High-Voltage Intelligent Power Devices Application Note(SSOP30)

Table of Contents

1. Products discussed herein

1.1. Product offerings

Table 1.1 High-voltage intelligent power devices

Part Number	Ratings	Features						Type
		6-Input	3-Phase Distribution PWM Circuit	Level-Shifter & Driver	over-current Protection	Thermal Shutdown	Under voltage Protection	
TPD4204F	600 V/ 2.5 A	Y	–	Y	Y	Y	Y	180° (Note)
TPD4206F	500 V/ 2.5 A	Y	–	Y	Y	Y	Y	180° (Note)
TPD4207F	600 V/ 5 A	Y	–	Y	Y	Y	Y	180° (Note)

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

HVIPDs for sine-wave (180-degree) type

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

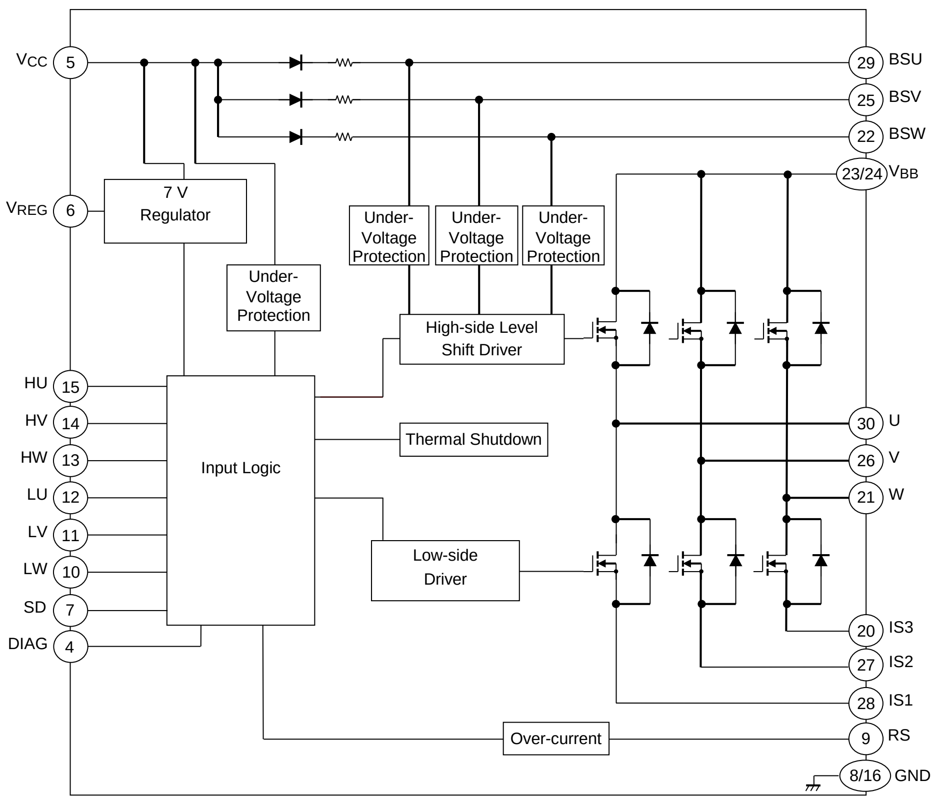


Figure 1.1 Block diagram for an HVIPD for sine-wave (180-degree) type

Table 1.2.1 Controller IC list sine-wave drive type (Example of products)

Part Number	Package	Vcc / Io	Position Sensing	Features					
				Lead Angle Control	Built-in Oscillator	Overcurrent Protection	Gate Block Protection	Position Signal Abnormality Protection	V_{CC} Under voltage Protection
TB6551FAG	SSOP24	12V/2mA	Hall effect IC	External setting	-	Y	Y	Y	Y
TB6556FG	SSOP30	12V/2mA		Current Feedback	-	Y	Y	Y	Y
TB6584FNG/AFNG (Note 1)	SSOP30	18V/2mA	Hall element or Hall effect IC		Y	Y	Y	Y	Y
TB6634FNG	SSOP30	18V/2mA			Y	Y	Y	Y	Y
TB6631FNG	SSOP30	18V/2mA		RPM Feedback (Note 2)	Y	Y	Y	Y	Y
TC78B041FNG	SSOP30	18V/2mA		Intelligent Phase Control (Note 3)	Y	Y	Y	Y	Y
TC78B042FTG	QFN32	18V/2mA			Y	Y	Y	Y	Y

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

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

Note 3: Toshiba's original automatic phase adjustment function.

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

Part Number	Package	ROM Size (Bytes)	RAM Size (Bytes)	Max. Operating Frequency (MHz)	Operating Voltage (V)	
					Min	Max
TMPM375FSDMG	SSOP30	64 K	4 K	40(Note 1)	4.5	5.5
TMPM372FWUG	LQFP64	128 K	6 K	80(Note 2) 32(Note 1)	4.5	5.5
TMPM373FWDUG	LQFP48					
TMPM374FWUG	LQFP44					
TMPM370FYDFG	QFP100	256 K	10 K	80(Note 2)	4.5	5.5
TMPM370FYFG	LQFP100					
TMPM376FDDFG	QFP100	512 K	32 K	80(Note 2)	4.5	5.5
TMPM376FDFG	LQFP100					

Note 1: Ambient temperature -40℃～105℃

Note 2: Ambient temperature -40℃～85℃

2. Outline dimensions and marking of the SSOP30 package

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

2.1. Package outline dimensions

P-SSOP30-1120-1.00-001

Unit: mm

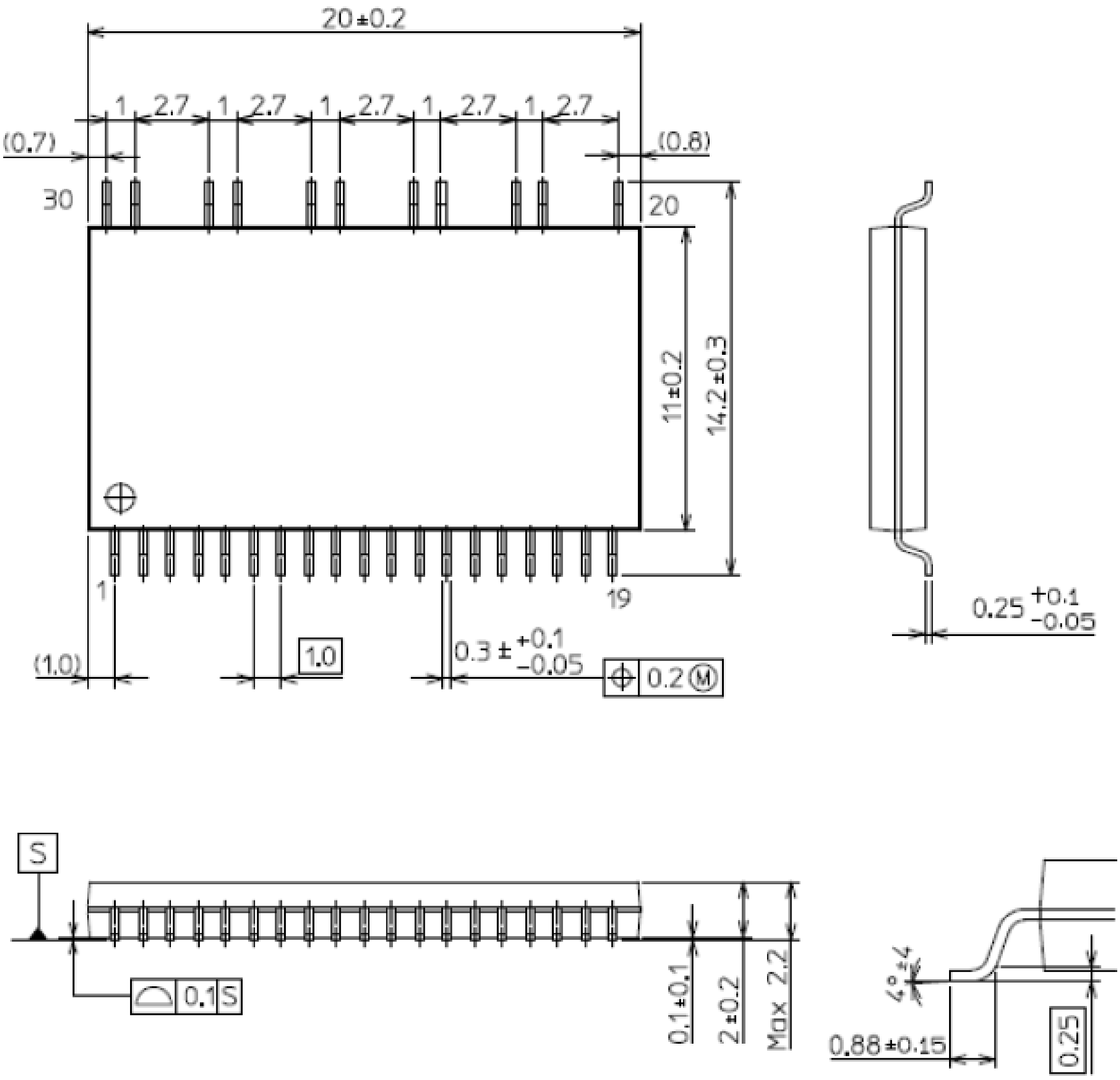


Figure 2.1 Outline dimensions of the SSOP30 package

2.2. Marking

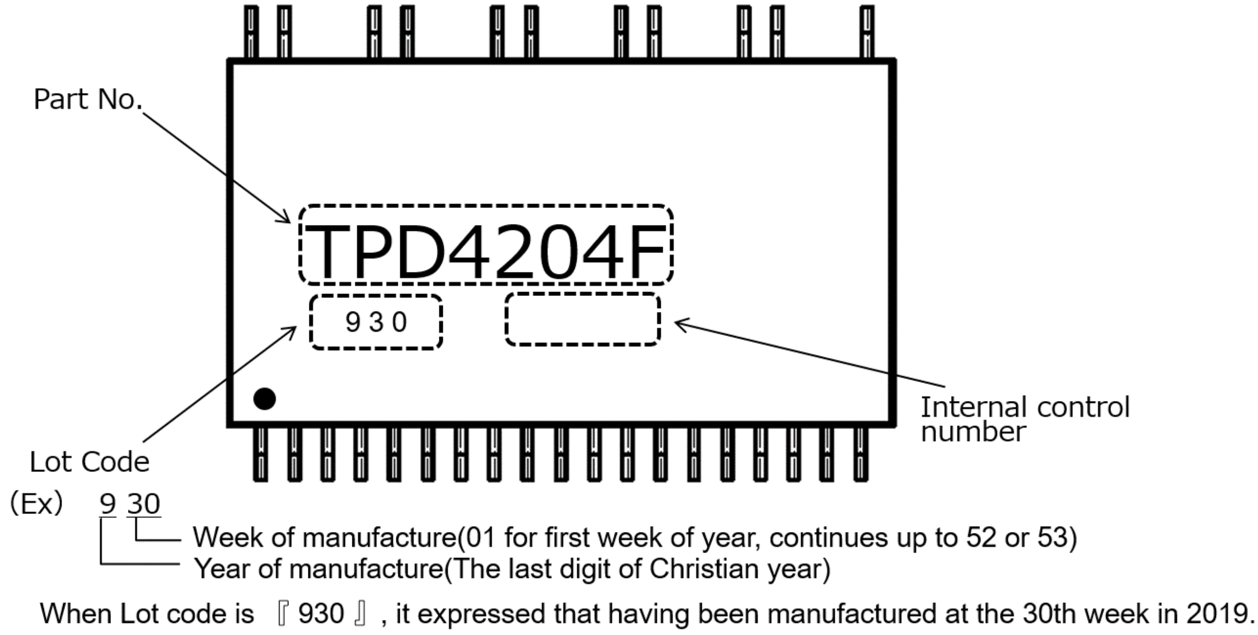


Figure 2.2 Part marking on the SSOP30 package

2.3. PCB land pattern dimensions（Reference）

(Unit: mm)

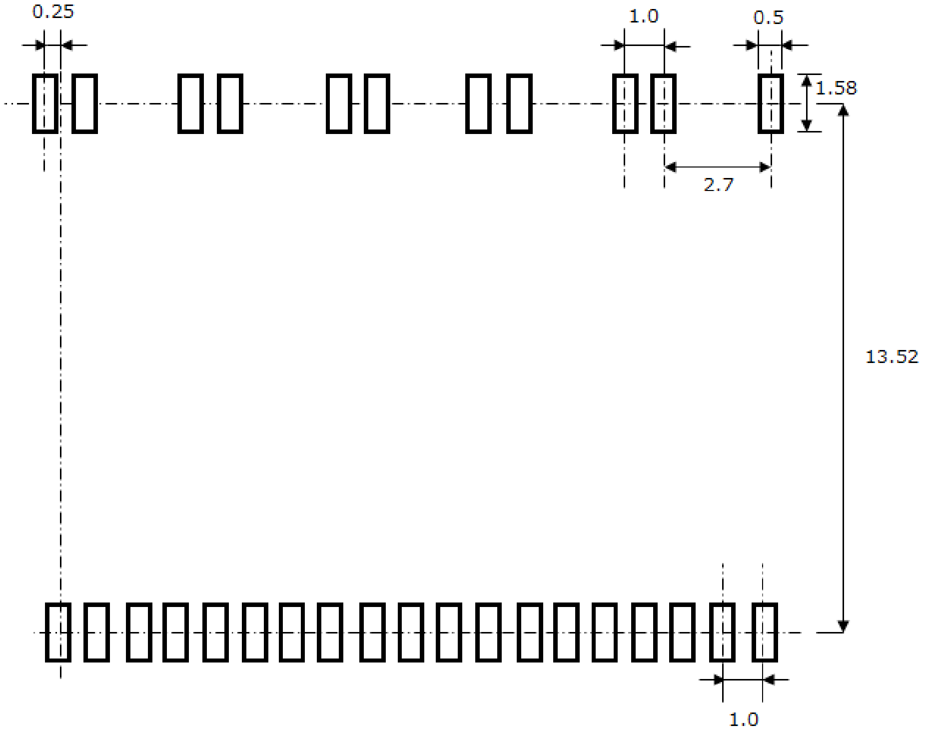


Figure 2.3 Land pattern of the SSOP30(Reference)

2.4. Soldering

Recommended soldering methods

Table 2.4 Adaptation table

Reflow soldering	Flow soldering	Soldering iron
3 times maximum	Not supported	Only once

1) Reflow

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

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

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

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

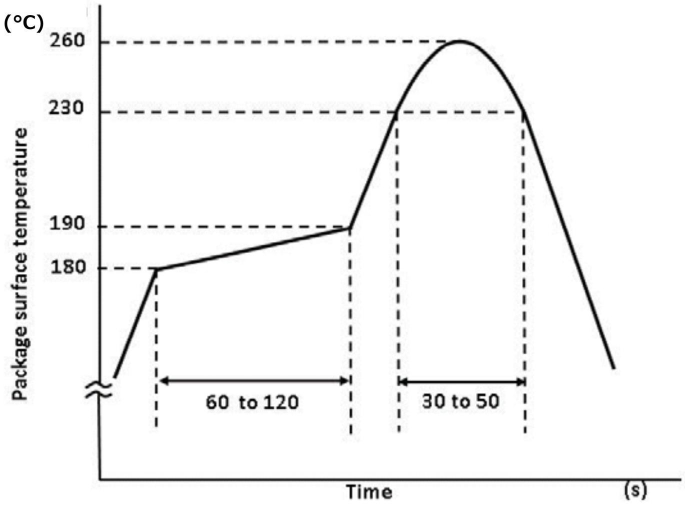


Figure 2.4 Example of a reflow soldering profile

2) Flow

This package is not suitable for solder flow mounting.

3) Soldering iron

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

•Note:
Check solder bonding strength via in house testing at the substrate mounting stage.

2.5. Attaching a heatsink

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

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

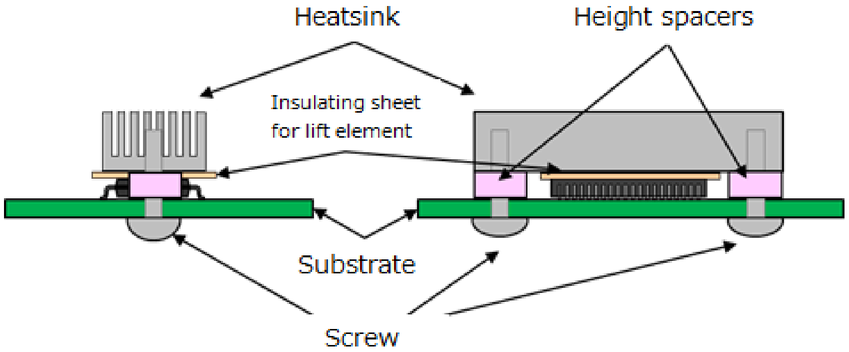


Table 2.5.1
Example of parts used

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

Figure 2.5.1 Heatsink attachment example (using an insulating sheet)

  2) Example of using resin or gelatinous insulating material

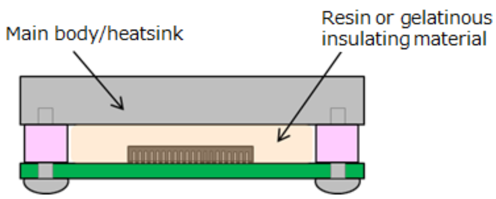


Figure 2.5.2 Heatsink attachment example (using resin or gelatinous insulating material)

  3) Example of other heatsink attachment method

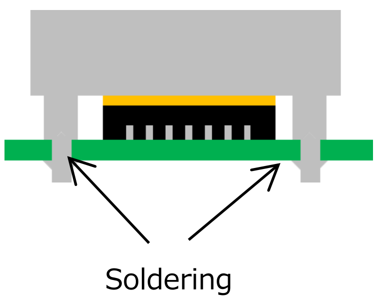


Figure 2.5.3 Soldering

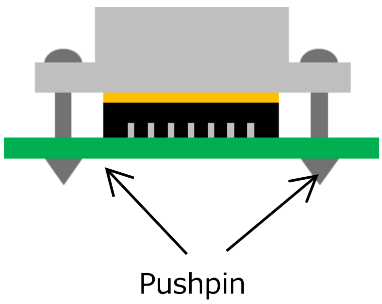


Figure 2.5.4 Pushpin

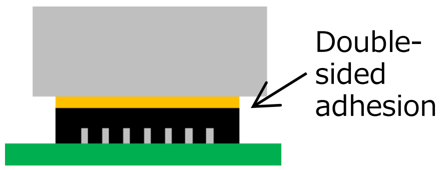


Figure 2.5.5 Adhesion attachment

The result of having measured the case temperature in the substrate for evaluation which attached the radiator plate with soldering is shown in reference.

Evaluation conditions: V_{BB}=280V, V_{CC}=15V, motor number of rotations =regularity (1500rpm),
fc=16.5kHz, Ta=25℃

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

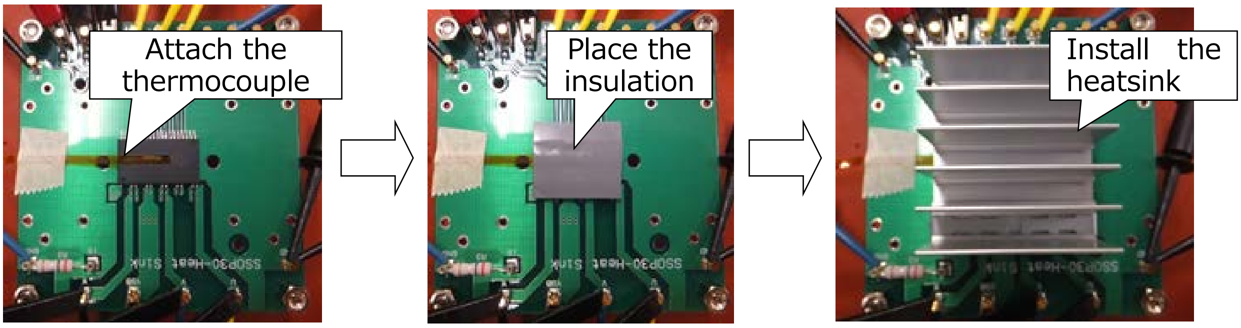
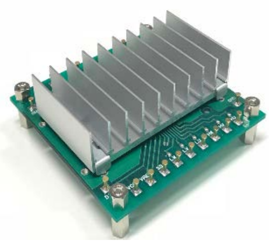
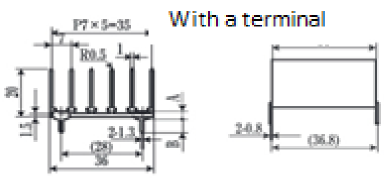
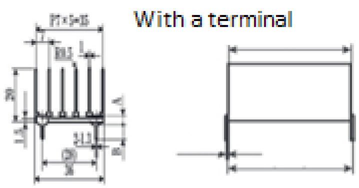
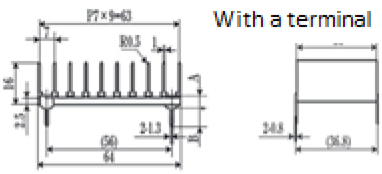


Figure 2.5.6 The substrate for evaluation, and a temperature survey position

Table 2.5.2 Example of a model name of heatsink

TYPE－A	TYPE-B	TYPE-C
		
Sankyo Thermo Tech Type:20FSH036-L36-WFL-B  Length:36 × Width:36 × Height:20mm Surface area:115cm^2	Sankyo Thermo Tech Type:20FSH036-L64-WFL-B  Length:36 × Width:64 × Height:20mm Surface area:202cm^2	Sankyo Thermo Tech Type:16FSH064-L36-WFL-B  Length:36 × Width:64: × Height:16mm Surface area:163cm^2

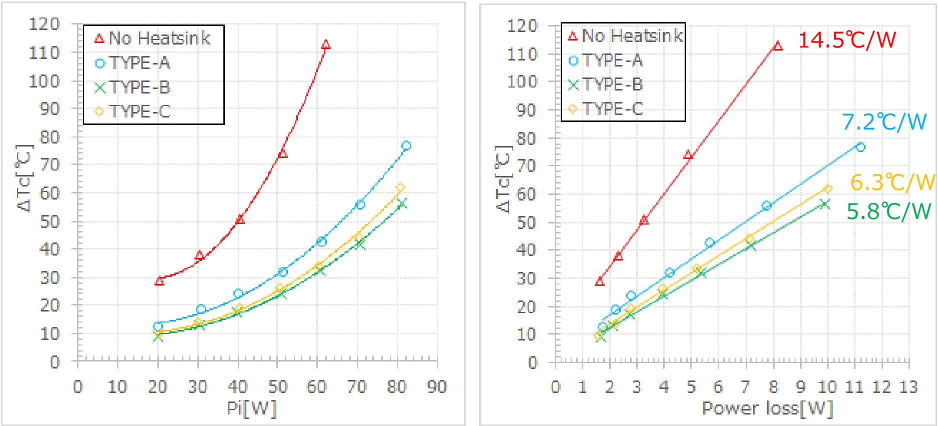


Figure 2.5.7 Input electric power (Pi)- ΔTc and power loss- ΔTc in various heatsink

・Mounting to substrate

Where the SSOP30 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.

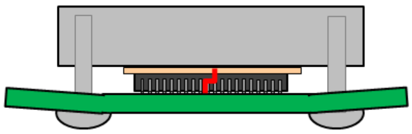


Figure 2.5.8 Bent PCB

・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 lea d 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 Pin description

Pin No.	Symbol	Description
1	NC	No-connect pin, which is not connected to the internal chip
2	NC	No-connect pin, which is not connected to the internal chip
3	NC	No-connect pin, which is not connected to the internal chip
4	DIAG	Open-drain diagnostic output. Connect a pull-up resistor to the DIAG pin. The DIAG pin is driven Low in the event of a fault (an overcurrent, overtemperature, or under voltage condition).
5	V_{CC}	Control power supply pin (15V typical)

6	V_{REG}	7V regulator output pin
7	SD	External protection input (Active-Low, no hysteresis)
8	GND	Ground pin
9	RS	Overcurrent detection pin
10	LW	Control pin for the low-side Phase-W MOSFET. The MOSFET turns off when LW ≤ 1.5V and turns on when LW ≥ 2.5V.
11	LV	Control pin for the low-side Phase-V MOSFET. The MOSFET turns off when LV ≤ 1.5 V and turns on when LV ≥ 2.5V.
12	LU	Control pin for the low-side Phase-U MOSFET. The MOSFET turns off when LU ≤ 1.5 V and turns on when LU ≥ 2.5V.
13	HW	Control pin for the high-side Phase-W MOSFET. The MOSFET turns off when HW ≤ 1.5V and turns on when HW ≥ 2.5V.
14	HV	Control pin for the high-side Phase-V MOSFET. The MOSFET turns off when HV ≤ 1.5V and turns on when HV ≥ 2.5V.
15	HU	Control pin for the high-side Phase-U MOSFET. The MOSFET turns off when HU ≤ 1.5V and turns on when HU ≥ 2.5V.
16	GND	Ground pin
17	NC	No-connect pin, which is not connected to the internal chip
18	NC	No-connect pin, which is not connected to the internal chip
19	NC	No-connect pin, which is not connected to the internal chip
20	IS3	Source pin for the Phase-W MOSFET
21	W	Phase-W output pin
22	BSW	Phase-W bootstrap capacitor connection pin
23	V_{BB}	High-voltage power supply pin
24	V_{BB}	High-voltage power supply pin
25	BSV	Phase-V bootstrap capacitor connection pin
26	V	Phase-V output pin
27	IS2	Source pin for the Phase-V MOSFET
28	IS1	Source pin for the Phase-U MOSFET
29	BSU	Phase-U bootstrap capacitor connection pin
30	U	Phase-U output pin

* The NC pins are no-connect pins that are not connected to the internal chip.

Even if the NC pins are left open, they do not affect the electrical characteristics of the device. However, we recommend soldering them onto a PCB.

4. Functional descriptions and usage considerations

4.1. Protection features

Under voltage protection

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

V_{BS}UVD (= 10V typical), all the high-side MOSFET outputs shut down. When V_{BS} rises back to V_{BS}UVR (= 10.5V typical), 0.5V higher than V_{BS}UVD, the high-side MOSFETs return to normal operation and operate according to the control signals. V_{BS} under voltage protection does not cause the DIAG output to toggle.

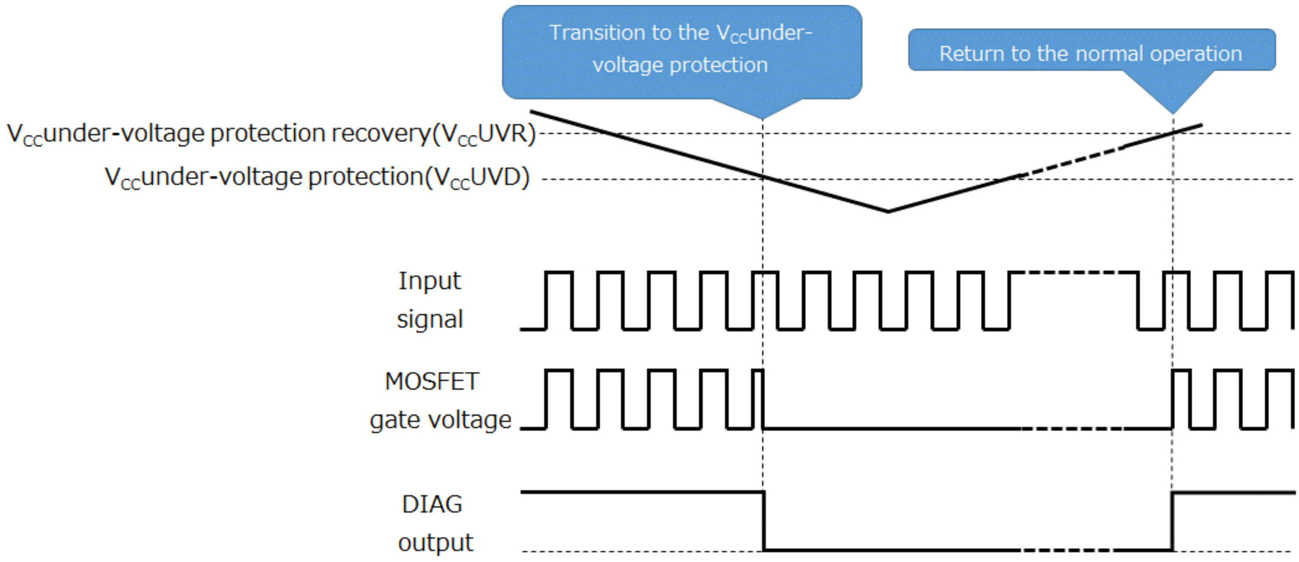


Figure 4.1.1 V_{CC} Under voltage protection

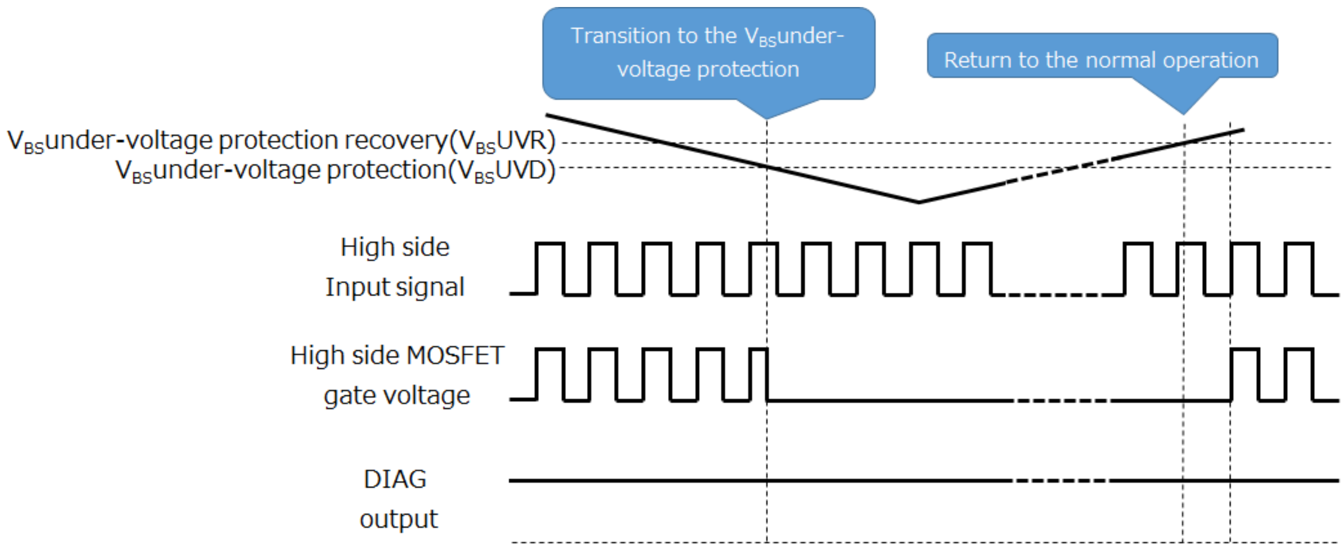


Figure 4.1.2 V_{BS} Under voltage protection

Overcurrent protection

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

Selecting a current-limiting resistor:

$I_O = V_R \div R_1$

V_R: Current-limiting voltage, I_O: Current limit, R_1: Current-limiting resistor

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

Characteristics	Symbol	Min	Typ.	Max
Current-limiting voltage	V_R	0.46	0.5	0.54

Setting the current-limiting delay time

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

Current-limiting delay time (D_t) = filtering time (dead time) + control circuit delay

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

Table 4.2 Current-limiting delay time (from the Electrical Characteristics table) Unit: μs

Characteristics	Symbol	Min	Typ.	Max
Current-limiting delay time	D_t	1.5	3	5

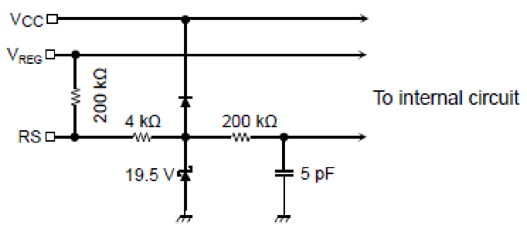


Figure 4.1.3 Internal circuit of the RS pin

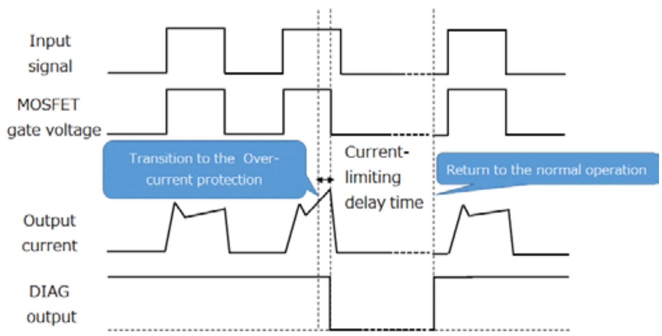


Figure 4.1.4 Overcurrent protection operation

Thermal shutdown

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

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

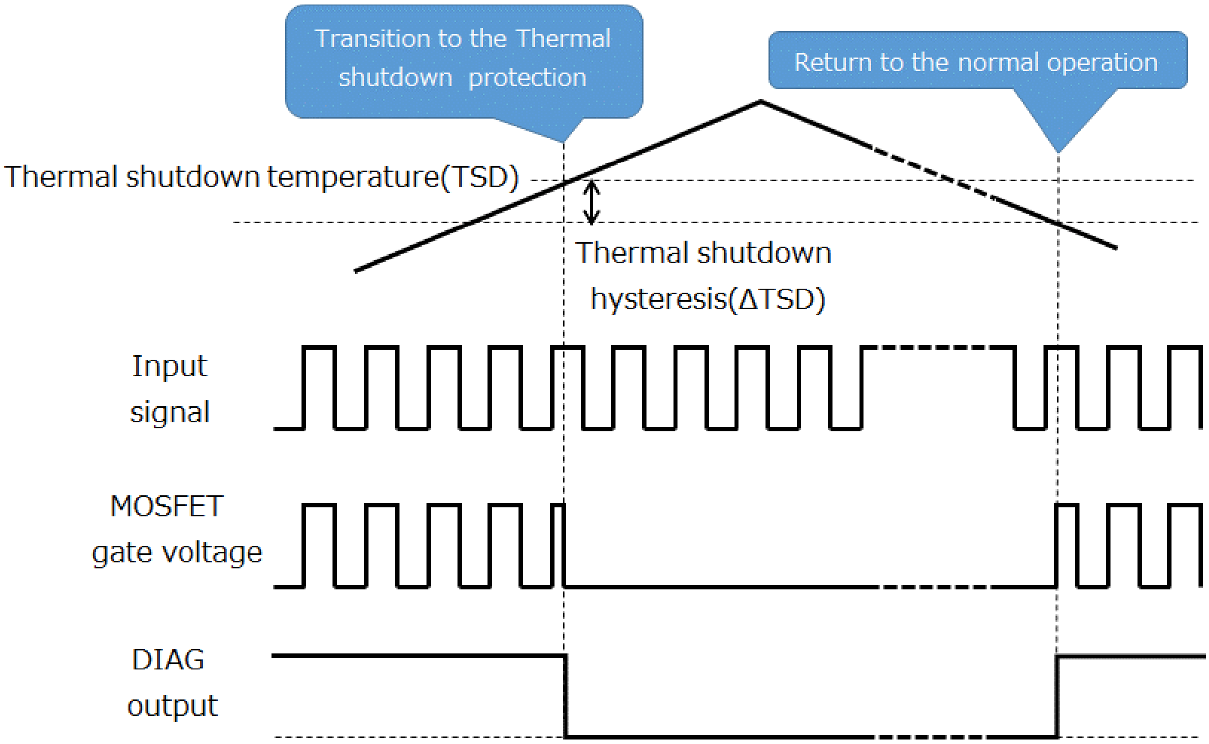


Figure 4.1.5 Thermal shutdown operation

SD function

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

4.2. V_{REG} power supply

A regulated supply voltage from the V_{REG} pin is generated from the V_{CC} power supply. V_{REG} can be used as a power supply not only for the internal circuit but also for an external control IC or other peripheral ICs.

Add an external capacitor to the V_{REG} pin to prevent oscillation. A capacitor with a value of 0.1

μF to 1μF is recommended.

As I_{REG} increases, V_{REG} becomes more susceptible to oscillation. Adjust the value of the capacitor if V_{REG} oscillates under actual usage conditions. Table 4.2 shows the V_{REG} output voltage.

Table 4.2 Regulator voltage (at V_{CC}=15V, I_{REG}=30mA) Unit: V

Min	Typ.	Max
6.5	7	7.5

4.3. Power supply sequencing

We do not recommend the following power sequences:

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

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

Table 4.3.1 At power-up

At power-up			○/×
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-down

At power-down			○/×
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 down, 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 MOSFET conduction loss: $P_H = I^2 \times R_{onH} \times (1/8 + D/3\pi \times \cos\theta) \times 3$

•Low-side MOSFET conduction loss: $P_L = I^2 \times R_{onL} \times (1/8 + D/3\pi \times \cos\theta) \times 3$

•Flywheel diode conduction loss: $P_D = I \times V_F \times (1/8 - D/3\pi \times \cos\theta) \times 6$

I_p: Peak motor winding current (A)

R_{onH}/R_{onL}: On-resistance of the output MOSFET (Ω)

V_F: Forward voltage drop of the FRD (V)

D: PWM duty cycle (on-duty cycle of the high-side MOSFETs)

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: Switching frequency (Hz)

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

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

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

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

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

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

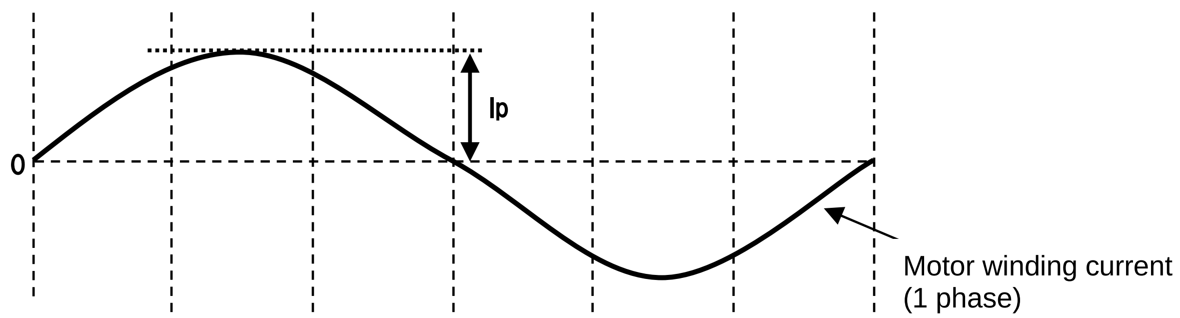


Figure 4.4 Motor current waveform for power loss calculation

5. Application circuit example

5.1. Application circuit example

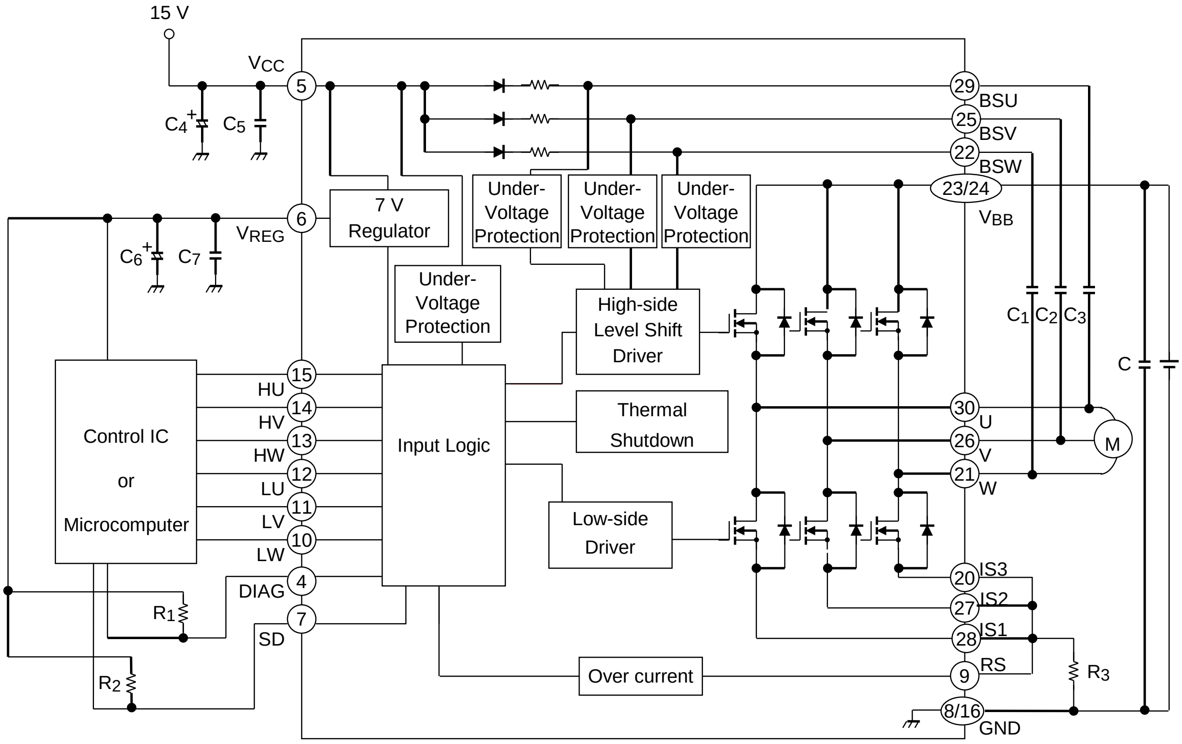


Figure 5.1 Application circuit example (for tripping the current limiter with an HVIPD)

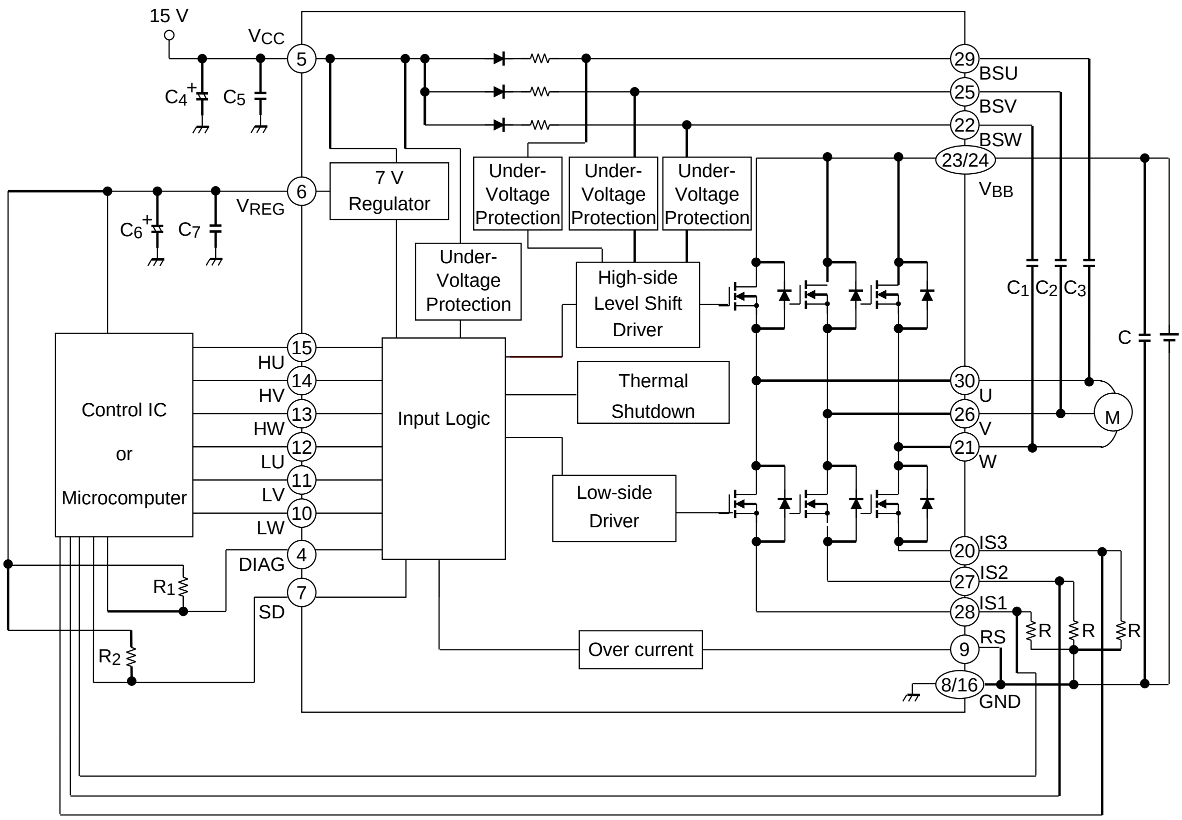


Figure 5.2 Application circuit example (for tripping the current limiter with a motor controller IC or an MCU)

Table 5.1 shows typical external parts.

Table 5.1 External parts for the application circuit

Part	Recommended Value	Purpose	Note
C_1, C_2, C_3	25V/2.2μF	Bootstrap capacitors	(Note 1)
C_4	25V/10μF	V_{CC} voltage stability	(Note 2)
C_5	25V/0.1μF	V_{CC} surge absorption	(Note 2)
C_6	25V/1μF	V_{REG} voltage stability	(Note 2)
C_7	25V/1000pF	V_{REG} surge absorption	(Note 2)
R_1	5.1kΩ	DIAG pull-up resistor	(Note 3)
R_2	10kΩ	SD pull-up resistor	(Note 4)
R_3	0.35Ω±1% (1W)	Overcurrent detection	(Note 5)

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

Calculating the value of the bootstrap capacitor required

$CB = IB \times$ maximum high-side drive period / $(V_{CC} - V_F(BSD) + V_F(FRD) - 13.5)$ (F)

CB: Minimum capacitance of the bootstrap capacitor

IB: Maximum supply current of the high-side driver

V_F (BSD): Forward voltage of the bootstrap diode

V_F (FRD): Forward voltage of the flywheel diode

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

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

Note 3 and Note 4: The recommended pull-up resistor values are:

R_1: 1kΩ to 10kΩ

R_2: 5kΩ to 15kΩ

Note 5: The current-sensing level is expressed as: $I_O = V_R \div R_3$ (V_R = 0.5V typical)
In order that IS1/IS2/IS3 terminals which connects shunt resistance may avoid malfunction and destruction, please wiring length be short and design.
When wiring length becomes long, please attach the diode for surge protection between IS1/IS2/IS3 terminals -GND terminal.

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