Square-Wave control Type TPD4162F/TPD4166F Application note

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1. Products discussed herein

1.1. Product offerings

Table 1.1.1 Product List

Product name	Ratings	Function						Commutation
		3-Phase Distribution PWM Circuit	Level-Shifter & Driver	current limit Protection	Over current Protection	Thermal Shutdown	Under voltage Protection	
TPD4162F	600 V/0.7 A	Y	Y	Y	Y	Y	Y	120°
TPD4166F	600 V/1.0 A	Y	Y	Y	Y	Y	Y	120°

1.2. Block Diagram/Application Circuit Example

TPD4162F and TPD4166F, various control circuits into the devices, and IGBTs and FRDs are installed on output stage. This supports direct drive of a brushless DC motor with square wave input signals from either a Hall sensor or a Hall IC without requiring a PWM controller IC. Figure 1.2.1 shows a block diagram, and Figure 1.2.2 shows an example of an application circuit.

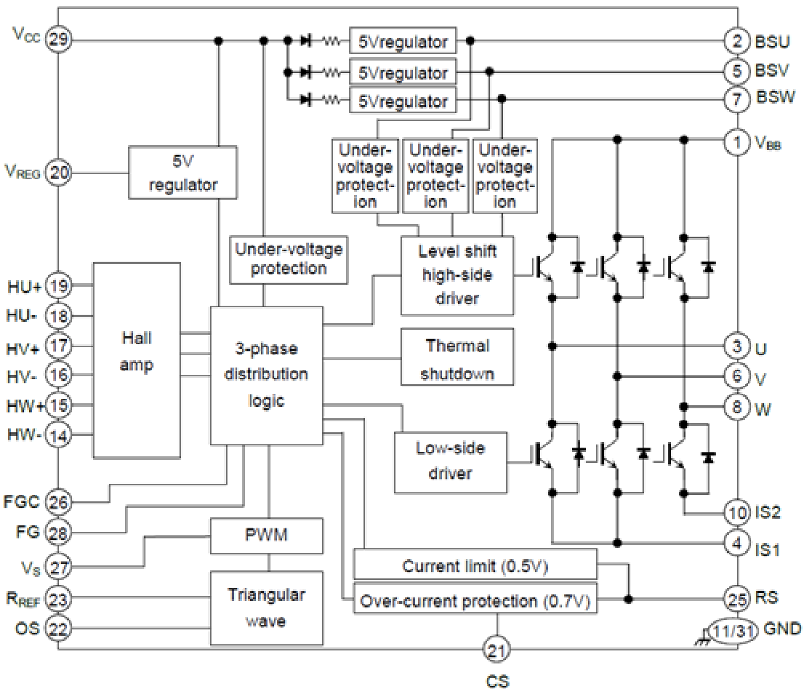


Figure 1.2.1 Block Diagram

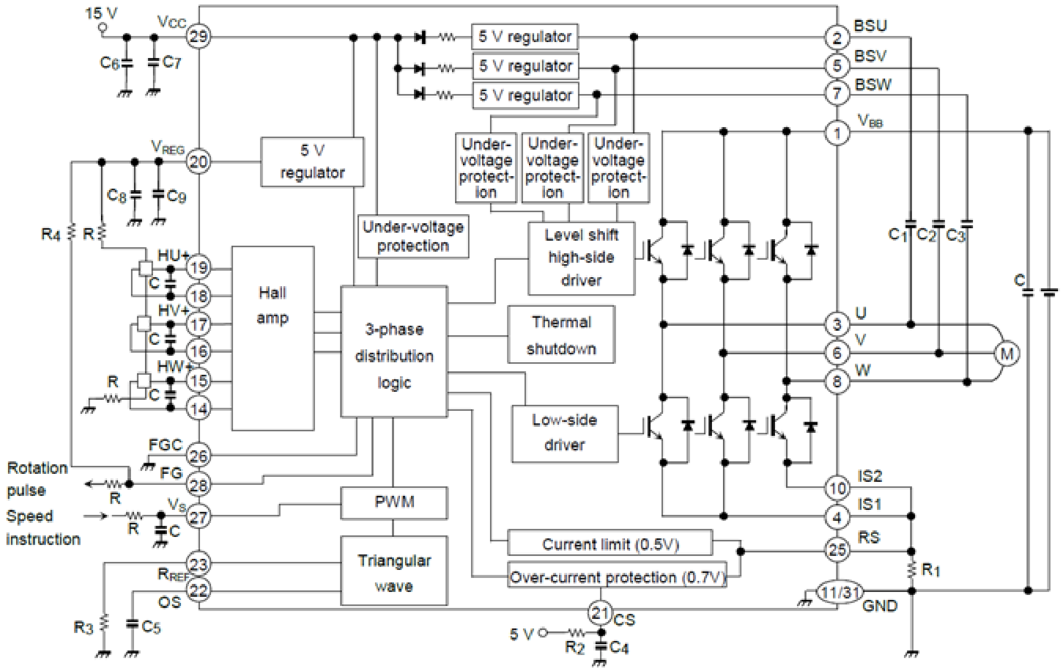


Figure 1.2.2 Example of Application Circuit

Table 1.2.1 shows typical external parts.

Table 1.2.1 External parts for the application circuit

Part	Typical	Purpose	Remarks
C_1, C_2, C_3	25 V/2.2 µF	Bootstrap capacitor	(Note 1)
R_1	1 Ω ± 1 % (1 W)	Current detection	(Note 2)
R_2	2 MΩ± 5 %	Over-current protection recovery setup	(Note 3)
C_4	25 V / 470 pF	Over-current protection recovery setup	(Note 3)
C_5	25 V/1000 pF ± 5 %	PWM frequency setup	(Note 4)
R_3	27 kΩ ± 5 %	PWM frequency setup	(Note 4)
C_6	25 V/10 µF	Control power supply stability	(Note 5)
C_7	25 V/0.1 µF		
C_8	25 V/10 µF	V_{REG} power supply stability	(Note 5)
C_9	25 V/0.1 µF		
R_4	5.1 kΩ± 5 %	FG pin pull-up resistor	(Note 6)

Note 1: The required bootstrap capacitance value varies according to the motor drive conditions. Although the IC can operate at above the V_{BS} undervoltage level, it is however recommended that the capacitor voltage be greater than or equal to 3.5 V to keep the power dissipation small.

Note 2: The following formula shows the detection current: $I_O = V_R \div R_1$ (at $V_R = 0.5$ V (typ.))
Do not exceed a detection current when using the IC.
TPD4162F : 0.7 A , TPD4166F : 1 A

Note 3: Over-current protection recovery and the refreshment operating time at the time of a return are set up in the combination of C_4 and R_2 which were shown in the formula. And it is recommended that, C_4 and R_2 is refreshment operating to 190 µs or more. If the CS pin is not used, connect to the V_{REG} pin.

Over-current protection recovery time $=1.06 \times C_4 \times R_2$ [s]

Refreshment operating time $=0.21 \times C_4 \times R_2$ [s]

Note 4: With the combination of C_5 and R_3 shown in the table, the PWM frequency is around 20 kHz. The IC intrinsic error factor is around 10 %.
The PWM frequency is broadly expressed by the following formula. (In this case, the stray capacitance of the printed circuit board needs to be considered.)

$f_c = 0.65 \div \{ C_5 \times (R_3 + 4.25\ k\Omega)\}$ [Hz]

R_3 creates the reference current of the PWM triangular wave charge/discharge circuit. If R_3 value is too small, the triangular wave becomes distorted because the supply current from R_{REF} exceeds the current capacity of internal circuits of the IC. Set R_3 to at least 9 kΩ.

Note 5: When using the IC, adjustment is required in accordance with the use environment. Place as close to the base of the IC leads as possible to improve noise elimination.

Note 6: The FG pin is open drain. If the FG pin is not used, connect to the GND.

Note 7: If noise is detected on the Input signal pin, add a capacitor between inputs.

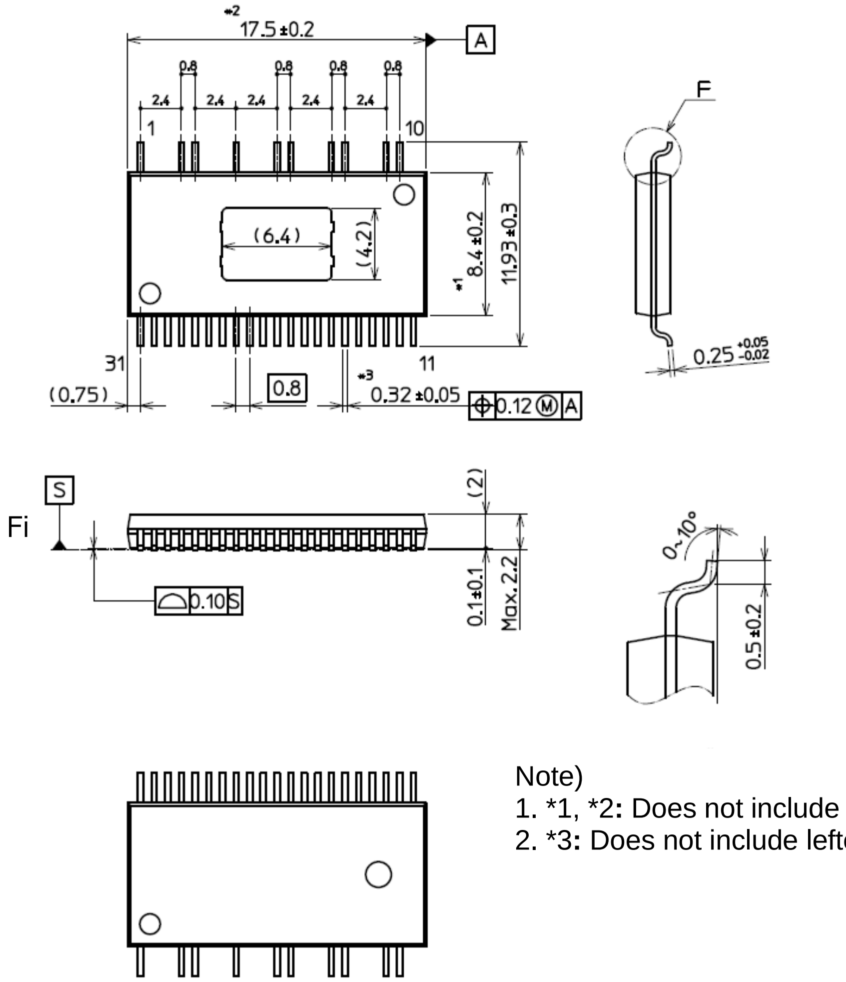
Note 8: A Hall device should be an indium antimony system. It is recommend that the peak Hall device voltage be set more than 300 mV.

2. Outline dimensions and marking of the HSSOP31 package

The HSSOP31 package simplifies board trace routing because it has high-voltage and control pins on opposite sides. In addition, the HSSOP31 package is thin and small.

2.1. Package outline dimensions

P-HSSOP31-0918-0.80-002 Unit :mm



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

Weight: 0.7 g (typ.)

Figure. 2.1 Dimensions of HSSOP31 packages

2.2. Marking

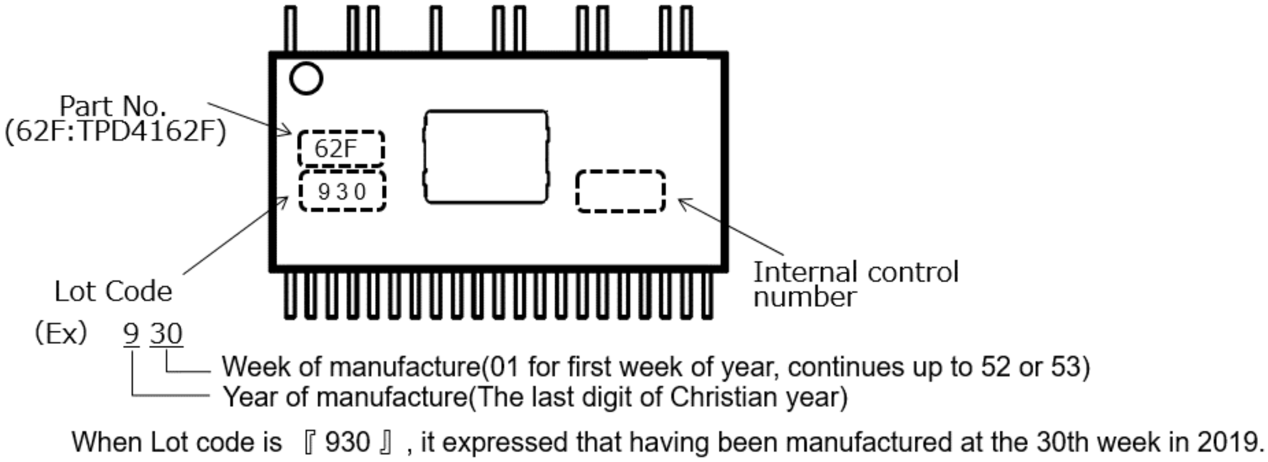


Figure 2.2 Part marking on the HSSOP31 package

2.3. PCB land pattern dimensions（Reference）

(Unit: mm)

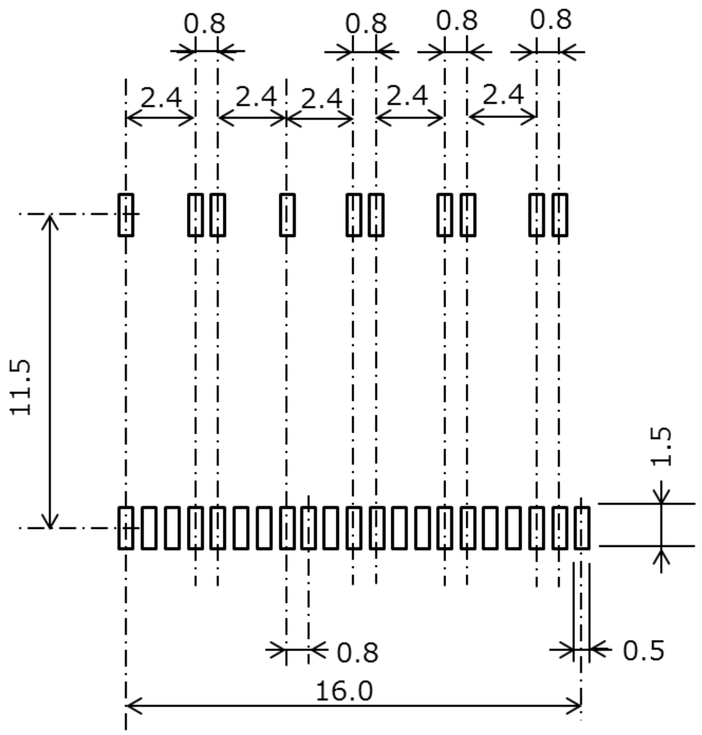


Figure 2.3 Land pattern of the HSSOP31(Reference)

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
Reflow Zone / period : 230°C or more / 30 to 50 seconds
Pre heat / 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.

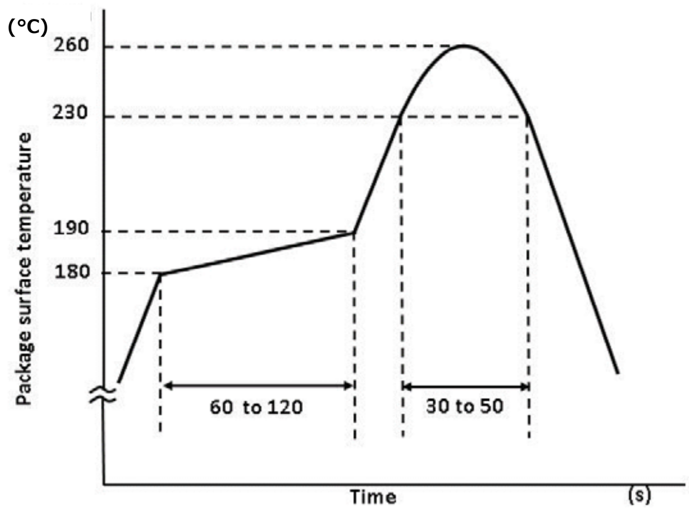


Figure 2.4 Example of a reflow soldering profile

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 3 sec
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

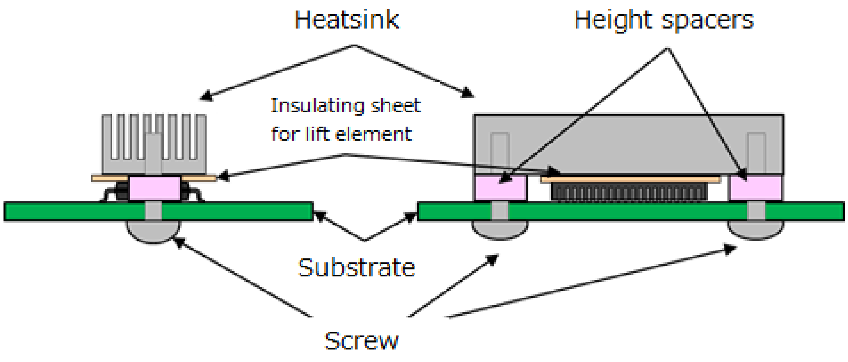


Table 2.5.1
Example of parts used

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

Figure 2.5.1 Heatsink attachment example (using an insulating sheet)

2) Example of using resin or gelatinous insulating material

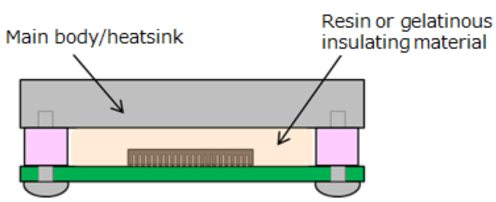
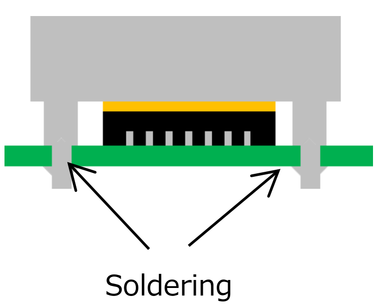
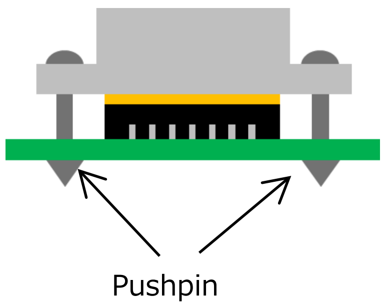


Figure 2.5.2 Heatsink attachment example (using resin or gelatinous insulating material)

3) Example of other heatsink attachment method





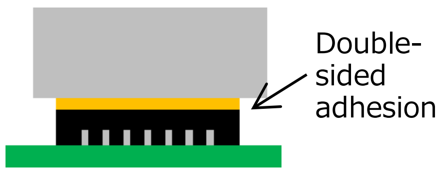


Figure 2.5.3 Soldering **Figure 2.5.4 Pushpin** **Figure 2.5.5 Adhesion attachment**

・Mounting to substrate

Where the HSSOP31 package is sandwiched between the heat sink and the substrate, it the static load should be no greater than 10 N. 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.

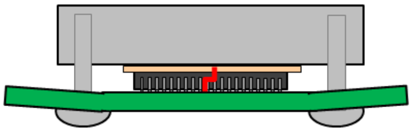


Figure 2.5.6 Bent PCB

・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	V_{BB}	High-voltage power supply input pin.
2	BSU	U-phase bootstrap capacitor connecting pin.
3	U	U-phase output pin.
4	IS1	IGBT emitter/FRD anode pin.
5	BSV	V-phase bootstrap capacitor connecting pin.
6	V	V-phase output pin.
7	BSW	W-phase bootstrap capacitor connecting pin.
8	W	W-phase output pin.
9	NC	Unused pin, which is not connected to the chip internally.
10	IS2	IGBT emitter/FRD anode pin.
11	GND	Ground pin.
12	NC	Unused pin, which is not connected to the chip internally.
13	NC	Unused pin, which is not connected to the chip internally.
14	HW-	W-phase Hall element signal input pin. (Hall IC can be used.)
15	HW+	W-phase Hall element signal input pin. (Hall IC can be used.)

16	HV-	V-phase Hall element signal input pin. (Hall IC can be used.)
17	HV+	V-phase Hall element signal input pin. (Hall IC can be used.)
18	HU-	U-phase Hall element signal input pin. (Hall IC can be used.)
19	HU+	U-phase Hall element signal input pin. (Hall IC can be used.)
20	V_{REG}	5 V regulator output pin.
21	CS	Over-current protection detection pin.
22	OS	PWM triangular wave oscillation frequency setup pin. (Connect a capacitor to this pin.)
23	R_{REF}	PWM triangular wave oscillation frequency setup pin. (Connect a resistor to this pin.)
24	NC	Unused pin, which is not connected to the chip internally.
25	RS	Input for current limit and over-current protection detection pin.
26	FGC	FG pulse count select pin. FGC = High or open : 3 pulse/electrical angle: 360° FGC = Low : 1 pulse/electrical angle: 360°
27	V_S	Speed control signal input pin. (PWM reference voltage input pin.)
28	FG	Revolution pulse output pin.
29	V_{CC}	Control power supply pin.
30	NC	Unused pin, which is not connected to the chip internally.
31	GND	Ground 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 IGBTs from operating in an unsaturated region when the V_{CC} and V_{BS} voltages drop. When V_{CC} drops to V_{CC}UVD (= 11 V typical), all the IGBT outputs are shut down regardless of the input states. Under voltage protection has a hysteresis of 0.5 V. When V_{CC} rises back to V_{CC}UVR (= 11.5 V typical), the IGBTs return to normal operation and turn on according to the input states. When V_{BS} drops to V_{BS}UVD (= 3 V typical), all the high-side IGBT outputs are shut down. When V_{BS} rises back to V_{BS}UVR (= 3.5 V typical), 0.5 V higher than V_{BS}UVD, the high-side IGBTs return to normal operation and operate according to the control signals.

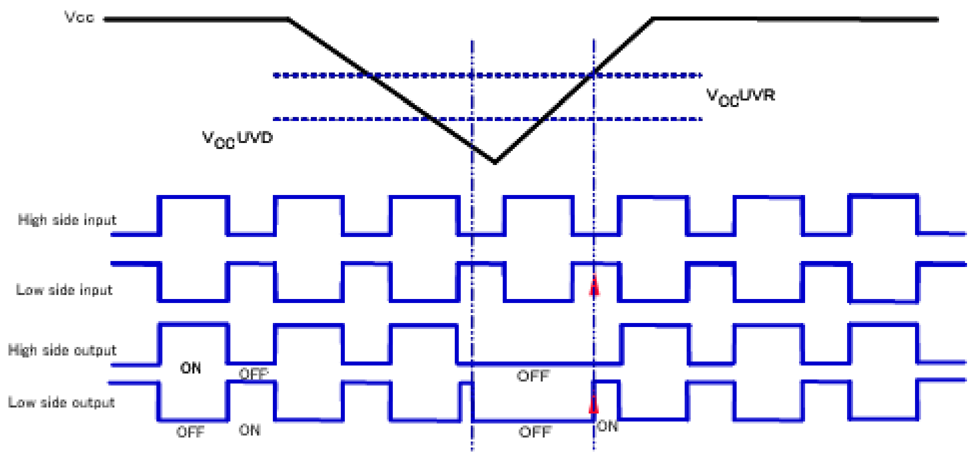


Figure 4.1.1 Low-Side Operation (V_{CC})

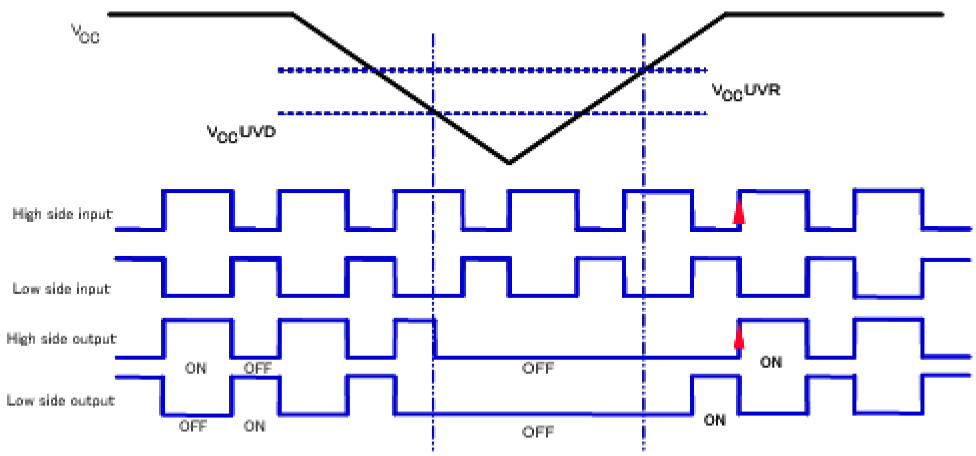


Figure 4.1.2 High-Side Operation (V_{CC})

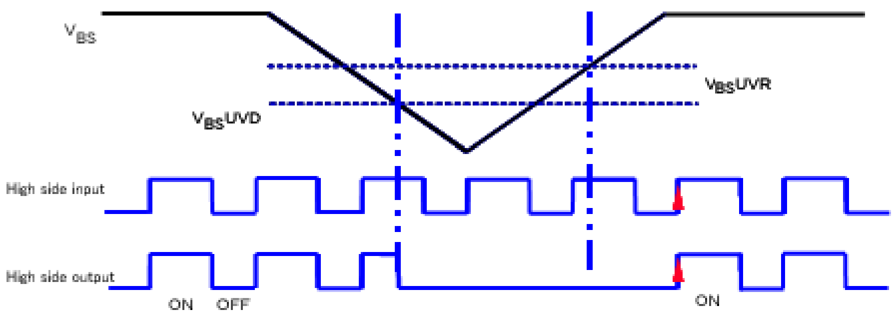


Figure 4.1.3 High-Side Operation (V_{BS})

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 IGBT outputs are 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 IGBTs 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.

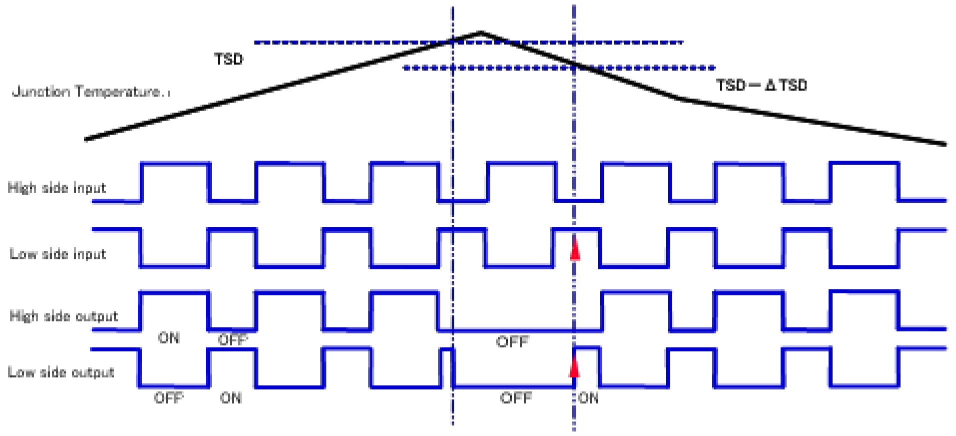


Figure 4.1.4 Thermal shutdown during low-side operation

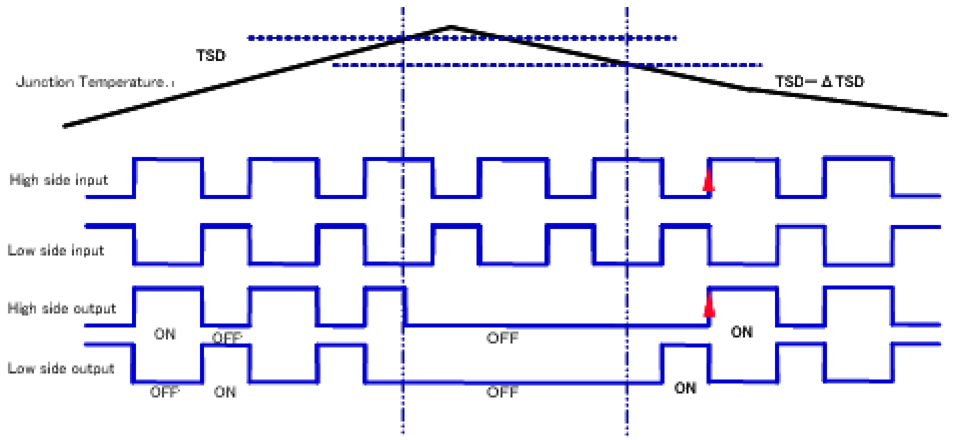


Figure 4.1.5 Thermal shutdown during high-side operation

Current Limit Protection

The current limit function shuts down the ON high-side IGBT to suppress a current increase when the output current increases and exceeds the setting due to a temporary overload, etc. The timing chart below shows the operation of the current limit function when the V-phase is operating on the high side and the U-phase is operating on the low side.

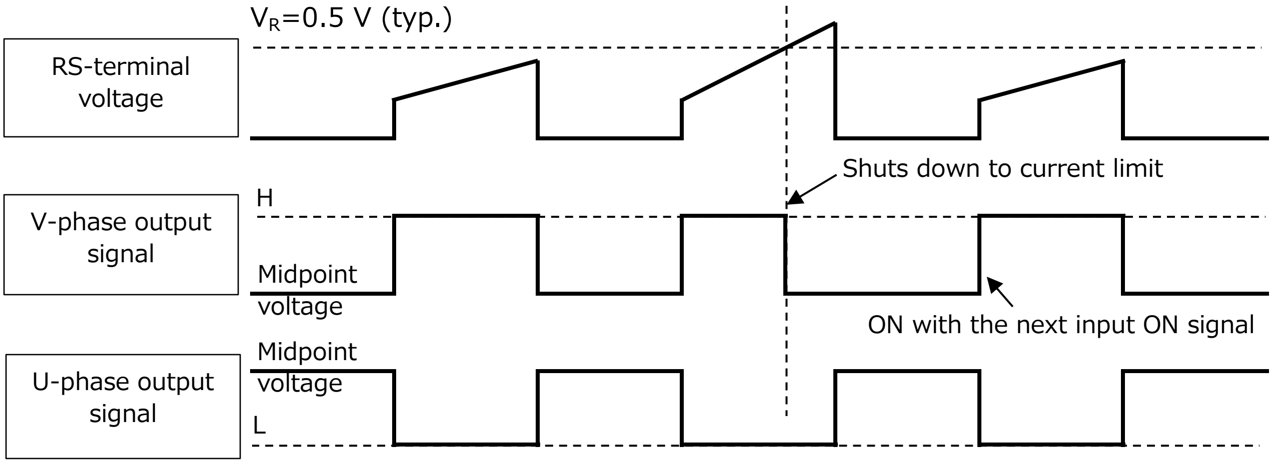


Figure 4.1.6 Timing Chart in Current Limit Operation

When the RS pin (over-current detection pin) voltage exceeds the current limit voltage V_R=0.5 V (typ.), it operates and shuts down the high-side IGBT until the next ON input signal. The regenerative current flows through the body diodes of the output IGBT of the other phases, so the motor does not stop, but the current supplied from the power supply is reduced.
The RS-terminal is directly connected to the IS1 and IS2 terminals, and an external resistor for detecting current is connected between the RS-terminal and GND. The current flowing through each phase of the motor is output from the IS1 and IS2 terminals as is. This current is converted to voltage by an external resistor and detected. Therefore, the detection current is set by the external resistor R_1 of the RS pin.

Setting the Current Limit Protection Resistor

$I_O = V_R \div R_1$

V_R: Current Limit Protection Operating Voltage,

I_O: Current Limit Protection Setting, R_1: Current Limit Protection Resistor

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

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

Overcurrent protection

The overcurrent protection function shuts down the high-side/low-side IGBT of the all output phases when a motor lock or the like occurs due to an external factor. The overcurrent protection function operates when the RS pin voltage exceeds the overcurrent protection operation voltage V_{CS}=0.7 V (typ.). The timing chart below shows the case where the overcurrent protection operates when the V-phase is operating on the high side and the U-phase is operating on the low side.

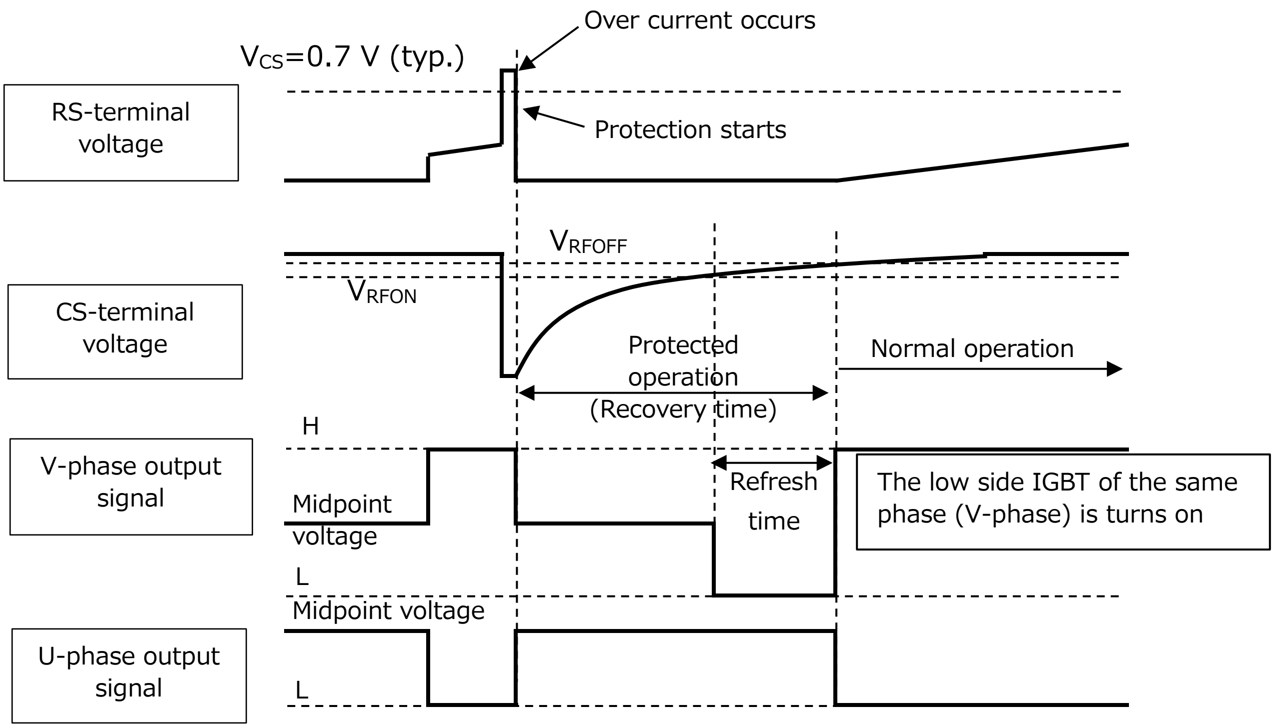


Figure 4.1.7 Timing Chart for Overcurrent Protection Operation

The over-current protection function shuts down the high-side / low-side IGBT of the output of all phases when the RS-terminal voltage rises rapidly and the V_{CS} is reached prior to the current limit function operating. The RS pin voltage drops to nearly 0 V because current no longer flows when the protection operation starts, but the protection operation continues until the external capacitor of the CS pin (over-current protection pin) is charged and V_{ROFF} reacheds the threshold. This capacitor is used to set the recovery time from the start of protection to the return to normal operation. Although the capacitor is charged during normal operation, it is discharged at the same time as the over-current is detected, and charging starts at the start of protection.

There are two types of thresholds: the first threshold at which the bootstrap capacitor starts charging to operate the high-side IGBT and the second threshold at which charging ends and normal operation starts. A series of operations to charge bootstrap capacitors is called refresh operations.When the CS-pin voltage reaches the refresh operation starting voltage V_{RFON}, the low side IGBT of the same phase as the high side IGBT which was operating just before the over-current protection operated turns on, and charging of the bootstrap capacitor starts.

Subsequently, when the CS pin voltage reaches the refresh operation stop voltage V_{RFOFF}, IGBTs of the all phases start normal operation according to the input signal.

4.2. V_{REG} power supply

The power supply output to V_{REG} pin is generated from V_{CC} power supply. V_{REG} power supply does not supply power to the internal circuits of ICs only, it can be used for other peripheral ICs. Please add a capacitor to a V_{REG} pin as prevention of oscillation. The recommended capacitance is 0.1 µF to 1 µF.

As I_{REG} increases, V_{REG} oscillates more easily. If there is oscillation in actual operating environments, tune with variable capacitance. The output-voltage values of V_{REG} power supplies are as shown in the table below.

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

Min	Typ.	Max
4.5	5	5.5

4.3. Bootstrap Circuit and Speed Control Voltage

The high-side driver power supply of this product adopts the bootstrap method.
The charge/discharge operation of the bootstrap capacitor is described below together with the PWM operation of the speed-control-voltage V_S.

Table 4.3 Output states V_S input voltages, bootstrap capacitor charging methods

V_S input voltage	High side IGBT	Low-side IGBT	Bootstrap Capacitor How to charge
0 V≤V_S<1.3 V	All phases OFF	All phases OFF	—
1.3 V≤V_S<2.1 V	All phases OFF	1/5 interval (Duty:20 %) ON	Low-side IGBT ON periods
2.1 V≤V_S<3.8 V	ON (PWM operation)	1/5 interval (Duty:20 %) ON	Low-side IGBT ON periods
3.8 V≤V_S≤5.4 V	ON (PWM operation)	OFF (phase of high side ON)	Low-side FRD recovery period

(1) V_S=0 V to 2.1 V

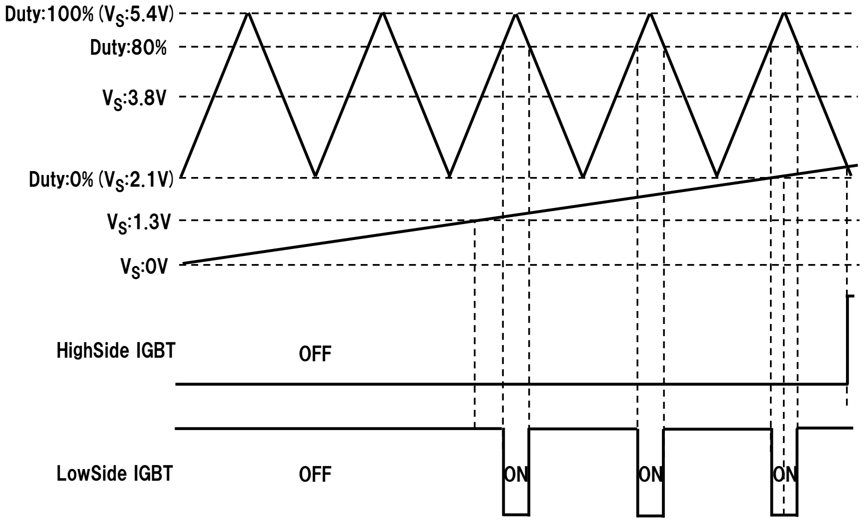


Figure 4.3.1 V_S and PWM Operation (V_S=0 V to 2.1 V)

The bootstrap capacitor is charged in the path shown in the figure below by turning on the low-side IGBT in 1/5 interval (Duty:20 %) with $V_S \geq 1.3$ V. As shown in the figure above, the high-side IGBT is turned on by comparing the triangle wave with V_S voltage at V_S=2.1 V. When the high-side IGBT turns on, the charges in the bootstrap capacitor are discharged in the path shown in the figure below.

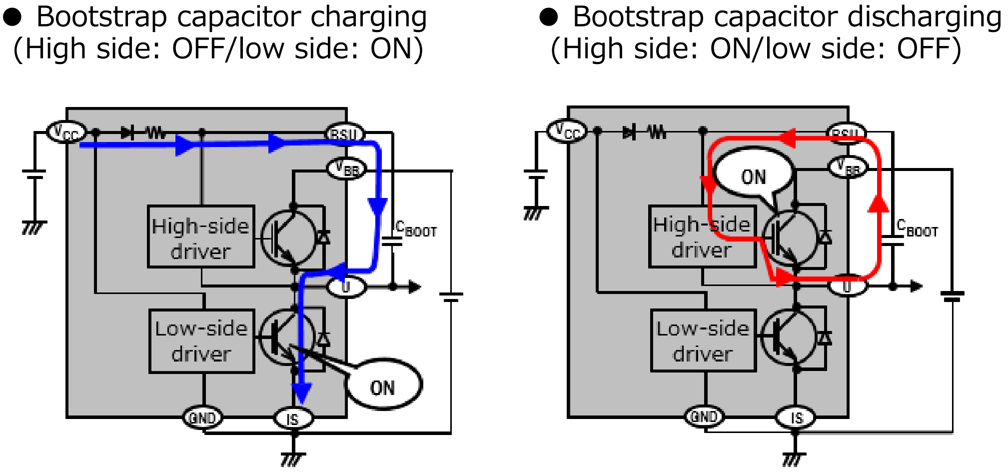


Figure 4.3.2 Bootstrap Capacitor Charge/Discharge Operation (V_S=1.3 V to 2.1 V)

(2) V_S=2.1 V to 3.8 V

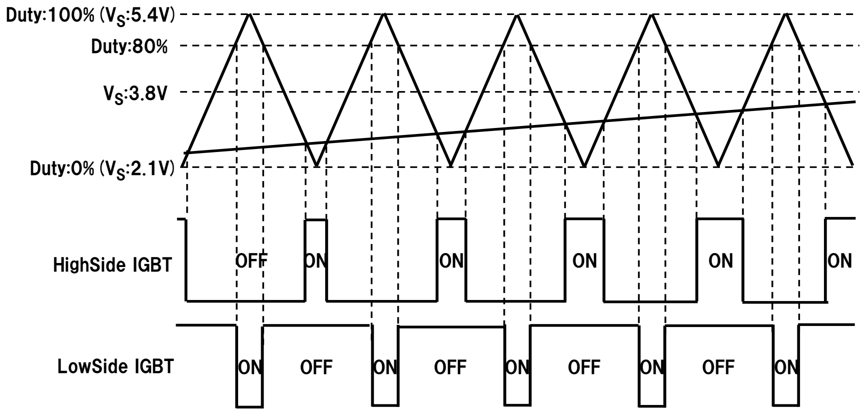


Figure 4.3. 3 V_S and PWM Operation (V_S=2.1 V to 3.8 V)

2.1 V≤V_S≤3.8 V, the ON-period of the high-side IGBT is determined by comparing the triangle wave with the V_S voltage as shown above. The bootstrap capacitor is charged in the same path as 1.3 V≤V_S≤ 2.1 V by turning on the low-side IGBT in 1/5 interval (Duty:20 %).

(3) V_S=3.8 V to 5.4 V

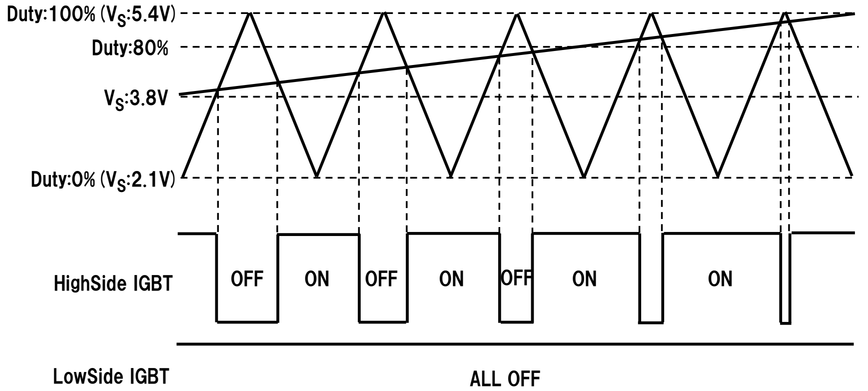


Figure 4.3. 4 V_S and PWM Operation (V_S=3.8 V to 5.4 V)

Even if 3.8V≤V_S≤ 5.4 V, the ON-period of the high-side IGBT is determined by comparing the triangle wave and V_S-voltage as shown above. The low-side IGBT is ALL OFF at 3.8 V≤V_S (Duty:55 % or more), but PWM control is performed at the high-side IGBT, the diode recovery current flows to the low-side FRD controlled by PWM, and the bootstrap capacitor is charged in the path shown in the figure below.

- Bootstrap capacitor charging (high side: OFF/low side: off)

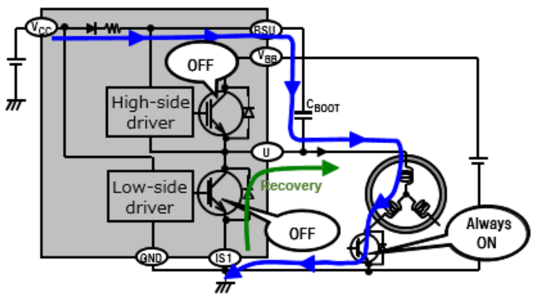


Figure 4.3.5 Bootstrap Capacitor Charge/Discharge Operation (V_S=3.8 V to 5.4 V)

Note that the continuous driving time of the high-side IGBT is extremely long compared to V_S < 5.4 V condition, because the 100 %Duty operation is performed under V_S>5.4 V condition. Especially when the motor rotation speed is slow, the amount of charge in the bootstrap capacitor must be noted.

4.4. Power supplying sequence

When switching the power supply to the circuit on/off, ensure that V_S < 1.3 V (all IGBT outputs off).We do not recommend the following power sequences:

At power-up: Powering up V_{CC} after V_{BB} and V_S power supply

At power-down: Powering down V_{CC} before V_{BB} and V_S power supply

Table 4.4.1 At power-up

At power-up			○/×
①	②	③	
V_{CC}	V_{BB}	V_S	○
V_{CC}	V_S	V_{BB}	○
V_{BB}	V_{CC}	V_S	○
V_{BB}	V_S	V_{CC}	×
V_S	V_{CC}	V_{BB}	○
V_S	V_{BB}	V_{CC}	×

Table 4.4.2 At power-down

At power-down			○/×
①	②	③	
V_{CC}	V_{BB}	V_S	×
V_{CC}	V_S	V_{BB}	×
V_{BB}	V_{CC}	V_S	○
V_{BB}	V_S	V_{CC}	○
V_S	V_{CC}	V_{BB}	○
V_S	V_{BB}	V_{CC}	○

○: Recommended, ×: Un-recommended

Note that the device could be broken if the V_{BB} line is cut off by a relay and others while the motor is running when the V_{CC} and V_{BB} power supply turn off, because a circulating current path to the V_{BB} power supply is blocked.

4.5. Calculating power losses

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

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

(1) Conduction loss: P_{on}

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

- High-side IGBT conduction loss: $P_H = I_{ave} \times V_{satH} \times D$ (W)
- Low-side IGBT conduction loss: $P_L = I_{ave} \times V_{satL}$ (W)
- Flywheel diode conduction loss: $P_D = I_{ave} \times V_F \times (1\text{-}D)$ (W)

I_{ave} = Motor winding current (Average) (A)

V_{satH}/ V_{satL} = Output IGBT voltage drop (V)

V_F= Forward voltage drop of the FRD (V)

D = PWM duty (high side IGBT ON duty)

(2) Switching loss: P_t

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

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

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

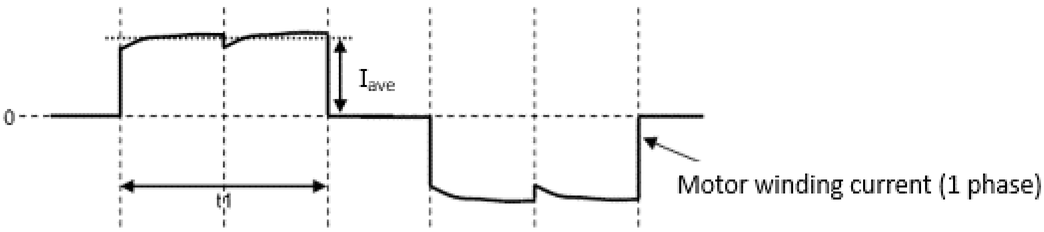
$P_{iBB} = V_{BB} \times I_{BB}$ (W)

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

(4) V_{CC} steady-state loss: P_{iCC}

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

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



I_{ave} : Average value of the motor winding current of period t1

Figure 4.5 Motor Current Waveform for Loss Calculation

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