loss: \( P_D = I_{ave} \times V_F \times (1 - D) \text{(W)} = 0.174 \text{W} \)

![Image](image_url)

2. Output IGBT switching loss: \( P_t \)
   \[
   P_t = (W_{on} + W_{off}) \times f_C \text{(W)}
   \]
   \[
   = (28 \mu \text{J/pulse} + 12 \mu \text{J/pulse}) \times 20 \text{kHz} = 0.8 \text{W}
   \]
   - \( W_{on} = \text{Turn-on loss (}\mu \text{J/pulse}\) (W)
   - \( W_{off} = \text{Turn-off loss (}\mu \text{J/pulse}\) (W)
   - \( f_C = \text{PWM switching frequency (Hz)} \)

![Image](image_url)
(3) $V_{BB}$ Current dissipation : $P_{BB}$ (W)

$$P_{BB} = V_{BB} \times I_{BB} \text{ (W)}$$

$$= 280V \times 1 \mu A = 0.0003 W$$

(4) $V_{CC}$ Current dissipation : $P_{CC}$

$$P_{CC} = V_{CC} \times I_{CC} \text{ (W)}$$

$$= 15V \times 2.2mA = 0.033 W$$

Follow, $P = P_{on} + P_{t} + P_{IBB} + P_{ICC}$

$$= 0.99W + 0.8W + 0.0003W + 0.033W$$

$$= 1.8233W \approx 1.82W$$
Sine-wave control type (180degree control)

TPD4123K/TPD4144K/TPD4135K/TPD4123AK/TPD4144AK/TPD4135AK

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

(1) Output regular loss : \( P_{on} \)

High side IGBT regular loss : \( P_{on} = I \times V_{satH} \times (1/8 + D/3 \pi \times \cos \theta) \times 3 \)

Low side IGBT regular loss : \( P_{on} = I \times V_{satL} \times (1/8 + D/3 \pi \times \cos \theta) \times 3 \)

Diode regular loss : \( P_{D} = I \times V_{F} \times (1/8 - D/3 \pi \times \cos \theta) \times 6 \)

\( I_{p} \) = Motor current (A)

\( V_{satH}/V_{satL} \) = Output saturation voltage (V)

\( V_{F} \) = FRD forward voltage (V)

\( D = PWM\_Duty \)

(2) Output IGBT switching loss : \( P_{t} \)

\( P_{t} = (W_{on} + W_{off}) \times f_{C}/\pi \times 6 \)

\( W_{on} \) = Turn-on loss (\( \mu \)J/pulse) (W)

\( W_{off} \) = Turn-off loss (\( \mu \)J/pulse) (W)

\( f_{C} \) = Frequency (Hz)

(3) \( V_{BB} \) Current dissipation : \( P_{\text{is}} \) (W)

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

\( I_{BB} \) = \( V_{BB} \) dissipation (W)

(4) \( V_{CC} \) Current dissipation : \( P_{\text{ICC}} \)

\( P_{\text{ICC}} = V_{CC} \times I_{CC} \) (W)

\( I_{CC} \) = \( V_{CC} \) dissipation (A)

Figure 5.23 Motor current waveform image for loss calculation (sine-wave control type)
6. Application circuit example

● Square-wave control type (TPD4151K/TPD4142K/TPD4146K)

> When a hall device is used

Figure 6.1 Application circuit example (Square-wave control type) @ Using hall device
※ A hall device should use an indium antimony system.

> When a hall IC is used

Figure 6.2 Application circuit example (Sine-wave control type) @ Using hall IC
※ Please input a Hall IC output into the + side of an input terminal, and impress 1/2 voltage of Hall IC power supply voltage to the - side. (For example, when the power supply voltage of Hall IC is 6V, 3V is impressed to the - side terminal.)
Standard external parts are shown in the following table.

### Table 6.1 External part constant of application circuit example (Square-wave control type)

<table>
<thead>
<tr>
<th>part</th>
<th>Typical</th>
<th>Purpose</th>
<th>Remark</th>
</tr>
</thead>
<tbody>
<tr>
<td>C1, C2, C3</td>
<td>25 V/2.2 μF</td>
<td>Boot strap capacitor</td>
<td>Note1</td>
</tr>
<tr>
<td>R1</td>
<td>0.62 Ω ± 1 % (1 W)</td>
<td>Current detection</td>
<td>Note2</td>
</tr>
<tr>
<td>C4</td>
<td>25 V / 1000 pF ± 5 %</td>
<td>PWM frequency setup</td>
<td>Note3</td>
</tr>
<tr>
<td>R2</td>
<td>27 kΩ ± 5 %</td>
<td>PWM frequency setup</td>
<td>Note3</td>
</tr>
<tr>
<td>C5</td>
<td>25 V/10 μF</td>
<td>V&lt;sub&gt;CC&lt;/sub&gt; power supply stability</td>
<td>Note4</td>
</tr>
<tr>
<td>C7</td>
<td>25 V/0.1 μF</td>
<td>V&lt;sub&gt;CC&lt;/sub&gt; surge absorption</td>
<td>Note4</td>
</tr>
<tr>
<td>C6</td>
<td>25 V/0.1 μF</td>
<td>V&lt;sub&gt;REG&lt;/sub&gt; power supply stability</td>
<td>Note4</td>
</tr>
<tr>
<td>C8</td>
<td>25 V/1000pF</td>
<td>V&lt;sub&gt;REG&lt;/sub&gt; surge absorption</td>
<td>Note4</td>
</tr>
<tr>
<td>R3</td>
<td>5.1 kΩ</td>
<td>FG pin pull up resister</td>
<td>Note5</td>
</tr>
<tr>
<td>Z1</td>
<td>20 V/0.7 W</td>
<td>V&lt;sub&gt;CC&lt;/sub&gt; surge measure</td>
<td>Note6</td>
</tr>
<tr>
<td>Z2</td>
<td>390 V/1 W</td>
<td>V&lt;sub&gt;BB&lt;/sub&gt; surge measure</td>
<td>Note6</td>
</tr>
</tbody>
</table>

**Note1**: Boot strap capacitor (C<sub>1</sub>, C<sub>2</sub>, C<sub>3</sub>)

The optimal value of the bootstrap capacitor changes with switching frequency, output element on-duty, and the gate capacitance of output element IGBT.

Although it operated by the under voltage protected operation voltage of V<sub>BS</sub>, in order to keep the loss of output IGBT small, it recommends making voltage of a boot strap capacitor more than 13.5V.

● The boot strap capacitor minimum capacity

\[
C_B = I_B \times \text{The maximum high side on time} / (V_{CC} - V_F(BSD) + V_F(FRD) - 13.5) \ [F]
\]

C<sub>B</sub> : bootstrap capacitor capacity(min)

I<sub>B</sub> : High side driver consumption current (max)

V<sub>F</sub> (BSD) : Bootstrap diode forward voltage

V<sub>F</sub> (FRD) : FRD forward voltage

The case of duty operation (in particular high duty condition 3.8V ≦ V<sub>s</sub> ≦ 5.4V) and 100%Duty operation, please calculate the boot strap capacitor minimum capacity.

Since the under voltage protection of V<sub>BS</sub> may work if the output ON period of the high side IGBT continues for a long time, please give me suitable capacity selection.

**Note2**: Current detection resistance (R1)

Detection current is is expressed by the following formula. (It is referred to P21.)

\[
I_O = \frac{V_R}{R_1} \quad (V_R=0.5V \text{ typ.})
\]

Please use it so that the maximum of detection current is set below to absolute maximum rating.

**Note3**: PWM frequency setup capacitor / resistance(C4/R2)

It becomes the PWM frequency of about 20 kHz in the combination of C4 and R2.

PWM frequency is denoted in general by a lower type.

An error factor peculiar to IC is about 10%.

Under the present circumstances, please consider to the stray capacitance of a substrate.

\[
f_c = 0.65 \times \{ C_4 \times (R_2 + 4.25 \text{kΩ}) \} \quad [\text{Hz}]
\]

Although the standard current of the charging/discharging circuit of PWM is made by R2, if the value of R2 is too small, a triangle wave will be distorted exceeding the current capacity of IC internal circuit. R2 should choose more than 9kΩ.

**Note4**: V<sub>CC</sub>/V<sub>REG</sub> power supply stability / surge absorption (C6/C8/C7/C8)

According to actual usage environment, a unite lump is needed.

When surge voltage occurs, it recommends adding the ceramic capacitor of low capacity as an object for surge absorption.
Moreover, at the time of mounting, in order to heighten the noise rejection effect, please arrange in the position near the root of IC lead.

Note5 : FG pin pull up resister (R3)
FG terminal has open Drain structure.
When you don’t use FG pin, please connect with GND.
Please keep in mind that the consumption current of a power supply will become large if a pull-up resistor is too small.

Note6 : Zener diode for surge measure (Z1/Z2)
When surge voltage occurs, it recommends adding the zener diode below absolute maximum rating voltage.
Please arrange in the position near the root of IC lead.

● The measure against an input signal noise
<When a hall device is used>
It recommends adding the noise rejection capacitor between input pins (example: HU+/HU-).

<When a hall IC is used>
It recommends adding the noise rejection low pass filter (resistance + capacitor) between input terminal (HU+/HV+/HW+)-GND.
However, when adding a low pass filter, it is necessary to take into consideration the process hold-up time of an input signal.
● Sine-wave control type (TPD4123K/TPD4144K/TPD4135K/TPD4123AK/TPD4144AK/TPD4135AK)

> TPD4123K/TPD4144K/TPD4135K

Figure 6.3 Application circuit example (Sine-wave control type) @K type

> TPD4123AK/TPD4144AK/TPD4135AK

Figure 6.4 Application circuit example (Sine-wave control type) @AK type
Standard external parts are shown in the following table.

### Table 6.2 External part constant of application circuit example (Sine-wave control K type)

<table>
<thead>
<tr>
<th>part</th>
<th>Typical</th>
<th>Purpose</th>
<th>Remark</th>
</tr>
</thead>
<tbody>
<tr>
<td>C1, C2, C3</td>
<td>25 V/2.2 μF</td>
<td>Boot strap capacitor</td>
<td>Note1</td>
</tr>
<tr>
<td>R1</td>
<td>0.62 Ω ± 1 % (1 W)</td>
<td>Current detection (TPD4123K)</td>
<td>Note2</td>
</tr>
<tr>
<td></td>
<td>0.35 Ω ± 1 % (1.5 W)</td>
<td>Current detection (TPD4144K)</td>
<td>Note2</td>
</tr>
<tr>
<td></td>
<td>0.2 Ω ± 1 % (1.5 W)</td>
<td>Current detection (TPD4135K)</td>
<td>Note2</td>
</tr>
<tr>
<td>C4</td>
<td>25 V/10 μF</td>
<td>Vcc power supply stability</td>
<td>Note3</td>
</tr>
<tr>
<td>C5</td>
<td>25 V/0.1 μF</td>
<td>Vcc surge absorption</td>
<td>Note3</td>
</tr>
<tr>
<td>C6</td>
<td>25 V/1 μF</td>
<td>VREG power supply stability</td>
<td>Note3</td>
</tr>
<tr>
<td>C7</td>
<td>25 V/1000 pF</td>
<td>VREG surge absorption</td>
<td>Note3</td>
</tr>
<tr>
<td>R2</td>
<td>5.1 kΩ</td>
<td>DIAG pin pull up resistar</td>
<td>Note4</td>
</tr>
<tr>
<td>Z1</td>
<td>390V/1W</td>
<td>VBB surge measure</td>
<td>Note5</td>
</tr>
<tr>
<td>Z2</td>
<td>20V/0.7W</td>
<td>Vcc surge measure</td>
<td>Note5</td>
</tr>
</tbody>
</table>

Note1: Boot strap capacitor (C1, C2, C3)
The optimal value of the bootstrap capacitor changes with switching frequency, output element on-duty, and the gate capacitance of output element IGBT.
Although it operated by the under voltage protected operation voltage of VBS, in order to keep the loss of output IGBT small, it recommends making voltage of a boot strap capacitor more than 13.5V.

- The boot strap capacitor minimum capacity
  
  \[ C_s = I_B \times \text{The maximum high side on time} / (V_{cc} - V_F (BSD) + V_F (FRD)) - 13.5 \] [F]
  
  - \( I_B \): High side driver consumption current (max)
  - \( V_F (BSD) \): Bootstrap diode forward voltage
  - \( V_F (FRD) \): FRD forward voltage

A setup of control IC or a microcomputer, since the under voltage protection of VBS may work if the output ON period of the high side IGBT continues for a long time, please give me suitable capacity selection.

Note2: Current detection resistance (R1)
Detection current is is expressed by the following formula. (It is referred to P26.)
\[ I_O = V_R / R_1 (V_R=0.5V \text{ typ.}) \]
Please use it so that the maximum of detection current is set below to absolute maximum rating.
Note 3: $V_{CC}/V_{REG}$ power supply stability / surge absorption ($C_5/C_6/C_7/C_8$)
- According to actual usage environment, a unite lump is needed.
- When surge voltage occurs, it recommends adding the ceramic capacitor of low capacity as an object for surge absorption.
- Moreover, at the time of mounting, in order to heighten the noise rejection effect, please arrange in the position near the root of IC lead.

Note 4: DIAG pin pull up resistors (R3)
- DIAG terminal has open Drain structure.
- When you don't use FG pin, please connect with GND.
- Please keep in mind that the consumption current of a power supply will become large if a pull-up resistor is too small.

Note 5: Zener diode for surge measure ($Z_1/Z_2$)
- When surge voltage occurs, it recommends adding the zener diode below absolute maximum rating voltage.
- Please arrange in the position near the root of IC lead.
7. Selecting a heat sink and method of mounting

7.1. Calculating junction temperature / Selecting method of a heat sink

You can compute junction temperature of a device using a case temperature and device loss.

\[
T_j = T_c + P \times R_{jc}
\]

- \(T_j\): Junction temperature (max) [°C]
- \(T_c\): Case temperature [°C]
- \(P\): Device loss [W]
- \(R_{jc}\): Case-Junction heat resistance [°C/W] ≈ 5°C/W

Selecting method of a heat sink

As radiation design technique, a heat sink, there is a way to answer with the outside bill.
When heat dissipation nature wants to improve, please attach a heat sink to a metal heat dissipation side.
The optimal heat sink can be selected by calculation shown below.

![Diagram showing heat dissipation components and equations]

**Figure 7.1 Selecting method of heat sink**

The following expression is realized from the above figure.

\[
R_f + R_c + R_{jc} < \frac{(T_j - T_a)}{R_{jc}}
\]

(Example) Usage environment temperature (max) \(T_a = 50°C\),
Junction temperature (max) \(T_j = 135°C \times 80%\)

In this case of Heat sink – Case heat resistance is \(R_c = 3°C/W\)
and Case – Junction heat resistance is \(R_{jc} = 5°C/W\).

\[
R_f + 3 + 5 < \frac{(135 \times 0.8 - 50)}{5}
\]

\[R_f < 3.6 \frac{°C}{W}\]

Heat sink resistance: It is necessary to choose the heat sink below 3.6 °C/W.

● Applying of silicon grease
Contact thermal resistance is improved by applying silicon grease between device and heat sink. Please put a light coat and uniform of silicon grease. Nonvolatile silicon grease is recommendable. There is the possibility that volatile one have a cracking of grease and a change for the worse of heat radiation effect when use for a long time.

● Tightening torque
It has the possibility to break the screw thread/hole or give damage of strain with excessive tightening torque. When over some tightening torque point, contact thermal resistance became saturated. Following table is the recommendation of tightening torque to avoid the device stress with optimum contact thermal resistance. Carry out a temporary bundle if needed.

Table 7.1 Recommended Screw, tightening torque and Maximum tightening torque

<table>
<thead>
<tr>
<th>Recommended Screw</th>
<th>Recommended tightening torque</th>
<th>Maximum tightening torque</th>
</tr>
</thead>
<tbody>
<tr>
<td>M2.6</td>
<td>0.5 N·m</td>
<td>0.6 N·m</td>
</tr>
</tbody>
</table>

● Flatness of the surface
The surface where the device is attached must be sufficiently smooth. Warps, large bumps or hollows in the surface, or foreign bodies such as punching burrs or chips lodged between the device and the attachment face can cause devise failure in the worst case. To avoid these problems, the flatness of the surface where the device is attached should be within 50 μm.

Figure 7.2 Flatness of the surface

■ Handling precautions
- This product has a MOS structure and is sensitive to electrostatic discharge. When handling this product, ensure that the environment is protected against electrostatic discharge.
- Package have an exposed metal portion on the reverse side mold surface of marking area. This portion is at the same potential as product GND pin (1/16 pin). As necessary, please make safety provisions for insulation between package and heat sink.

Figure 7.3 The example of heat sink attachment
7.3. Substrate packaging method

- Recommended lead hole diameter (diameter) ••• 1.18mm
  I recommend designing hole form with an ellipse.
  By lengthening hole form a little, the flexibility to a spread of a lead pitch can be given in the direction of the package short side.

- Recommended lead pitch (short side) ••• 17.15mm
  Distance between lead tips (Lead central part) = 17.5mm
  Distance between leads in a package undersurface part (Lead central part) = 16.8mm
  The center value of 17.15 mm of 17.5 mm and 16.8 mm is appropriate to a hole design.

- Recommended screw hole diameter (diameter) ••• 2.6mm (Heat sink mounting)
  I recommend pasting up a heat sink using a 6mm washer.

![Figure 7.4 Substrate packaging method](image-url)
8. Packing specifications

- **Stick**
  ![Figure 8.1 Stick for DIP26](image)

- **Interior design**
  ![Figure 8.2 Interior for DIP26](image)
9. Introduction of evaluation boards

A power supply can be impressed to the evaluation board of the following figure, and motor evaluation can be carried out in simple by connecting a motor.

Since I also prepare a substrate manual collectively, please contact a brokerage department, when you want an evaluation board.

● Square-wave control type (TPD4151K/TPD4142K/TPD4146K)

<table>
<thead>
<tr>
<th>Parts</th>
<th>Typical</th>
</tr>
</thead>
<tbody>
<tr>
<td>C_1</td>
<td>1.2μF/25V</td>
</tr>
<tr>
<td>C_2</td>
<td>1.2μF/25V</td>
</tr>
<tr>
<td>C_3</td>
<td>1.2μF/20V</td>
</tr>
<tr>
<td>C_4</td>
<td>100μF/25V</td>
</tr>
<tr>
<td>C_5</td>
<td>10μF/25V</td>
</tr>
<tr>
<td>C_6</td>
<td>10μF/25V</td>
</tr>
<tr>
<td>C_7</td>
<td>1μF/25V</td>
</tr>
<tr>
<td>C_8</td>
<td>0.1μF/25V</td>
</tr>
<tr>
<td>C_9</td>
<td>0.01μF/25V</td>
</tr>
<tr>
<td>R_1</td>
<td>0.02Ω</td>
</tr>
<tr>
<td>R_2</td>
<td>22kΩ</td>
</tr>
<tr>
<td>R_3</td>
<td>5.1kΩ</td>
</tr>
<tr>
<td>R_4</td>
<td>1kΩ</td>
</tr>
<tr>
<td>R_5</td>
<td>1kΩ</td>
</tr>
</tbody>
</table>

Table 8.1 External part constant 1

Figure 8.1 The picture of evaluation board 1

Figure 8.2 The circuit of evaluation board 1
● Sine-wave control type (TPD4123K/TPD4144K/TPD4135K/TPD4123AK/TPD4144AK/TPD4135AK)

> The evaluation board of 180 degree control (Combination with TB6551FG/FA)

**Table 8.2 External part constant 2**

<table>
<thead>
<tr>
<th>Parts</th>
<th>Typical</th>
</tr>
</thead>
<tbody>
<tr>
<td>C1</td>
<td>10μF/25V</td>
</tr>
<tr>
<td>C2</td>
<td>0.1μF/1W</td>
</tr>
<tr>
<td>C3</td>
<td>10μF/25V</td>
</tr>
<tr>
<td>C4</td>
<td>10μF/25V</td>
</tr>
<tr>
<td>C5</td>
<td>10μF/25V</td>
</tr>
<tr>
<td>C6</td>
<td>0.1μF/1W</td>
</tr>
<tr>
<td>C7</td>
<td>10μF/25V</td>
</tr>
<tr>
<td>C8</td>
<td>0.01μF/1W</td>
</tr>
<tr>
<td>C9</td>
<td>0.01μF/1W</td>
</tr>
<tr>
<td>C10</td>
<td>0.01μF/1W</td>
</tr>
<tr>
<td>C11</td>
<td>10μF/25V</td>
</tr>
<tr>
<td>C12</td>
<td>0.1μF/500V</td>
</tr>
<tr>
<td>C13</td>
<td>0.1μF/500V</td>
</tr>
<tr>
<td>R1</td>
<td>1kΩ</td>
</tr>
<tr>
<td>R2</td>
<td>1kΩ</td>
</tr>
<tr>
<td>R3</td>
<td>0.25Ω/1W</td>
</tr>
<tr>
<td>R4</td>
<td>1kΩ</td>
</tr>
<tr>
<td>R5</td>
<td>10kΩ</td>
</tr>
<tr>
<td>R6</td>
<td>10kΩ</td>
</tr>
<tr>
<td>VR1</td>
<td>1MΩ</td>
</tr>
</tbody>
</table>

**Table 8.3 Switch connection table 1**

<table>
<thead>
<tr>
<th>Switch</th>
<th>Pin Description</th>
<th>Remarks</th>
<th>Condition</th>
<th>Condition</th>
</tr>
</thead>
<tbody>
<tr>
<td>SW1</td>
<td>Reset input</td>
<td>L: Reset</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>SW2</td>
<td>Forward/Reverse selection</td>
<td>L: Forward, H: Reverse</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>SW3</td>
<td>Output logic selection</td>
<td>L: Low active, H: High active</td>
<td>H</td>
<td>-</td>
</tr>
<tr>
<td>SW4</td>
<td>Deadtime setup input</td>
<td>L: 3.8μs, H or Open: 1.9μs</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>SW5</td>
<td>SD pin setup input</td>
<td>L: GND, OPEN: An external input is possible, H: SD pin is pulup</td>
<td>H</td>
<td>H</td>
</tr>
</tbody>
</table>

**Figure 8.3 The picture of evaluation board 2**

**Figure 8.4 The circuit of evaluation board 2**
● Sine-wave control type (TPD4123K/TPD4144K/TPD4135K/TPD4123AK/TPD4144AK/TPD4135AK)

> The evaluation board of 150 degree control (Combination with TB6586BFG)

**Table 8.4 External part constant 2**

<table>
<thead>
<tr>
<th>Parts</th>
<th>Typical</th>
</tr>
</thead>
<tbody>
<tr>
<td>C₁</td>
<td>10μF /25V</td>
</tr>
<tr>
<td>C₂</td>
<td>0.1μF /25V</td>
</tr>
<tr>
<td>C₄</td>
<td>10μF /25V</td>
</tr>
<tr>
<td>C₅</td>
<td>10μF /25V</td>
</tr>
<tr>
<td>C₆</td>
<td>0.1μF /25V</td>
</tr>
<tr>
<td>C₇</td>
<td>10μF /25V</td>
</tr>
<tr>
<td>C₉</td>
<td>10μF /25V</td>
</tr>
<tr>
<td>C₁₀</td>
<td>1μF /630V※</td>
</tr>
<tr>
<td>C₁₁</td>
<td>0.01μF /630V※</td>
</tr>
<tr>
<td>C₁₂</td>
<td>0.01μF /25V</td>
</tr>
<tr>
<td>C₁₃</td>
<td>0.01μF /25V</td>
</tr>
<tr>
<td>C₁₄</td>
<td>4.7μF /25V</td>
</tr>
<tr>
<td>C₁₅</td>
<td>1000pF /25V</td>
</tr>
<tr>
<td>C₁₆</td>
<td>4.7μF /25V</td>
</tr>
<tr>
<td>C₁₇</td>
<td>1000pF /25V</td>
</tr>
<tr>
<td>C₁₈</td>
<td>390pF /25V</td>
</tr>
<tr>
<td>R₄</td>
<td>0.25Ω /1W※</td>
</tr>
<tr>
<td>R₅</td>
<td>6.2kΩ</td>
</tr>
<tr>
<td>R₆</td>
<td>1kΩ</td>
</tr>
<tr>
<td>R₇</td>
<td>0Ω</td>
</tr>
<tr>
<td>R₈</td>
<td>1kΩ</td>
</tr>
<tr>
<td>R₉</td>
<td>0Ω</td>
</tr>
<tr>
<td>R₁₀</td>
<td>10kΩ</td>
</tr>
<tr>
<td>R₁₁</td>
<td>10kΩ</td>
</tr>
<tr>
<td>R₁₂</td>
<td>1MΩ</td>
</tr>
</tbody>
</table>

**Table 8.5 Switch connection table 2**

<table>
<thead>
<tr>
<th>Switch</th>
<th>Pin Description</th>
<th>Remarks</th>
<th>Condition</th>
</tr>
</thead>
<tbody>
<tr>
<td>SW₁</td>
<td>Forward/Reverse selection input</td>
<td>L: Forward, H: Reverse</td>
<td></td>
</tr>
<tr>
<td>SW₂</td>
<td>120° /150° commutation selection input</td>
<td>L: 150° commutation, H: 120° commutation</td>
<td></td>
</tr>
<tr>
<td>SW₃</td>
<td>SD pin setup input</td>
<td>L: GND, OPEN: An external input is possible, H: SD pin is pulup</td>
<td></td>
</tr>
</tbody>
</table>

**Figure 8.5 The picture of evaluation board 3**

**Figure 8.6 The circuit of evaluation board 3**
10. FAQ

● General
Q: What is SOI?
A: It's a mark of Silicon On Insulator and is the structure of which a semiconductor device was composed on the insulator.

Q: What is DIP?
A: The shape of the package is expressed in a mark of Dual Inline Package. A lead terminal is arranged in 2 series parallelism, and substrate wiring can be pulled around easily.

Q: What kind of use is it used for?
A: It's used for the fan motor of an air conditioner indoor machine and outdoor unit, air cleaner, bathroom dry fan, dry fan for washing machine, refrigerator compressor, pump, ventilator and general purpose inverter.

Q: How much is dv/dt resistance?
A: When high dv/dt occurs in U/V/W pins, it is designed so that the false pulse by dv/dt may not be transmitted to an internal circuit. Furthermore, the product checked that impressed ±15kV/μs dv/dt in the range of Tj=-40~135°C and malfunction did not occur, when there was no CR filter temporarily.

Q: What is a way of thermal shutdown detection?
A: It has a diode for overheating detection built-in, and it's being detected by the VF temperature dependence of the diode.

Q: Is this product guarantee about short-circuit?
A: This product isn't guaranteed about Short-circuit.

Q: A careful point with a substrate design?
A: This product is used both high voltage and low voltage. Please separate high voltage, high current line and low voltage, low current line at the circuit design. Also, please arrange the additional parts which had a noise extermination for its object in base of an IC lead as much as possible. Especially, please shorten the distance from IPD to the shunt-resistance. The impedance from IPD to shunt-resistance should be low as much as possible. The shunt-resistance is setting for the over-current-protection. It is connected to RS pin.

Q: How much is the maximum of the PWM frequency.
A: When the PWM frequency set high, the junction temperature becomes high with increase of switching loss. Recommendation of a PWM frequency is less than 25 kHz.

Q: How to protect from a surge.
A: The countermeasure example of protection from a surge is below.
- Insertion of Zener diode for overvoltage absorption (The Zener diode voltage below the maximum rating is used by all means.) For example, a Vcc pin, when taking a measure, less than 20 V of Zener diode voltage is selected.
- A capacitor for surge absorption is inserted (The enough capacity which can absorb a surge is arranged in the nearby location to become the root of an IC lead.)

● Square-wave control type(TPD4151K/TPD4142K/TPA4146K)
Q: In TPD4151K, it is correspondence of the incorrect connection with AC200V power supply?
A: In case that the IC is erroneously connected to 200VAC power supply, it can withstand a voltage of up to 315V for 1 min under the condition of V_S<1.1V

● Sine-wave control type(TPD4123K/TPD4144K/TPD4135K/TPA4123AK/TPD4144AK/TPA4135AK)
Q: Dead time setting.
A: High side IGBT and low side IGBT of this product become off, when the both high side input and low side input are turned on at the same time. This logic of this product is dead time free. But, please set the dead time because of the internal circuit propagation delay. This product can establish at least 1.4 μs.
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