High-Voltage Intelligent Power Devices Application Note

TPD4163K, TPD4163F
TPD4164K, TPD4164F
TPD4165K

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1. Applicapable products

1.1. Product overview

TPD4163K, TPD4163F, TPD4164K, TPD4164F and TPD4165K are high voltage intelligence devices and they are single chip inverter ICs using TOSHIBA original trench-isolation-type high-voltage SOI (Silicon on insulator) process.

Each product has control circuit such as IGBT gate drive circuit, bootstrap circuit for high side gate drive power supply, various protection circuits, level shift circuit and logic circuit. And it has also 6 pieces of IGBT and FRD in single chip device. It has function of direct driving of three phase brushless DC motor. It is the optimal product for motor drive in home appliance.

The HVIPDs can be used in combining with Toshiba's microcomputer or motor controller IC to drive a motor with sine-wave (180° commutation) type so as to achieve low noise and low vibration.

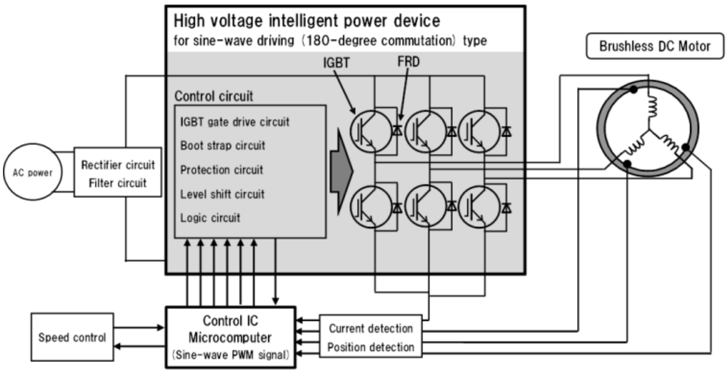


Figure 1.1.1 High-voltage intelligent power devices

1.2. Applicable product list

Table 1.2.1 Product list of High-voltage intelligent power devices

Product name	Rating	Package	Output characteristic		Function						
			Output saturation voltage (Typ.)	FRD forward voltage (Typ.)	6-input	3-Phase Distribution PWM Circuit	Current limit	over-current Protection	Thermal Shutdown	Under voltage Protection	Shutdown (SD) pin control
TPD4163K	600V/1A	HDIP30	2.6V (Ic=0.5A)	2.0V (IF=0.5A)	✓	–	–	✓	✓	✓	✓
TPD4163F	600V/1A	HSSOP31	2.6V (Ic=0.5A)	2.0V (IF=0.5A)	✓	–	–	✓	✓	✓	✓
TPD4164K	600V/2A	HDIP30	3.0V (Ic=1A)	2.5V (IF=1A)	✓	–	–	✓	✓	✓	✓
TPD4164F	600V/2A	HSSOP31	3.0V (Ic=1A)	2.5V (IF=1A)	✓	–	–	✓	✓	✓	✓
TPD4165K	600V/3A	HDIP30	2.6V (Ic=1.5A)	1.9V (IF=1.5A)	✓	–	–	✓	✓	✓	✓

Table 1.2.2 Product example of motor control IC with sine-wave PWM control

Product name	Package	V_{CC} / Io	Position sensing	Function				
				Lead angle control	Built-in oscillator	Lock detection	Current limit	Other protection function [Note 1]
TB6551FAG	SSOP24	12V/2mA	Hall effect IC	External setting	–	–	✓	✓
TB6556FG	SSOP30	12V/2mA		Current Feedback	–	–	✓	✓
TB6584FNG/AFNG (Note 2)	SSOP30	18V/2mA	Hall element or Hall effect IC		✓	–	✓	✓
TB6634FNG	SSOP30	18V/2mA			✓	✓	✓	✓
TB6631FNG	SSOP30	18V/2mA		RPM Feedback (Note 3)	✓	–	✓	✓
TC78B041FNG	SSOP30	18V/2mA		Intelligent Phase Control (Note4)	✓	✓	✓	✓
TC78B042FTG	QFN32	18V/2mA			✓	✓	✓	✓

Note 1: Including gate block protection, position signal abnormality protection and VCC undervoltage protection

Note 2: Specifications such as modulation generation method and automatic advance angle mode differ. Refer to the data sheet of each product for details.

Note 3: Internal auto lead angle control based on the frequency of the FG signal.

Note 4: Toshiba's original automatic phase adjustment function.

Table 1.2.3 Product example of microcontroller with sine-wave PWM control

Product name	Package	ROM size (Bytes)	RAM size (Bytes)	Max operating frequency (MHz)	Operating Voltage (V)	
					Min	Max
TMPM375FSDMG	SSOP30	64K	4K	40 (Note 1)	4.5	5.5
TMPM372FWUG	LQFP64	128K	6K	80 (Note 2) 32 (Note 1)	4.5	5.5
TMPM373FWDUG	LQFP48					
TMPM374FWUG	LQFP44					
TMPM370FYDFG	QFP100	256K	10K	80 (Note 2)	4.5	5.5
TMPM370FYFG	LQFP100					
TMPM376FDDFG	QFP100	512K	32K	80 (Note2)	4.5	5.5
TMPM376FDFG	LQFP100					

Note 1: Ambient temperature -40 °C to 105 °C

Note 2: Ambient temperature -40 °C to 85 °C

1.3. Block diagram

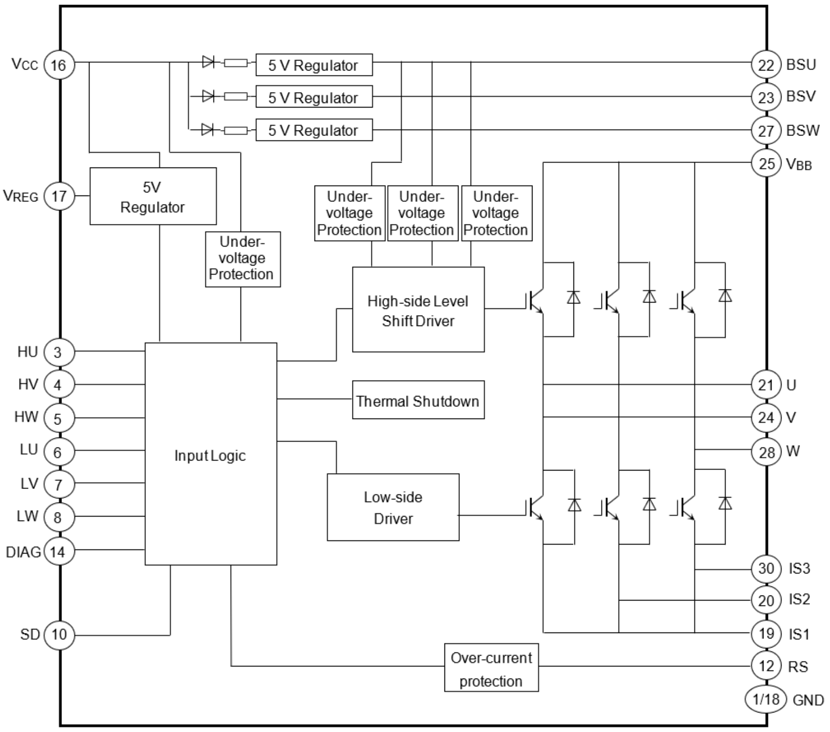


Figure 1.3.1 Block diagram for TPD4163K/TPD4164K/TPD4165K

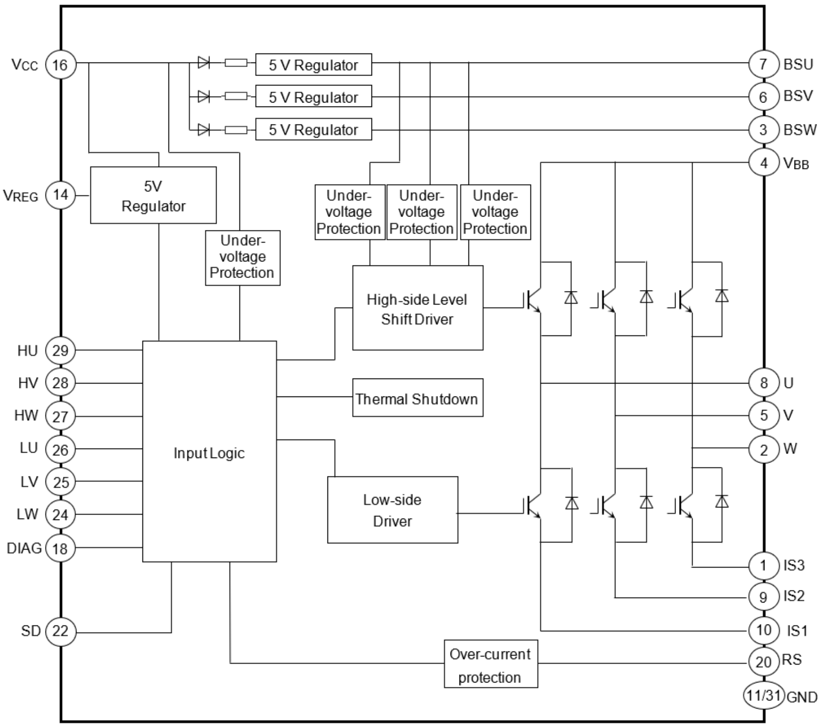


Figure 1.3.2 Block diagram for TPD4163F/TPD4164F

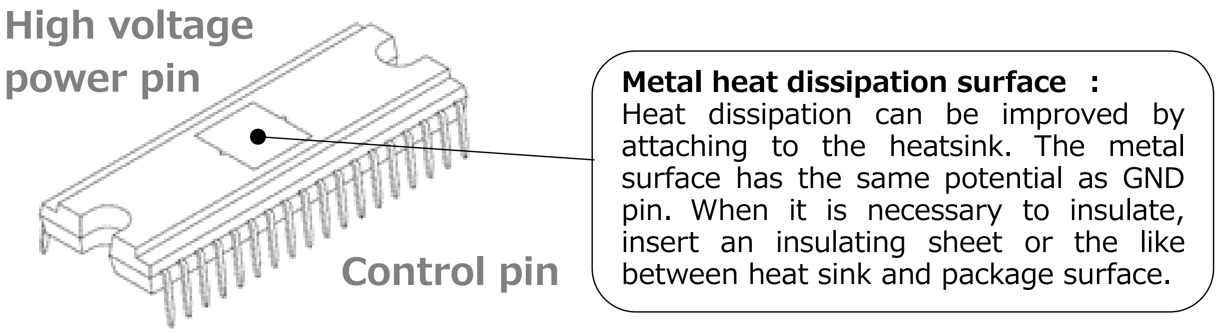
2. Package information

Two types of packaging are available: HDIP30 (lead insert type) and HSSOP31 (surface mount type). Select the package according to the application, mounting method of the board, etc.

2.1. HDIP30

HDIP30 package has high voltage power pins and control pins separated on both sides of the package, making it easier to design the PCB. In addition, while the package thickness has been made thinner, a wide pin-to-pin distance is ensured for high voltage pins.

Metal heat dissipation surface is exposed on the package surface, and heat dissipation can be improved by attaching the heatsink. HDIP30 package supports to mount by flow and soldering iron.



Metal heat dissipation surface : Heat dissipation can be improved by attaching to the heatsink. The metal surface has the same potential as GND pin. When it is necessary to insulate, insert an insulating sheet or the like between heat sink and package surface.

Figure 2.1.1 HDIP30 packege

2.1.1. Package dimensions

Package Code: P-HDIP30-1233-1.78-001

Unit: mm

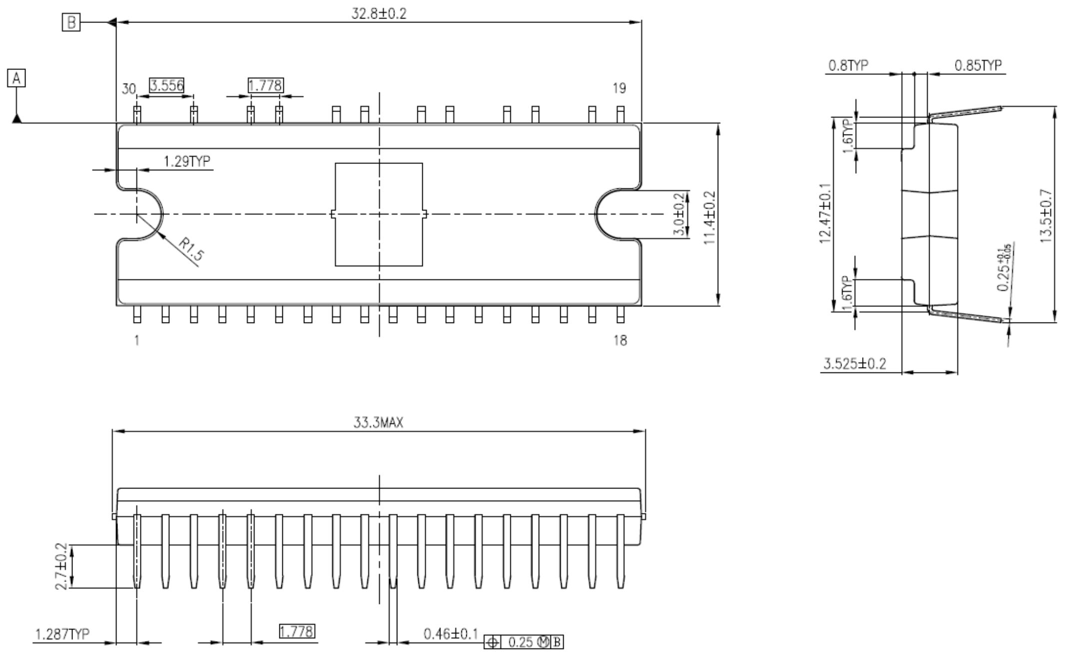


Figure 2.1.2 Dimensions of HDIP30 package

2.1.2. Marking

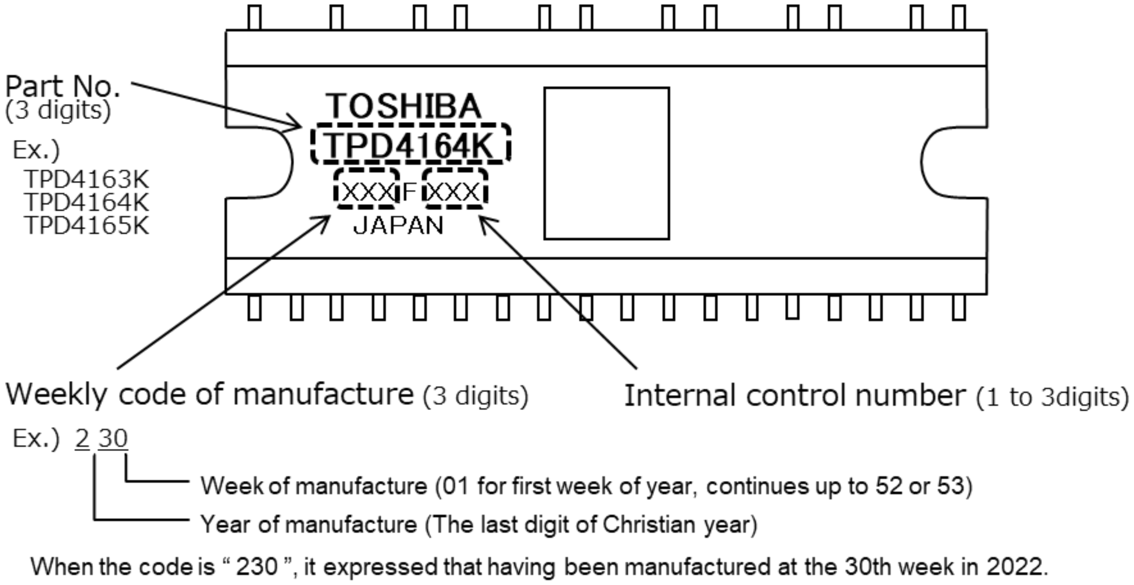


Figure 2.1.3 Part marking on HDIP30 package

2.1.3. PCB land pattern dimensions（Reference)

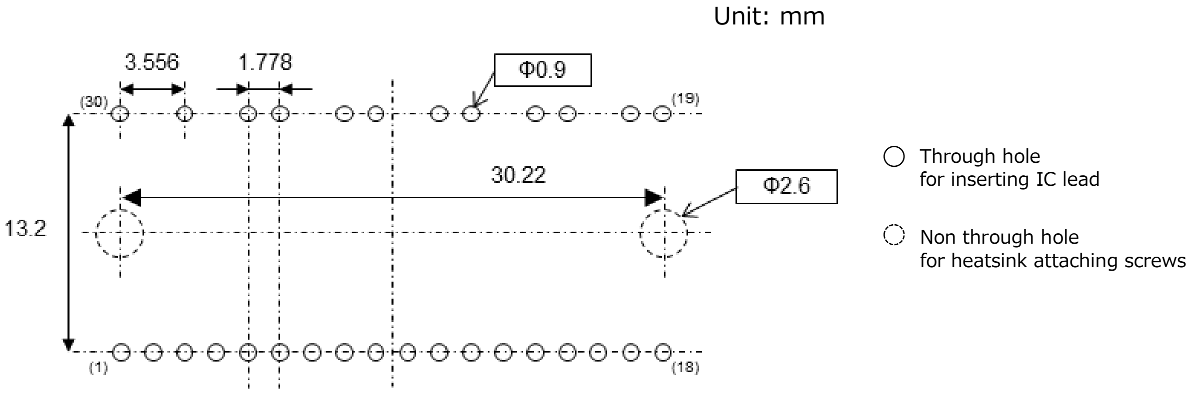


Figure 2.1.4 Land pattern of HDIP30 package (Reference)

2.1.4. 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.

● 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 2.1.1 Recommended Screw, tightening torque and Maximum tightening torque

Recommended Screw	Recommended tightening torque	Maximum tightening torque
M2.6	0.5 N･m	0.6 N･m

● 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.

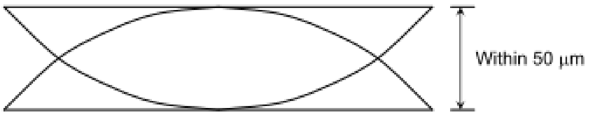


Figure 2.1.5 Flatness of the surface

■ 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 same side mold surface of marking area. This portion is at the same potential as product GND pin (1/18 pin) .As necessary, please make safety provisions for insulation between package and heat sink.

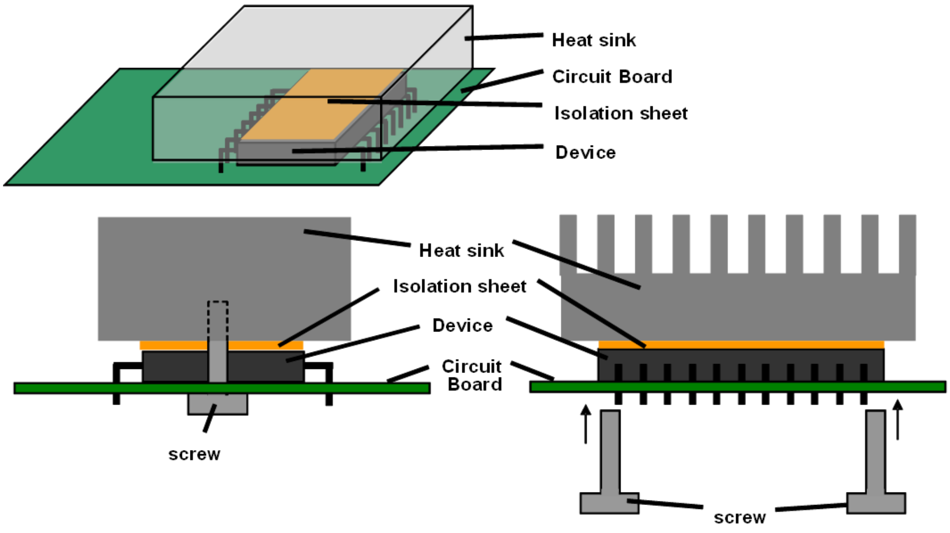


Figure 2.1.6 The example of heatsink attachment

2.2. HSSOP31

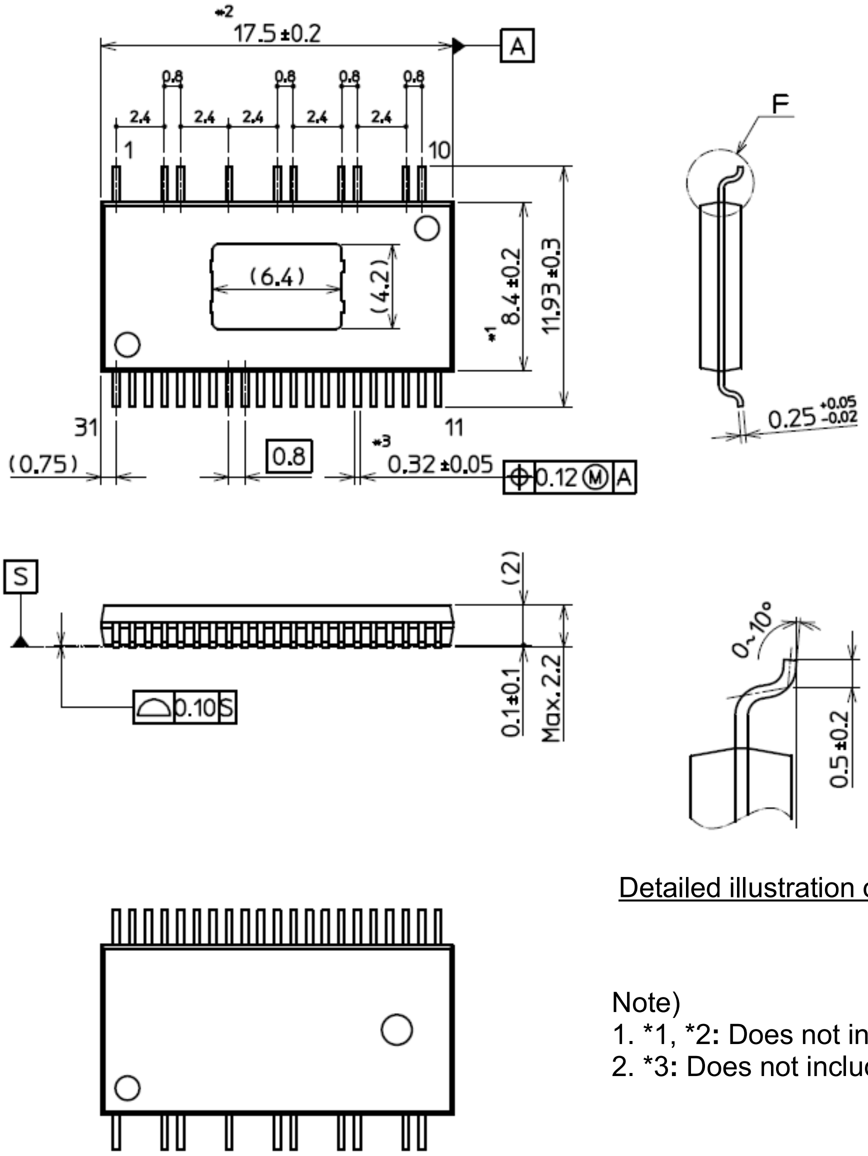
HSSOP31 package has high voltage power pins and control pins separated on both sides of the package, making it easier to design the PCB. In addition, the package thickness has been made thinner, and the size has been made smaller.

Metal heat dissipation surface is exposed on the package surface, and heat dissipation can be improved by attaching the heatsink. HSSOP31 package supports to mount by reflow and soldering iron.

2.2.1. Package dimensions

Package Code: P-HSSOP31-0918-0.80-002

Unit: mm



Detailed illustration of Part F.

Note)
1. *1, *2: Does not include leftover resin.
2. *3: Does not include leftover tiebar.

Figure 2.2.1 Dimensions of HSSOP31 package

2.2.2. Marking

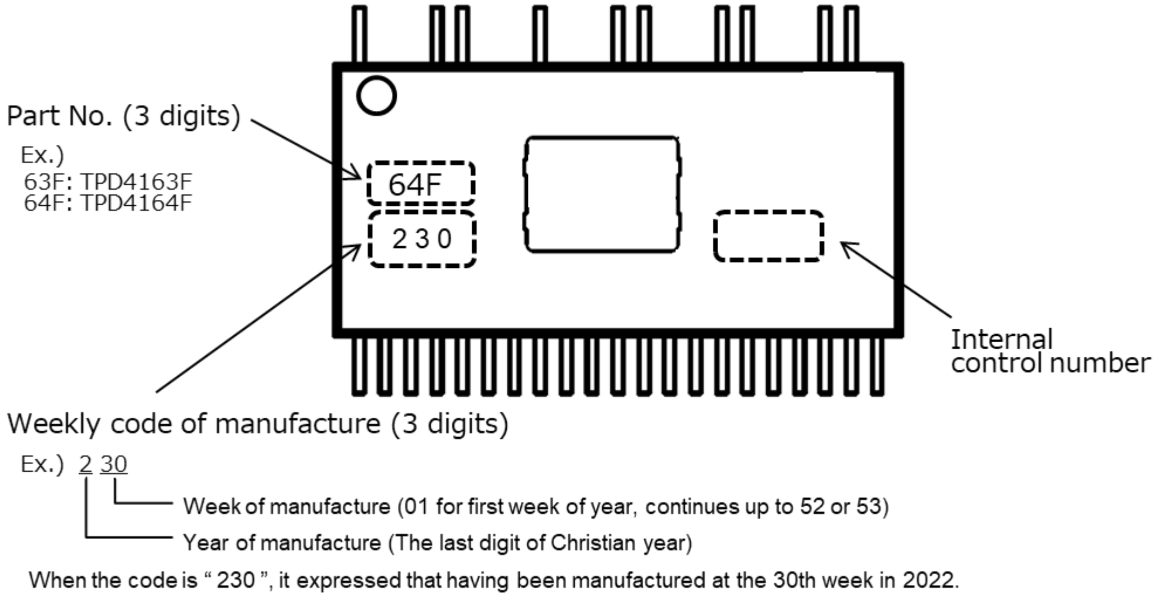


Figure 2.2.2 Part marking on HDIP31 package

2.2.3. PCB land pattern dimensions (Reference)

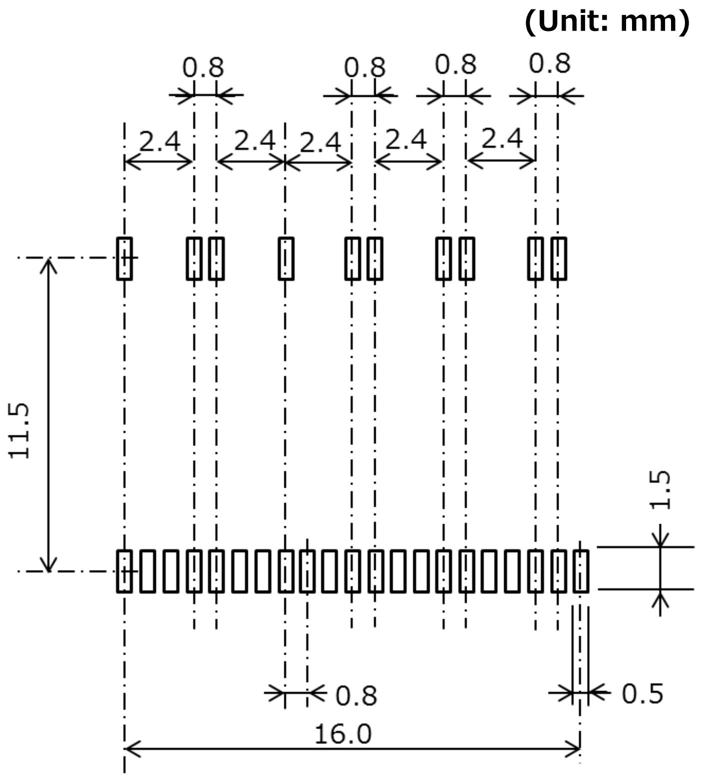


Figure 2.2.3 Land pattern of HSSOP31 package (Reference)

2.2.4. 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

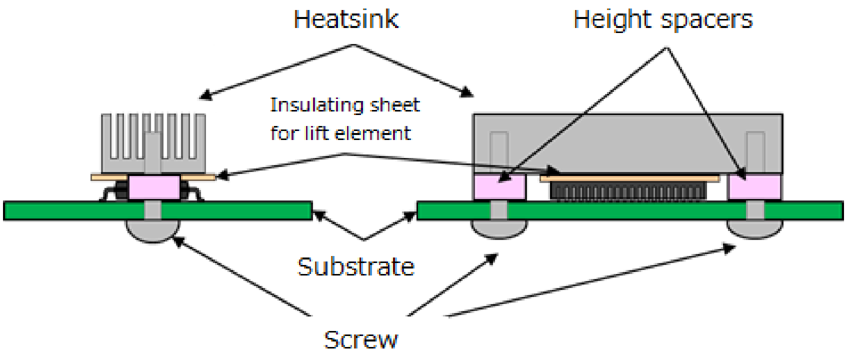


Table 2.2.1 Example of parts used

Parts	spec example
Screw	M3
Insulating sheet	Soft material t=0.5mm
Height spacer	t=2.5mm Holes:3.2Φ

Figure 2.2.4 Heatsink attachment example (using an insulating sheet)

(2) Example of using resin or gelatinous insulating material

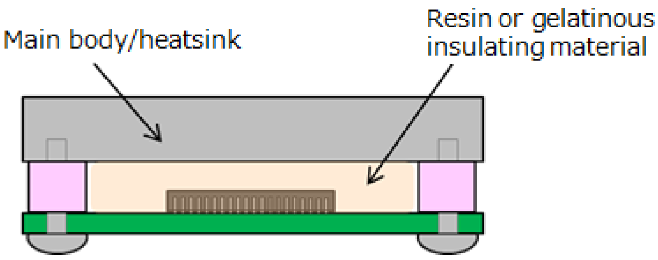


Figure 2.2.5 Heatsink attachment example (using resin or gelatinous insulating material)

(3) Example of other heatsink attachment method

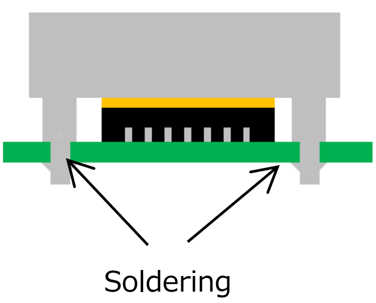


Figure 2.2.6 Soldering

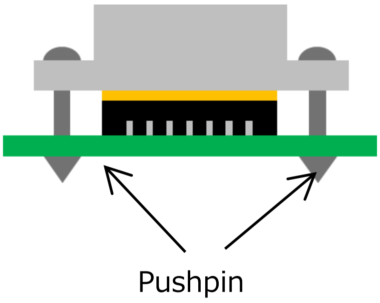


Figure 2.2.7 Pushpin

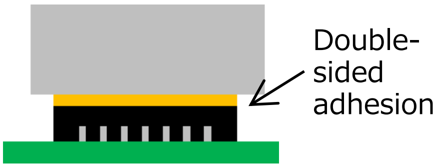


Figure 2.2.8 Adhesion attachment

- **Mounting to substrate**

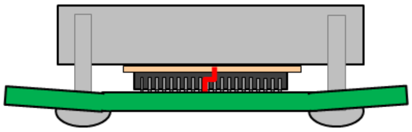


Figure 2.2.9 Bent PCB

Where the HSSOP31 package is sandwiched between the heat sink and the substrate, it the static load should be no greater than 10N. The load should be spread uniformly across the device, and screw mountings should not result in substrate bending as shown in right Figure, as the resulting distortion could cause device damage or failure. Consider using spacers or equivalent to attach the heat sink so as to prevent substrate bending.

- **Flatness**

The surface beneath the heat sink to which the device is attached must be suitably smooth and flat. The heat sink should likewise show no signs of warping or undulation and should be free of foreign matter such as burrs and scraps from pressing and cutting processes. In the worst case scenario this could lead to device failure. And heat fins fixed to the top of the package can cause device failure due to heat stress. Hard components (such as the heat sink) should be mounted onto the package together with a buffer layer (typically soft insulating sheet or conductive gel). Silicon grease should be avoided.

3. Pin description

3.1. Pin assignment

Table 3.1.1 Pin description

Pin No.		**Symbol**	**Pin Description**
TPD4163K **TPD4164K** **TPD4165K**	**TPD4163F** **TPD4164F**		
1/18	11	GND	Ground pin.
2/9/11/13/ 15/26/29	12/13/15/ 17/19/23	NC *	Unused pin, which is not connected to the chip internally.
3	29	HU	The control terminal of IGBT by the high side of U. It turns off less than 1.5 V. It turns on more than 2.5 V.
4	28	HV	The control terminal of IGBT by the high side of V. It turns off less than 1.5 V. It turns on more than 2.5 V.
5	27	HW	The control terminal of IGBT by the high side of W. It turns off less than 1.5 V. It turns on more than 2.5 V.
6	26	LU	The control terminal of IGBT by the low side of U. It turns off less than 1.5 V. It turns on more than 2.5 V.
7	25	LV	The control terminal of IGBT by the low side of V. It turns off less than 1.5 V. It turns on more than 2.5 V.
8	24	LW	The control terminal of IGBT by the low side of W. It turns off less than 1.5 V. It turns on more than 2.5 V.
10	22	SD	Input pin of external protection. (“L” active, It doesn't have hysteresis.)
12	20	RS	Over current detection pin.
14	18	DIAG	With the diagnostic output terminal of open drain, a pull-up is carried out by resistance. It turns on at the time of unusual.
16	16	V_{CC}	Control power supply pin. (15 V typ.)
17	14	V_{REG}	5 V regulator output pin.
19	10	IS1	U-phase IGBT emitter and FRD anode pin.
20	9	IS2	V-phase IGBT emitter and FRD anode pin.
21	8	U	U-phase output pin.
22	7	BSU	U-phase bootstrap capacitor connecting pin.
23	6	BSV	V-phase bootstrap capacitor connecting pin.
24	5	V	V-phase output pin.
25	4	V_{BB}	High-voltage power supply input pin.
27	3	BSW	Unused pin, which is not connected to the chip internally.
28	2	W	W-phase bootstrap capacitor connecting pin.
30	1	IS3	W-phase output pin.

*NC pins are unused pins and are not connected to the chip internally. Although the electrical characteristics are not affected, it is recommended that the pins be soldered to the board.

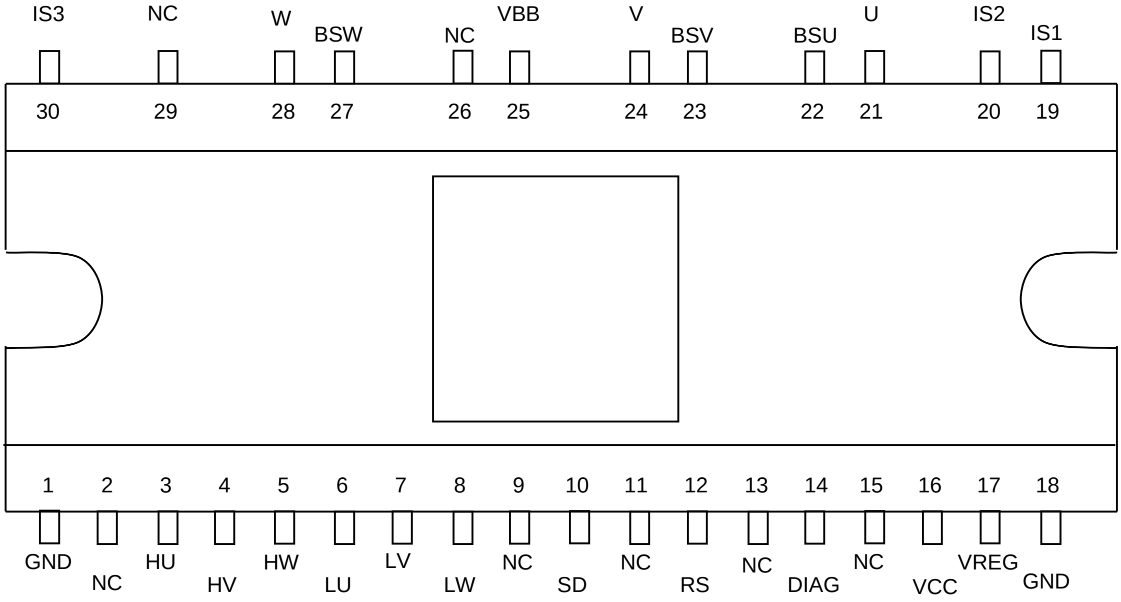


Figure 3.1.1　HDIP30 pin assignment（TPD4163K/TPD4164K/TPD4165K）

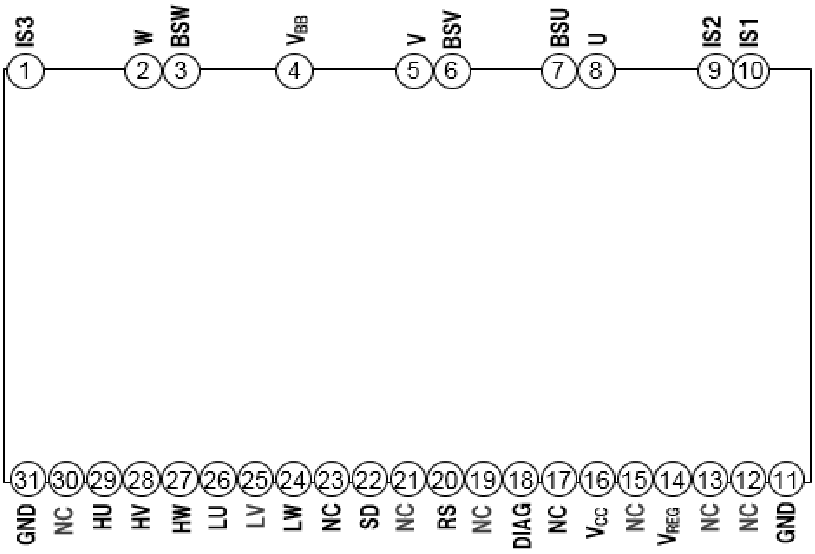


Figure 3.1.2　HSSOP31 pin assignment（TPD4163F/TPD4164F）

4. Usage considerations and functional descriptions

4.1. Application circuit example

The pin numbers in the figure indicate the number of TPD4163K, TPD4164K and TPD4165K.

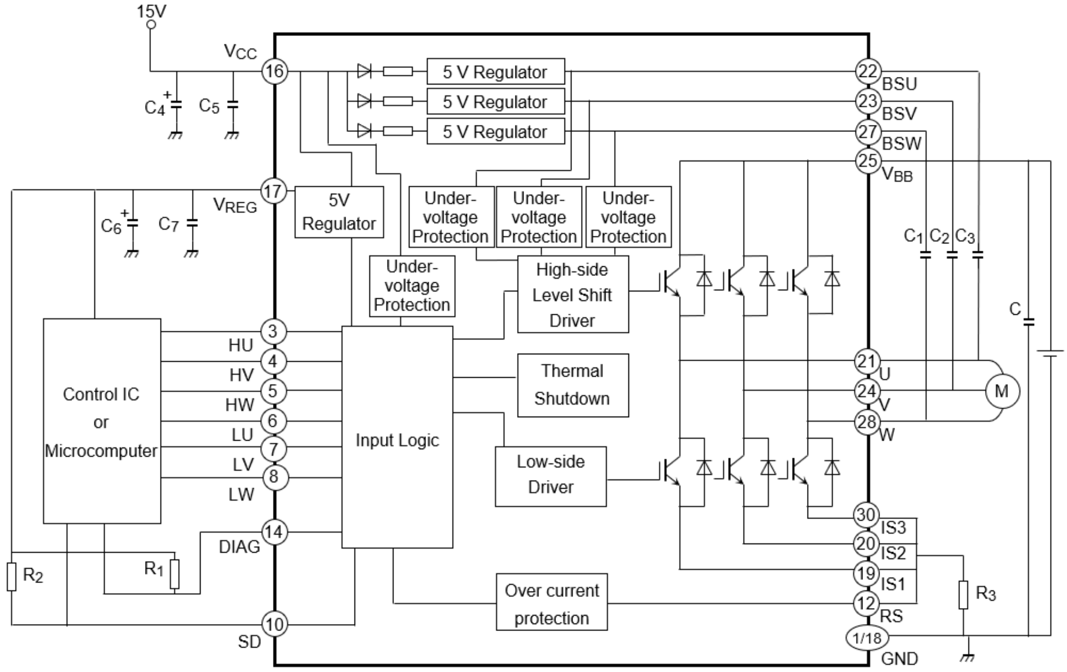


Figure 4.1.1 Application circuit example
(When using the overcurrent protection of HVIPD)

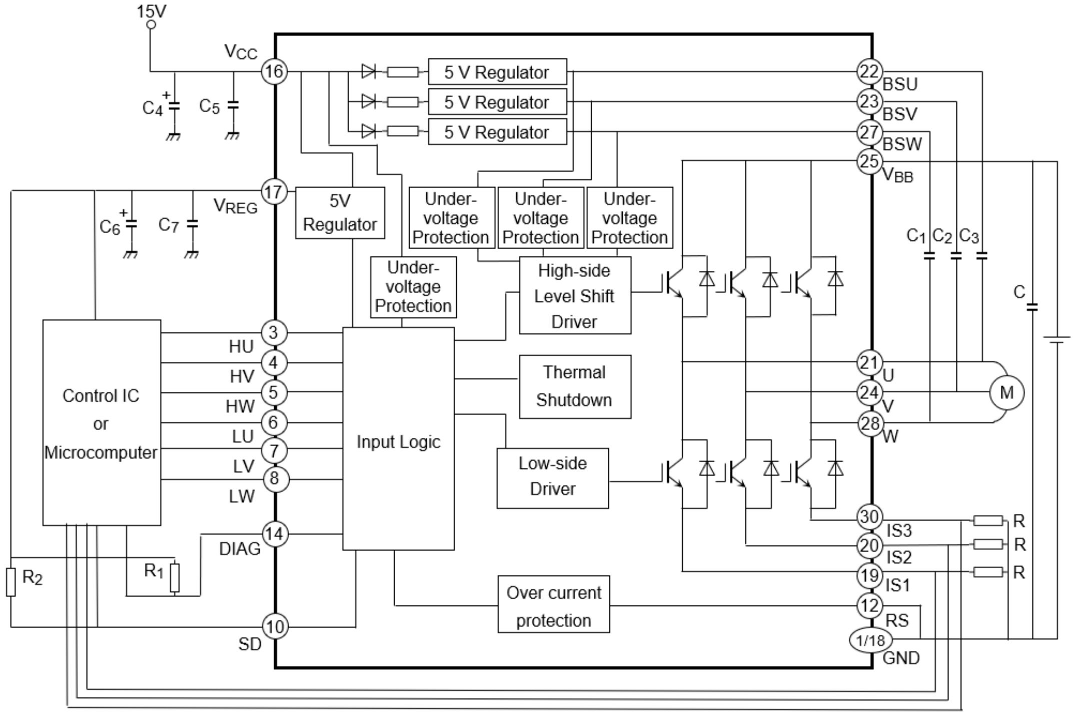


Figure 4.1.2 Application circuit example
(When using the overcurrent protection of external control IC)

The table below lists the standard external parts.

Table 4.1.1 Application circuit example: External parts value

Parts	Reference value		Purpose	Remarks
C_1, C_2, C_3	25 V/2.2 μF		Bootstrap capacitor	(1)
C_4	25 V/10 μF		VCC power supply stability	(2)
C_5	25 V/0.1 μF		VCC for surge absorber	(2)
C_6	25 V/10 μF		VREG power supply stability	(3)
C_7	25 V/0.1 μF		VREG for surge absorber	(3)
R_1	5.1 kΩ		DIAG pin pull-up resistor	(4)
R_2	10 kΩ		SD pin pull-up resistor	(5)
R_3	TPD4163F TPD4163K	0.62 Ω ± 1 % (1 W)	Overcurrent detection	(6)
	TPD4164F TPD4164K	0.35 Ω ± 1 % (1 W)		
	TPD4165K	0.2 Ω ± 1 % (2 W)		

(1) BSU, BSV and BSW pin

Connect the bootstrapped capacitor C1, C2 and C3 between BSU and U pin, between BSV and V pin, and between BSW and W pin, respectively. These pins are used to power the internal circuit that drives the high-side IGBT. The required capacity of the bootstrap capacitor depends on the drive conditions of the motor. 5V (typ.) is applied to the capacitor. Refer to the calculation formula and select a capacitor with sufficient derating considerations.

Table 4.1.2 BSU, BSV and BSW pin capacitor

Item	Parts No	Parts	Reference value
Between BSU and U Between BSV and V Between BSW and W	C1, C2, C3	Ceramic capacitors Electrolytic capacitor	25 V / 2.2μF

Calculating the value of the bootstrap capacitor required

Smaller capacitance among CB(ON) and CB(OFF) is the required capacitance.

CB(ON)=IBS(ON) x High-side IGBT on-time (max)
/ (5 + VF (FRD) - VBSUVD) [F]
CB(OFF)=IBS(OFF) x Low-side IGBT off-time (max)
/ (5 +VF (FRD)− V_{BS}UVD) [F]

CB: Minimum capacitance of the bootstrap capacitor
IBS(ON) : Maximum Bootstrap Current dissipation in high side ON (150μs)
IBS(OFF) : Maximum Bootstrap Current dissipation in high side OFF(140μs)
VF (FRD) : Forward voltage of the flywheel diode（V_FH or V_FL)
V_{BS}UVD : Maximum V_{BS} under voltage protection (4V)

(2) V_{CC} pin

Connect the ceramic capacitor and the electrolytic capacitor between Vcc and SGND/PGND as close to the IC as possible if needed in order to reduce the noise and the fluctuation of the voltage at Vcc terminal. In particular, the power supply fluctuations and the noise, which generate at high frequency, can be effectively reduced by connecting ceramic capacitors near the IC.

If you need to increase the noise tolerance of VCC lines, add a Zener Diode between VCC-GND as needed.

Table 4.1.3 V_{CC} pin Connecting Capacitors

Item	Parts No	Parts	Reference value
Between V_{CC} and GND	C4	Electrolytic capacitor	25 V / 10μF
	C5	Ceramic capacitor	25 V / 0.1μF

(3) V_{REG} pin

V_{REG} pin is output pin of 5V voltage regulator. It can be used for power supply for pull-up resistor of DIAG pin, pin setting, and power supply of peripheral IC. At that time, the output current can be used within 30mA (max). To prevent oscillation, add a capacitor to VREG terminal. In addition, connect a capacitor as close to IC as possible between VREG and GND to minimize noise and fluctuations on VREG terminals.

Table 4.1.4 V_{REG} pin Connecting Capacitors

Item	Parts No	Parts	Reference value
Between V_{REG} and GND	C6	Electrolytic capacitor	25 V / 10μF
	C7	Ceramic capacitor	25 V / 0.1μF

Table 4.1.5 Regulator Voltage (Condition: V_{CC}=15V, I_{REG}=30mA) Unit: V

Characteristic	Symbol	Min	Typ.	Max
Regulator voltage	V_{REG}	4.5	5	5.5

(4) DIAG pin

DIAG pin is open-drain output-type pin. To use this pin as High/Low level output-signal, connect a pull-up resistor to the external power supply or V_{REG} pin. When the output MOSFET of DIAG pin is turned ON with a pull-up resistor connected, the voltage of the pin is set to L level. When it is turned OFF, the voltage of the pin is set to H level. When pulling up to VREG pin, it is recommended that the resistor be connected between 1 kΩ and 10 kΩ. When using a pull-up resistor for an external power supply, select a pull-up power supply voltage and resistor so that the output voltage 20V and output current 20mA of the absolute maximum rating are not exceeded.

When DIAG pin is not used, connect it to GND.

Table 4.1.6 DIAG Pin Connecting Resistor

Item	Parts No	Parts	Reference value	Recommended range
Between DIAG and power supply	R_1	Resistor	5.1kΩ	1kΩ to 10kΩ

(5) SD pin

By inputting Low level to SD pin, IGBTs of the U, V, and W-phase high-side and low-side can be switched all-off.

High/Low level of SD pin is detected using the input-voltage 2.5V (typ.) as the threshold. When connecting to an external circuit to input a signal, it is recommended to connect a pull-up resistor of 5kΩ to 15kΩ to VREG pin to prevent malfunction due to noise-induced effects.

When SD pin is fixed at High level, it is recommended to short-circuit VREG pin and SD pin.

Table 4.1.7 SD Pin Connecting Resistor

Item	Parts No	Parts	Reference value	Recommended range
Pull-up resistor between SD and V_{REG}	R2	Resistor	10kΩ	5kΩ to 15kΩ

(6) Resistor for connecting IS1,IS2 and IS3 pins and RS pin

Design IS1/IS2/IS3 terminals to be connected to the shunt resistor as short as possible to avoid malfunction and damage. Add a surge-protecting diode between IS1/IS2/IS3 terminal-GND terminals for longer wire lengths. Motor current flows through IS1, IS2 and IS3 terminals. Wire the terminals in a wider pattern.

As shown in Fig. 4.1.1, when using the overcurrent protection function with the 1-shunt resistor detection method, short-circuit IS1, IS2, IS3 pin and RS pin, connect a detection resistor between GND, and set the detection current of the overcurrent protection.

The relation between the over-current protection detection current I_O and the detection resistor R_1 is roughly calculated by the following formula.

$I_O = V_R / R_3$

Overcurrent Protective Operating Voltage V_R : 0.46V (Min), 0.5 V (Typ.), 0.54V (Max)

e.g.) If R_3 resistor is set to 0.51 Ω, I_{OU} (typ.) = 0. 5 V (typ.)/0.51 Ω≃0.98 A

Note that a large current flows through the detector resistor R_3, so pay careful attention to the ratings of the external components when selecting with margins. During operation, the power P across the sense resistor is calculated as maximum P=0.525Vx0.525V/ R_3. For example, when R_3=0.51 Ω, P=0.54W, so use a resistance higher than 1 W for the rated power.

Table 4.1.8 Current Detection Resistor
(When Using the Overcurrent Protection Function of the Product)

Item	Parts No	Parts	Reference value	Reference value
Current sensing resistor between IS1/IS2/IS3 and GND	R3	Resistor	TPD4163F TPD4163K	0.62 Ω ± 1 % (1 W)
			TPD4164F TPD4164K	0.35 Ω ± 1 % (1 W)
			TPD4165K	0.2 Ω ± 1 % (2 W)

To use the overcurrent protection function of the control IC or MCU as shown in Fig. 4.1.2, short-circuit RS pin to GND. Also, if noise is affected by the routing of the wires from the current detecting resistor across IS1/IS2/IS3-GND to the control IC or MCU, consider measures such as adding a low-pass filter to remove noise as needed.

(7) HU, HV, HW, LU, LV and LW pin

HU, HV, HW, LU, LV and LW pins control the on/off status of the U-, V-, and W-phase high-side and low-side IGBT. HU controls U-phase high side, HV controls V-phase high side, HW controls W-phase high side, LU controls U-phase low side, LV controls V-phase low side, and LW controls W-phase low side. Connect it to a control IC or microcontroller that generates three-phase brushless motor control signals.

(8) U, V and W pin

Connect each pin to the coil of the three-phase brushless motor. The motor current flows through each pin, so the wiring pattern should be wide.

(9) V_{BB} pin

V_{BB} pin is a high-voltage power supply pin and connected to the collector of the high-side IGBT. Take measures such as adding a capacitor between V_{BB} and GND so that the operating power supply 450V is not exceeded when the motor is stopped or during operation. Motor current flows through V_{BB} pin. Wire the pin in a wider pattern.

(10) GND pin

Design the circuit so that there is no path through which the motor current flows in the wire connecting GND terminal and the overcurrent detecting resistor. Also design the circuit so that the wires connecting HVIPD's GND pin to the control IC or MCU's GND pin do not flow the motor current.

4.2. Protection function

Under voltage protection

The HVIPD incorporates an under voltage protection circuit, which prevents internal IGBTs from operating in an unsaturated region when the VCC and VBS voltages drop.

When VCC drops to VCCUVD (= 11V typ.), all the IGBT 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 typ.), 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 IGBT outputs shut down when VCC drops below 11V, even if the DIAG output does not toggle.)

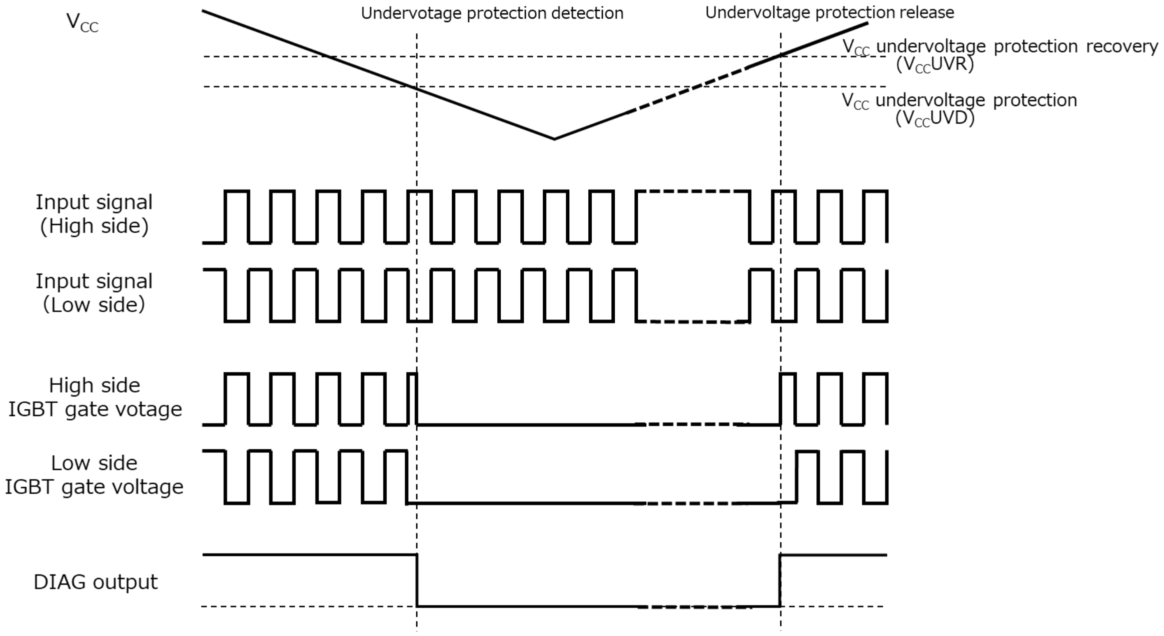


Figure 4.2.1 V_{CC} undervoltage protection operation

When VBS drops to VBSUVD (= 3V typ.), all the high-side IGBT outputs shut down. When VBS rises back to VBSUVR (= 3.5V typ.), 0.5V higher than VBSUVD, the high-side IGBTs return to normal operation and operate according to the control signals. VBS under voltage protection does not cause the DIAG output to toggle.

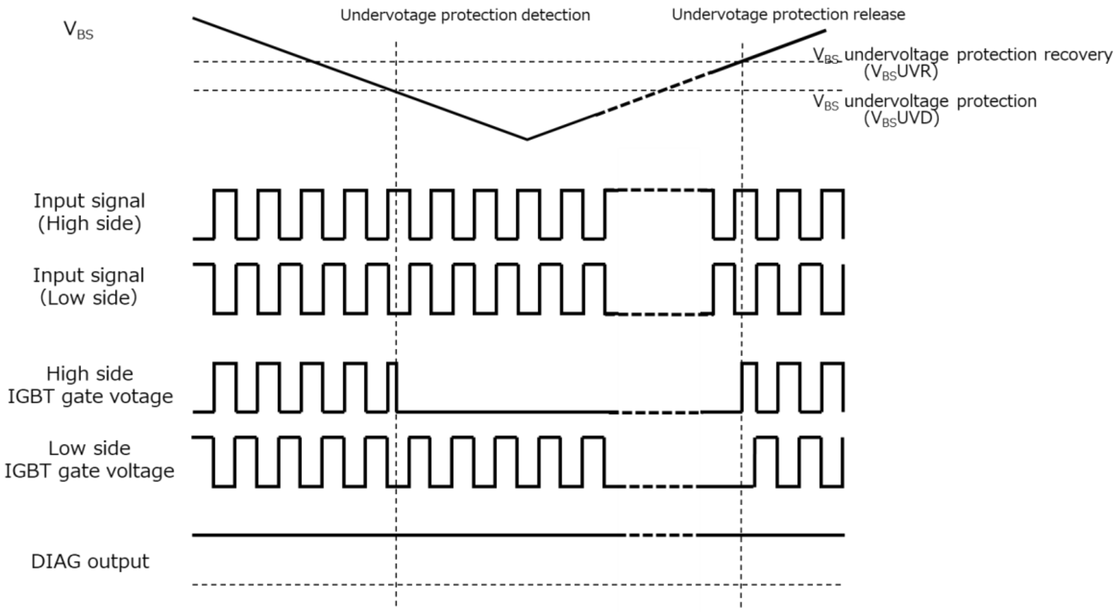


Figure 4.2.2 V_{BS} undervoltage protection operation

Overcurrent protection

The HVIPD incorporates the overcurrent protection circuit, which protects itself from excessive current at motor startup or when the rotor is locked. This protection function detects the voltage generated in the current-sensing resistor connected to the RS pin. When this voltage exceeds V_R (= 0.5V typ.), the IGBT outputs temporarily shut down after a delay of 2μs (typ.) to prevent a further increase in current. Setting the control signals to all-Lows releases the HVIPD from the shutdown state.

Selecting the overcurrent resistor:

$R_3 = V_R \div I_O$

V_R : Overcurrent voltage, I_O : Overcurrent, R_3 : Overcurrent resistor

Table 4.2.1 Overcurrent protection voltage Unit: V

Characteristics	Symbol	Min	Typ.	Max
Overcurrent protection voltage	V_R	0.46	0.5	0.54

Setting the overcurrent protection delay time

The HVIPD incorporates the filter into RS pin to prevent the current limiter from malfunctioning because of the noise at the overcurrent-sensing resistor. The delay time from when the overcurrent senses a current exceeding the overcurrent to when the IGBTs 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:

Overcurrent protection delay time (D_t) = filtering time (dead time) + control circuit delay

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

Table 4.2.2 Over current protection delay time Unit: μs

Characteristics	Symbol	Min	Typ.	Max
Over current protection delay time	D_t	—	2	3

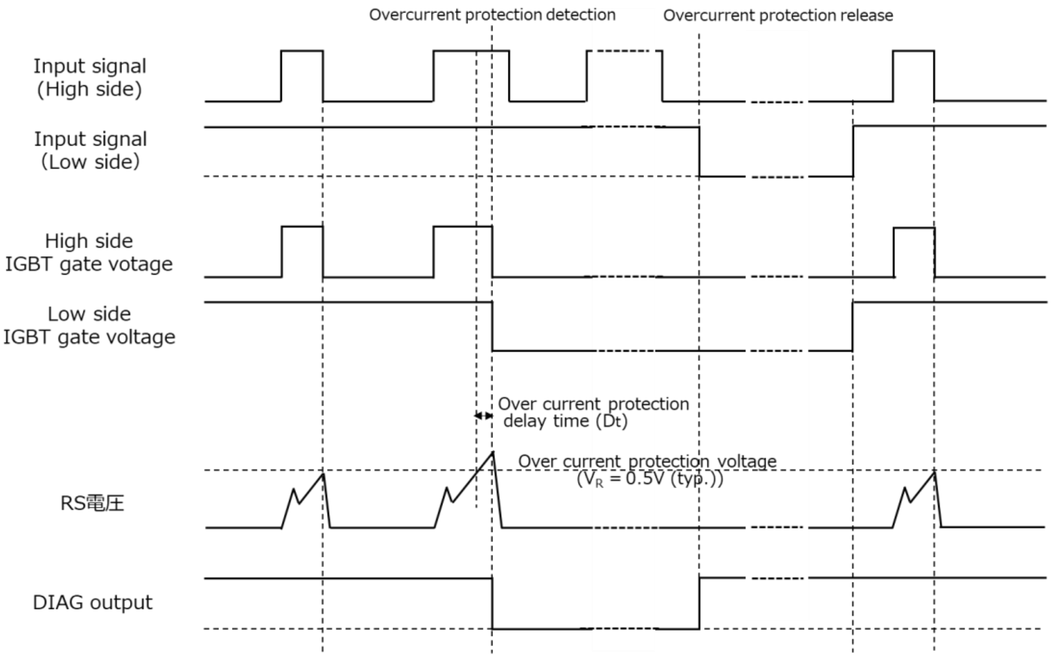


Figure 4.2.3 Overcurrent protection operation

Thermal shutdown

The HVIPD incorporates the 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 IGBT 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 IGBTs are heat sources. The time taken to shut down the IGBTs 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.

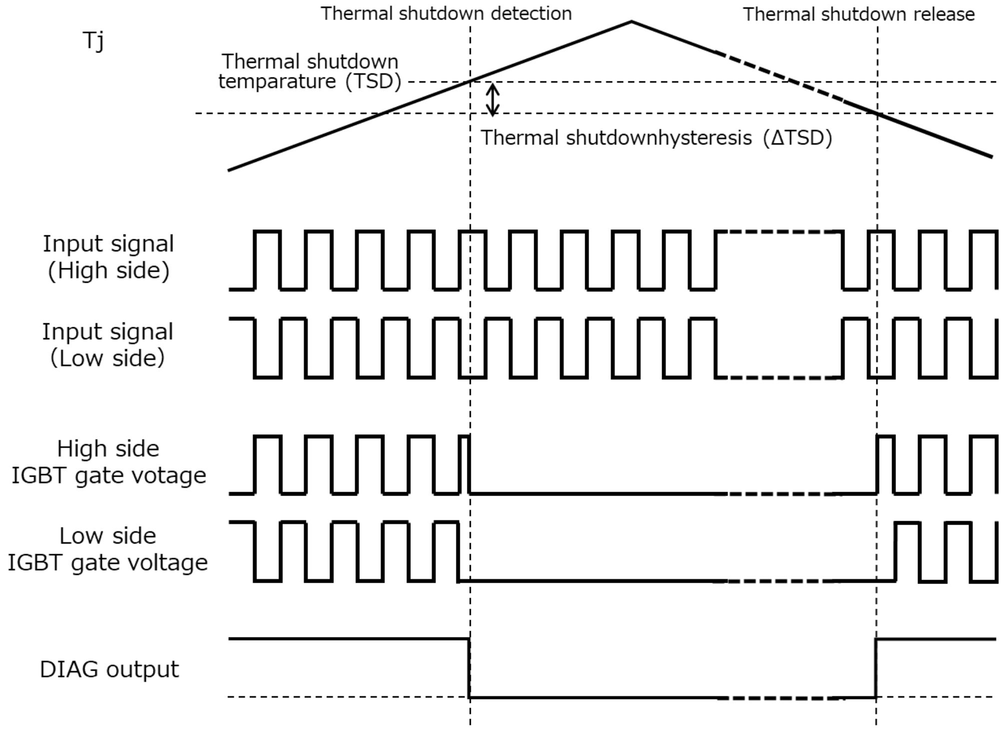


Figure 4.2.4 Thermal shutdown operation

SD function

The overcurrent condition may be detected by an external circuit. Setting the SD pin Low causes all the IGBT outputs to turn off after a delay of 2μs (typ.). Setting all control signals to low level releases the IGBT outputs from shutdown mode.

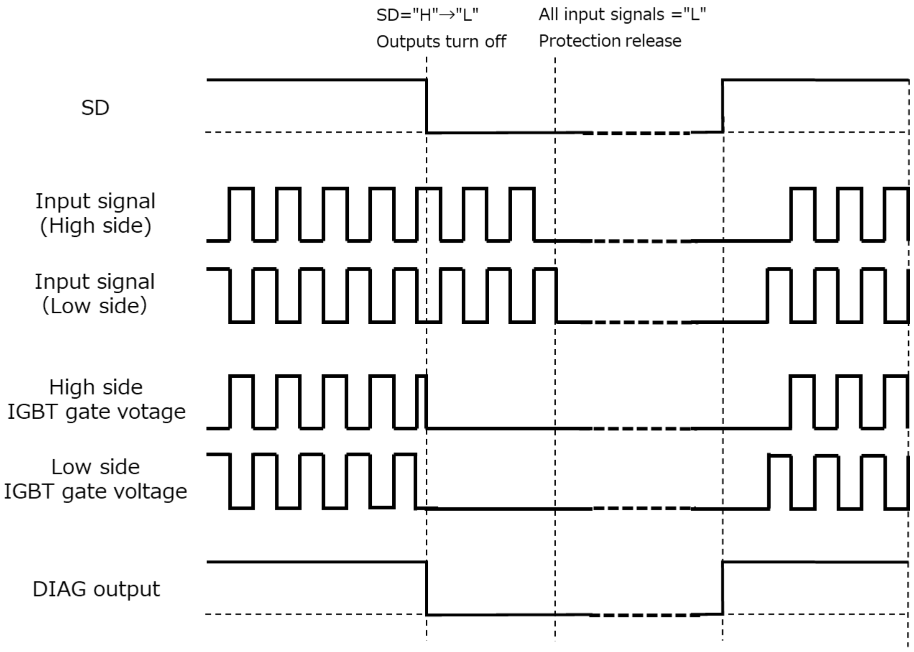


Figure 4.2.5 SD Function operation

4.3. Power supply sequencing

We do not recommend the following power sequences:

At power-on: Powering on V_{CC} after V_{BB} and control signals

At power-off: Powering off V_{CC} before V_{BB} and control signals

Table 4.3.1 At power-on

At power-on			✓/×
①	②	③	
V_{CC}	V_{BB}	Control signals	✓
V_{CC}	Control signals	V_{BB}	✓
V_{BB}	V_{CC}	Control signals	✓
V_{BB}	Control signals	V_{CC}	×
Control signals	V_{CC}	V_{BB}	✓
Control signals	V_{BB}	V_{CC}	×

Table 4.3.1 At power-off

At power-off			✓/×
①	②	③	
V_{CC}	V_{BB}	Control signals	×
V_{CC}	Control signals	V_{BB}	×
V_{BB}	V_{CC}	Control signals	✓
V_{BB}	Control signals	V_{CC}	✓
Control signals	V_{CC}	V_{BB}	✓
Control signals	V_{BB}	V_{CC}	✓

✓: Recommended, ×: Unrecommended

Note that even when V_{CC} and V_{BB} are powered off, the device might be permanently damaged if the V_{BB} line is disconnected by a relay or other means while the motor is running because this blocks a current recirculation path to V_{BB}.

4.4. Calculating power losses

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

$P = P_{on} + P_t + P_{iBB} + P_{iCC}$

(1) Conduction loss: P_{on}

$P_{on} = P_H + P_L + P_D$ (W)

- High-side IGBT conduction loss: $P_H = I \times V_{satH} \times (1/8 + D/3\pi \times COS\theta) \times 3$
- Low-side IGBT conduction loss: $P_L = I \times V_{satL} \times (1/8 + D/3\pi \times COS\theta) \times 3$
- 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)
V_{satH}/V_{satL} : Output saturation voltage (V)
V_F : Forward voltage drop of the FRD (V)
D : PWM duty cycle
θ : Power factor

(2) MOSFET switching loss: P_t

$P_t = (W_{ton} + W_{toff}) \times f_C / \pi \times 6$ (W)

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

(3) V_{BB} power consumption: P_{iBB} (W)

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

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

(4) V_{CC} power consumption: P_{iCC}

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

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

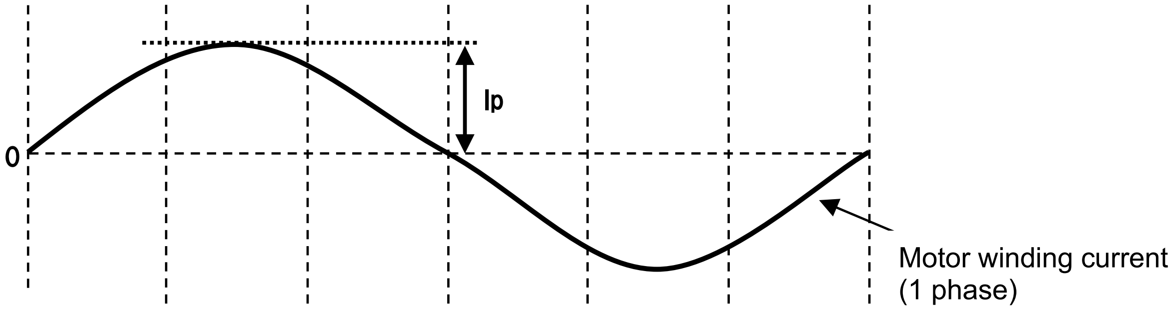


Figure 4.4.1 Motor current waveform for power loss calculation (sine-wave type)

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