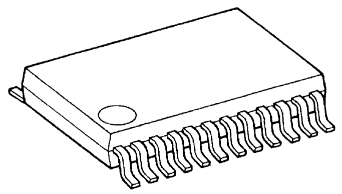
TOSHIBA Bi-CD Integrated Circuit Silicon Monolithic

TB6633FNG

3-Phase Full-Wave PWM Driver for Sensorless DC Motors

The TB6633FNG is a three-phase full-wave PWM driver for sensorless brushless DC (BLDC) motors. It controls motor rotation speed by changing the PWM duty cycle, based on the voltage of an analo control input.


SSOP24-P-300-0.65A

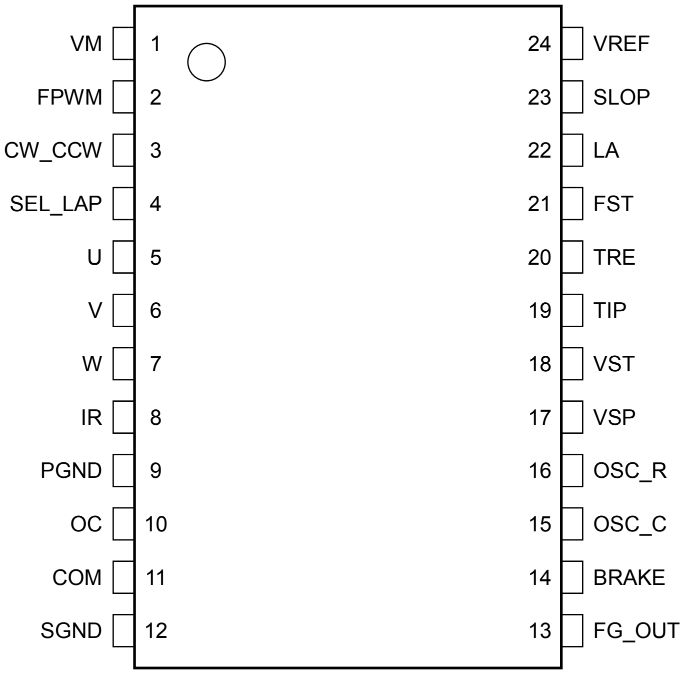
Weight: 0.136 g (typ.)

Features

- Sensorless drive in three-phase full-wave mode
- PWM chopper control
- Controls the PWM duty cycle based on an analog input (7-bit ADC)
- Output current: I_{OUT} = 0.6 A typ. (1 A max)
- Power supply: VM = 4.5 V to 22 V (25 V max)
- Forward and reverse rotation
- Lead angle control (0°, 15° and 30°)
- Overlapping commutation (120°, 135° and 150°)
- Selectable duty cycle modulation period upon state transitions of phase signals
- Rotation speed detecting signal (FG_OUT)
  TB6633FNG: 3 pulses per electrical degree
  TB6633AFNG: 1 pulses per electrical degree
- Adjustable startup settings
- Forced commutation frequency control (f_{osc} / (6×2^{17}), f_{osc} / (6×2^{18}) and f_{osc} / (6×2^{19}))
- Selectable PWM frequency
- Restart feature
- Overcurrent protection (ISD)
- Thermal shutdown (TSD)
- Undervoltage lockout (LVD)
- Current limiter
- Short brake control

Note : 8 pin (IR) of this product is sensitive to electrostatic discharge. When handling this product, protect the environment to avoid electrostatic discharge.

Pin Assignment



Pin Description

Pin No.	Symbol	I/O	Description
1	VM	—	Motor power supply pin
2	FPWM	I	PWM frequency (f_{PWM}) select input (This pin has a pull-down resistor.) High : $f_{PWM} \simeq f_{osc} / 128$ Example) $f_{PWM} \simeq 40$ kHz @ $f_{osc} = 5.1$ MHz Low, Open : $f_{PWM} \simeq f_{osc} / 256$ Example) $f_{PWM} \simeq 20$ kHz @ $f_{osc} = 5.1$ MHz
3	CW_CCW	I	Rotation direction select input (This pin has a pull-down resistor.) High : Counterclockwise (U → W → V) Low, Open : Clockwise (U → V → W)
4	SEL_LAP	I	Overlapping commutation select pin (This pin has a pull-down resistor.) High : Overlapping commutation Low, Open : 120° commutation
5	U	O	U-phase output
6	V	O	V-phase output
7	W	O	W-phase output
8	IR	—	Connection pin for an output shunt resistor
9	PGND	—	Power ground pin
10	OC	I	Overcurrent detection input (This pin has a pull-down resistor.) All PWM output signals are stopped when OC ≥ 0.25 V (typ.).
11	COM	I	Connection pin for the center tap of the motor
12	SGND	—	Signal ground pin
13	FG_OUT	O	Rotation speed output pin (open-drain) This output is held low at startup and when an abnormality is detected. In sensorless mode, pulses are generated at 3 ppr according to the back-EMF. Note: 3 ppr = 3 pulses per electrical degree (With a four-pole motor, six pulses are generated per revolution.)
14	BRAKE	I	Short brake control pin (This pin has a pull-down resistor.) High : Short brake Low, Open : Normal operation
15	OSC_C	—	OSC_C: Connection pin for the oscillator capacitor OSC_R: Connection pin for the oscillator resistor Example: Internal oscillating frequency (f_{osc}) ≃ 5.1 MHz (typ.) when OSC_C = 68 pF and OSC_R = 20 kΩ.
16	OSC_R	—	
17	VSP	I	Motor speed control input (This pin has a pull-down resistor.) 0 ≤ VSP ≤ V_{AD} (L); 1 V (typ.) : Output OFF V_{AD} (L) ≤ VSP ≤ V_{AD} (H); 4 V (typ.) : Sets the PWM duty cycle based on the analog input. V_{AD} (H) ≤ VSP ≤ VREF : 100 % duty cycle (127 / 128)
18	VST	—	Duty cycle setting pin for DC excitation and forced commutation modes 0 ≤ VST ≤ V_{AD} (L); 1 V (typ.) : 0 % duty cycle V_{AD} (L) ≤ VST ≤ V_{AD} (H); 4 V (typ.) : Sets the PWM duty cycle based on the analog input. V_{AD} (H) ≤ VST ≤ VREF : 100 % duty cycle (127 / 128)
19	TIP	—	Connection pin for a capacitor to set the DC excitation time
20	TRE	—	Connection pin for a capacitor to set the restart time upon abnormality detection
21	FST	I	Forced commutation frequency select input (This pin has a pull-down resistor.) Forced commutation frequency (f_{ST}): cycles per second equivalent to an electrical degree FST = High = $f_{ST} \simeq f_{osc} / (6 \times 2^{17})$ Example) $f_{ST} \simeq 6.4$ Hz @ $f_{osc} = 5.1$ MHz FST = Middle = $f_{ST} \simeq f_{osc} / (6 \times 2^{18})$ Example) $f_{ST} \simeq 3.2$ Hz @ $f_{osc} = 5.1$ MHz FST = Low, Open = $f_{ST} \simeq f_{osc} / (6 \times 2^{19})$ Example) $f_{ST} \simeq 1.6$ Hz @ $f_{osc} = 5.1$ MHz
22	LA	I	Lead angle select input (This pin has a pull-down resistor.) LA = High ≃ 30° lead angle LA = Middle ≃ 15° lead angle LA = Low, Open ≃ 0° lead angle
23	SLOP	I	Modulation scheme select input for phase signal state transitions (This pin has a pull-down resistor.) SLOP = High ≃ modulation SLOP = Middle ≃ test mode SLOP = Low, Open ≃ No modulation
24	VREF	—	Reference voltage output; VREF = 5 V (typ.)

Functional Description

The equivalent circuit diagrams may be simplified or some parts of them may be omitted for explanatory purposes.

Timing charts may be simplified for explanatory purposes.

1. Sensorless Drive Mode

Based on the analog voltage input at the VSP pin for a startup operation, the rotor is aligned to a known position in DC excitation mode. Then, the forced commutation signal is generated to start the motor rotation. As the motor rotates, the back-EMF occurs in each phase of the coil. When an input signal indicating the polarity of three phase voltage of the motor, including the back-EMF, is detected as a position signal, the motor driving signal is automatically switched from forced commutation signal to the normal commutation PWM signal that is based on the position signal input (back-EMF). Then, a BLDC motor starts running in sensorless commutation mode.

2. Startup Operation

At startup, no induced voltage is generated due to the stationary motor, and the rotor position cannot bedetected in sensorless mode. Therefore, the TB6633FNG rotor is first aligned to a known position in DC excitation mode for an appropriate period of time, and then the motor is started in forced commutation mode.

The DC excitation time is determined via the TIP pin. The forced commutation frequency is determined via the FST pin. The duty cycles for DC excitation and forced commutation modes are determined by the VST voltage. For sensorless mode, the PWM duty cycle is determined by the VSP value. A speed-control voltage should be applied to the VSP pin to start and stop the motor operation, and to control the motor speed. Since the time settings and startup torques (output duty cycle) for DC excitation and forced commutation vary depending on the motor type and load, they should be adjusted experimentally.

1) DC Excitation Mode

The DC excitation time is determined via the TIP pin.

DC excitation time: $T_2 = C_2 \times$ TIP pin voltage / TIP pin charge current

$C_2 = 0.1\ \mu F$, $T_2 = 0.1\ \mu F \times 3\ V$ (typ.) / $3\ \mu A$ (typ.) = 0.1 s

2) Forced Commutation Mode

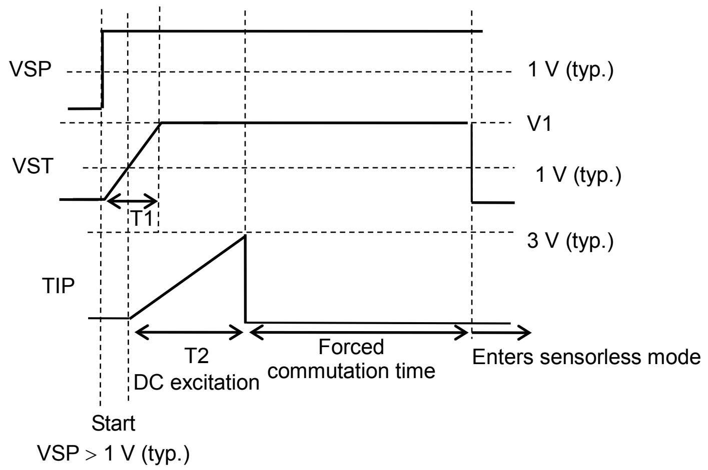
The forced commutation frequency is determined via the FST pin.

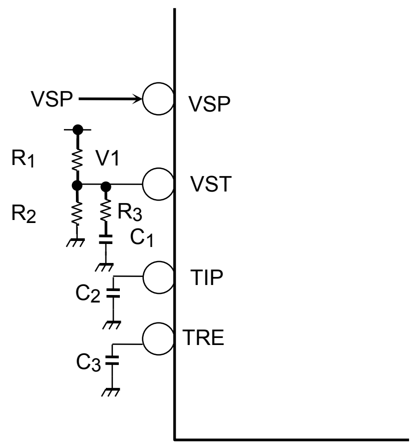
(The FST pin has a pull-down resistor.)

FST = High = Forced commutation frequency $f_{ST} \simeq f_{osc}/(6 \times 2^{17})$

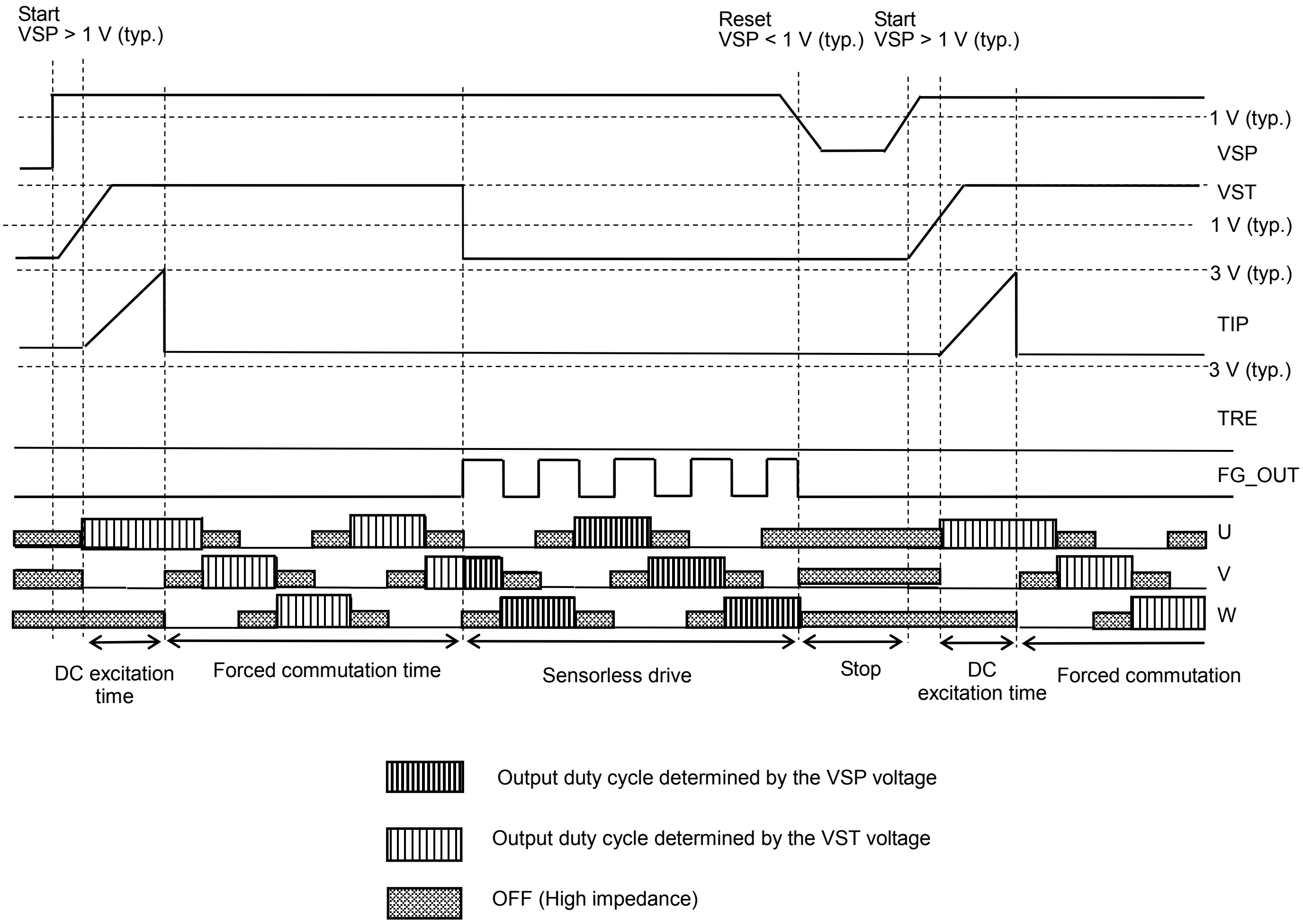
FST = Middle = Forced commutation frequency $f_{ST} \simeq f_{osc}/(6 \times 2^{18})$

FST = Low, Open = Forced commutation frequency $f_{ST} \simeq f_{osc}/(6 \times 2^{19})$





3) Timing Diagram of the Startup Operation (CW_CCW = Low: Clockwise rotation)



3. Restart Operation

When any abnormality is detected, output signals are turned off (high impedance) during the operation restart time.

The following events are detected as abnormalities:

1. The forced commutation time exceeds eight electrical-degree period.
2. The ISD circuit is activated.
3. The TSD circuit is activated.
4. The rotation speed falls below the forced commutation frequency for sensorless mode.
5. The short brake mode is exited.
6. The input is switched at CW_CCW pin for sensorless mode.
7. Maximum commutation frequency (FMAX)

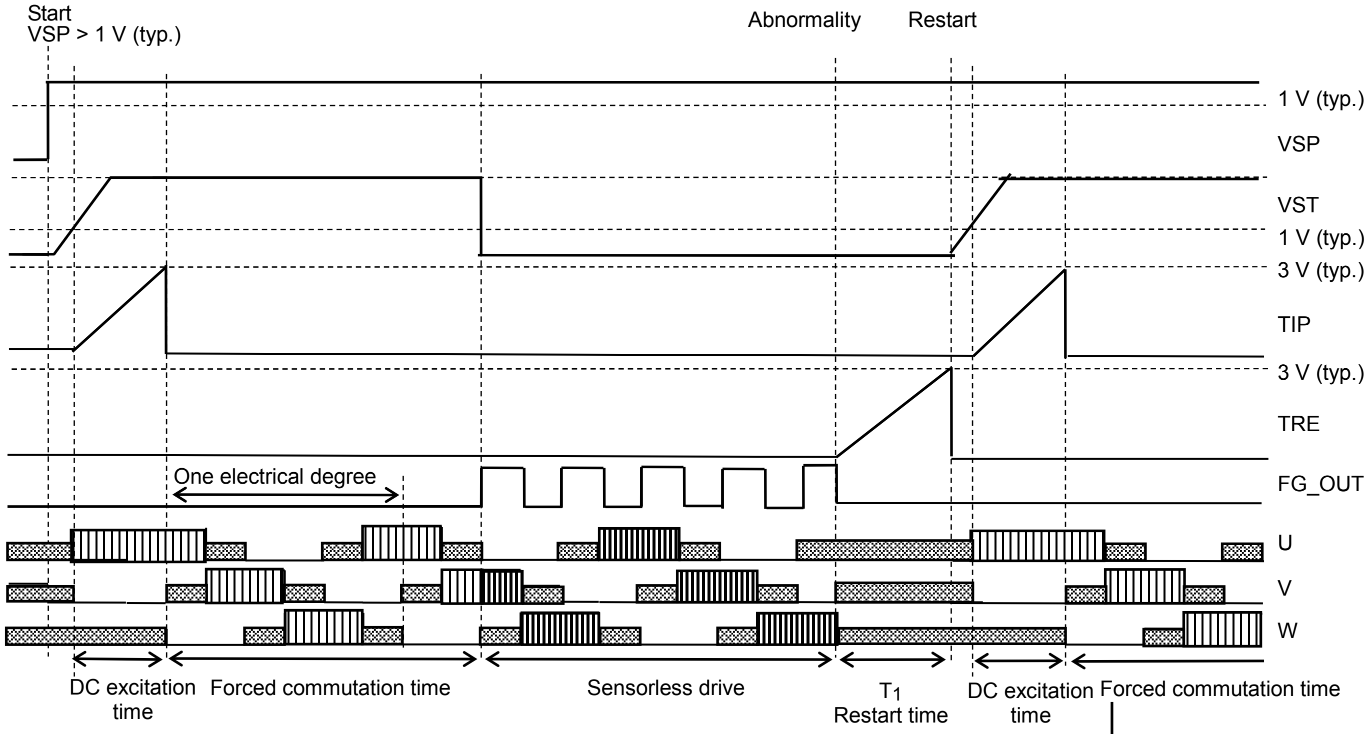
FST = High = FMAX = f_{osc} / (6 × 2^{11}) Example) FMAX = 400Hz per electrical degree @ f_{osc} = 5.1 MHz
FST = Middle = FMAX = f_{osc} / (6 × 2^{11}) Example) FMAX = 400Hz per electrical degree @ f_{osc} = 5.1 MHz
FST = Low = FMAX = f_{osc} / (6 × 2^{12}) Example) FMAX = 200Hz per electrical degree @ f_{osc} = 5.1 MHz

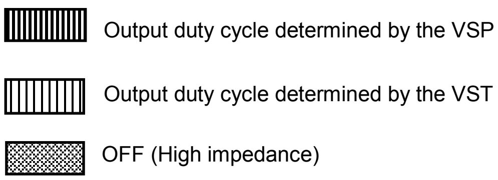
The restart time is determined via the TRE pin as follows:

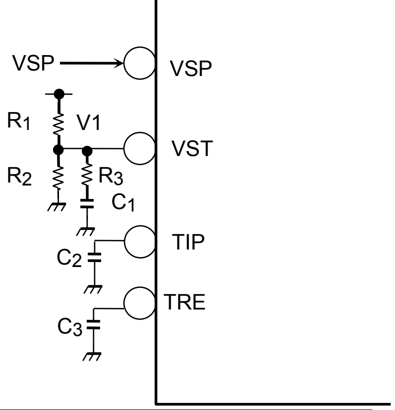
Restart time: $T_1 = C_3$ × TRE pin voltage / TRE pin charge current
C_3 = 1 μF, T_1 = 1 μF × 3 V (typ.) / 3 μA (typ.) = 1 s (typ.)

For example, when the motor does not rotate due to motor locking or when a mode transition from forced commutation mode to sensorless mode does not properly occur, the TB6633FNG begins cycling into the following operation:

Operation start when VSP >1 V (typ.) → DC excitation time → Forced commutation time of eight electrical-degree period → Restart time → DC excitation time …







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

Characteristics	Symbol	Rating	Unit
Power supply voltage	VM	25	V
Input voltage	V_{IN1} (Note 1)	−0.3 to 6.0	V
	V_{IN2} (Note 2)	−0.3 to 25	V
Output voltage	V_{OUT1} (Note 3)	25	V
	V_{OUT2} (Note 4)	6.0	V
Output current	I_{OUT1} (Note 5)	1 (Note 8)	A
	I_{OUT2} (Note 6)	5	mA
	I_{OUT3} (Note 7)	5	mA
Power dissipation	P_D	0.78 (Note 9)	W
Operating temperature	T_{opr}	−40 to 85	°C
Storage temperature	T_{stg}	−55 to 150	°C

Note: The absolute maximum ratings of a semiconductor device are a set of ratings that must not be exceeded, even for a moment. Do not exceed any of these ratings.
Exceeding the rating (s) may cause the device breakdown, damage or deterioration, and may result injury by explosion or combustion.
Please use the TB6633FNG within the specified operating ranges.

Note 1: V_{IN1} is applicable to the voltage at the following pins: FPWM, VSP, CW_CCW, LA, OC, SEL_LAP, FST, BRAKE and SLOP

Note 2: V_{IN2} is applicable to the voltage at the COM pin.

Note 3: V_{OUT1} is applicable to the voltage at the following pins: U, V and W

Note 4: V_{OUT2} is applicable to the voltage at the FG_OUT pin.

Note 5: I_{OUT1} is applicable to the current at the following pins: U, V and W

Note 6: I_{OUT2} is applicable to the current at the FG_OUT pin.

Note 7: I_{OUT3} is applicable to the current at the VREF pin.

Note 8: Output current may be limited by the ambient temperature or the device implementation.
The maximum junction temperature should not exceed T_{jmax} = 150°C

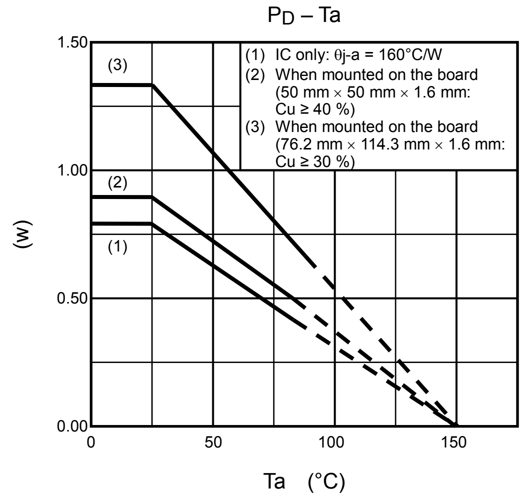
Note 9: Measured for the IC only. (Ta = 25°C)

Operating Ranges

Characteristics	Symbol	Min	Typ.	Max	Unit
Power supply voltage 1	VM_{opr1}	5.5	12	22	V
Power supply voltage 2 (Note 10)	VM_{opr2}	4.5	5	5.5	V

Note 10: Please pay attention to use the IC when VM is 5.5 V or less because the characteristics of the output ON resistance and the output voltage of VREF change.

Package Power Dissipation



Electrical Characteristics
(Ta = 25°C, VM = 12 V, unless otherwise specified)

Characteristics	Symbol	Test Conditions	Min	Typ.	Max	Unit
Static power supply current of VM	I_M	VSP = VST = 0 V, IR = TIP = COM = GND, The OSC_C = 68 pF, OSC_R = 20 kΩ	—	3.5	6	mA
Dynamic power supply current of VM	$I_{M\ (opr)}$	VSP = VST = 2.5 V, IR = TIP = COM = GND, The OSC_C = 68 pF, OSC_R = 20 kΩ	—	4	7	mA
Input current	I_{IN1} (H)	V_{IN} = 5 V FPWM, CW_CCW, SEL_LAP, BRAKE, FST, SLOP, LA	—	50	75	μA
	I_{IN1} (L)	V_{IN} = 0 V, FPWM, CW_CCW, SEL_LAP, BRAKE, FST, SLOP, LA	−1	0	—	
	I_{IN2} (H)	V_{IN} = 5 V, VSP	—	50	75	
	I_{IN2} (L)	V_{IN} = 0 V, VSP	−1	0	—	
Input voltage	V_{IN1} (H)	FPWM, CW_CCW, SEL_LAP, BRAKE	2.0	—	5.5	V
	V_{IN1} (L)		GND	—	0.8	
	V_{IN2} (H)	FST, SLOP, LA	4	—	VREF+ 0.3	
	V_{IN2} (M)		2	—	3	
	V_{IN2} (L)		GND	—	1	
Input voltage hysteresis	Vhys	FPWM, CW_CCW, SEL_LAP, BRAKE	—	0.45	—	V
Charge current of the TIP and TRE pins	Ich	OSC_R = 20 kΩ	2.4	3	3.6	μA
Setting time of the TIP and TRE pins	Tipre	TIP = 1 μF, TRE = 1 μF, OSC_R = 20 kΩ	—	1	—	s
Detection voltage of the TIP and TRE pins	V_{DET}	—	2.8	3	3.2	V
COM input current	Icom	COM = 6 V, VSP = VST = 2.5 V	−1	0	1	μA
Low-level FG_OUT output voltage	V_{FG_OUT}	I_{FG_OUT} = 5 mA	GND	—	0.5	V
FG_OUT leakage current	I_{LFG_OUT}	V_{FG_OUT} = 5.5 V	—	0	10	μA

Characteristics	Symbol	Test Conditions	Min	Typ.	Max	Unit
Output ON-resistance of the U, V and W pins	R_{ON1} (H)	I_{OUT} = 0.6 A	—	0.4	0.65	Ω
	R_{ON1} (L)	I_{OUT} = −0.6 A	—	0.4	0.65	
	R_{ON2} (H)	I_{OUT} = 1.0 A	—	0.4	0.65	
	R_{ON2} (L)	I_{OUT} = −1.0 A	—	0.4	0.65	
	R_{ON3} (H)	I_{OUT} = 0.6 A, VM = 4.5 V	—	0.45	0.75	
	R_{ON3} (L)	I_{OUT} = −0.6 A, VM = 4.5 V	—	0.45	0.75	
	R_{ON4} (H)	I_{OUT} = 1.0 A, VM = 4.5 V	—	0.45	0.75	
	R_{ON4} (L)	I_{OUT} = −1.0 A, VM = 4.5 V	—	0.45	0.75	
Output leakage current of the U, V and W pins	I_L (H)	V_{OUT} = 0 V	—	0	10	μA
	I_L (L)	V_{OUT} = 25 V	—	0	10	
Output diodes' forward voltage of the U, V and W pins	V_F (H)	I_{OUT} = 1.0 A	—	1.0	1.4	V
	V_F (L)	I_{OUT} = −1.0 A	—	1.0	1.4	
VSP reset input voltage	V_{VSPR}	—	0.9	1.0	1.1	V
PWM input voltage	V_{AD} (L)	VSP = VST, FPWM = L OSC_C = 68 pF, OSC_R = 20 kΩ	0.9	1.0	1.1	V
	V_{AD} (H)		3.6	4.0	4.2	
OC pin voltage for current detection	V_{OC1}	—	0.225	0.25	0.275	V
OC pin voltage threshold for overcurrent detection	V_{OC2}	—	0.675	0.75	0.825	V
PWM frequency	F_{C1} (H)	FPWM = H OSC_C = 68 pF, OSC_R = 20 kΩ	36	40	44	kHz
	F_{C1} (L)	FPWM = L OSC_C = 68 pF, OSC_R = 20 kΩ	18	20	22	
OSC frequency	OSC	OSC_C = 68 pF, OSC_R = 20 kΩ	4.55	5.1	5.65	MHz
ISD trip threshold	I_{SD}	—	—	2	—	A
Thermal shutdown	TSD	—	—	165	—	°C
	TSDhys	Thermal shutdown hysteresis	—	15	—	
UVLO trip threshold voltage of the VM pin	VM_{LVD}	—	—	3.5	—	V
UVLO recovery voltage of the VM pin	VM_{LVDR}	—	—	4.0	—	V
UVLO trip threshold voltage of the VREF pin	V_{RELVD}	—	—	3.5	—	V
UVLO recovery voltage of the VREF pin	V_{RERLVD}	—	—	4.0	—	V
VREF output voltage	VREF1	IVREF = −5 mA	4.5	5	5.5	V
	VREF2	IVREF = −5 mA, VM = 4.5 V	4.0	4.3	4.5	V

Application Circuit Example

Some of the functional blocks, circuits, or constants in the block diagram may be omitted or simplified for explanatory purposes.

The application circuits shown in this document are provided for reference purposes only. Thorough evaluation is required, especially at the mass production design stage.

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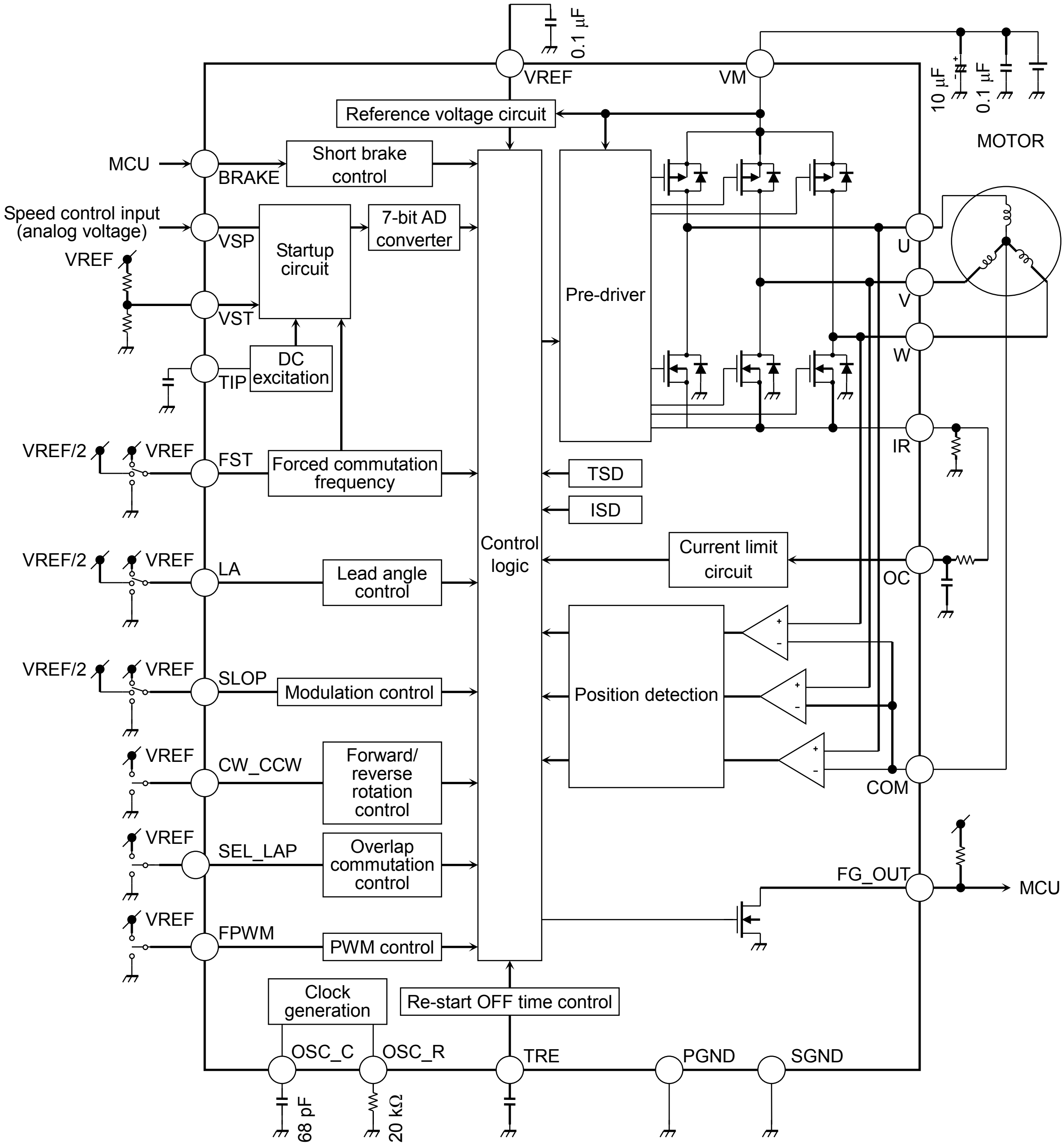
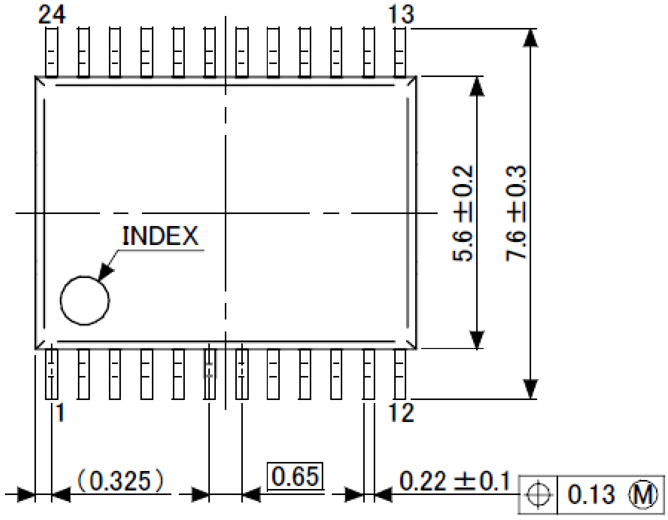
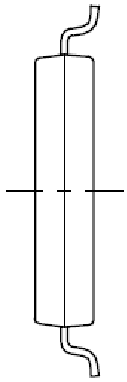
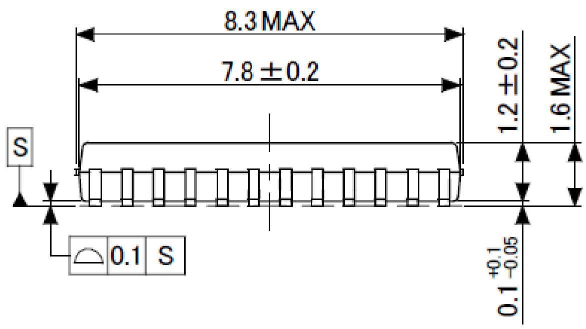


Package Dimensions

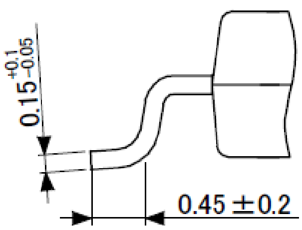
SSOP24-P-300-0.65A "Unit : mm"







Detailed diagram of tip of terminal



Weight: 0.136 g (typ.)

Notes on Contents

1. Block Diagrams

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2. Equivalent Circuits

The equivalent circuit diagrams may be simplified or some parts of them may be omitted for explanatory purposes.

3. Timing Charts

Timing charts may be simplified for explanatory purposes.

4. Application Circuits

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5. Test Circuits

Components in the test circuits are used only to obtain and confirm the device characteristics. These components and circuits are not guaranteed to prevent malfunction or failure from occurring in the application equipment.

IC Usage Considerations

Notes on handling of ICs

(1) The absolute maximum ratings of a semiconductor device are a set of ratings that must not be exceeded, even for a moment. Do not exceed any of these ratings.
Exceeding the rating(s) may cause the device breakdown, damage or deterioration, and may result injury by explosion or combustion.

(2) Use an appropriate power supply fuse to ensure that a large current does not continuously flow in case of over current and/or IC failure. The IC will fully break down when used under conditions that exceed its absolute maximum ratings, when the wiring is routed improperly or when an abnormal pulse noise occurs from the wiring or load, causing a large current to continuously flow and the breakdown can lead smoke or ignition. To minimize the effects of the flow of a large current in case of breakdown, appropriate settings, such as fuse capacity, fusing time and insertion circuit location, are required.

(3) If your design includes an inductive load such as a motor coil, incorporate a protection circuit into the design to prevent device malfunction or breakdown caused by the current resulting from the inrush current at power ON or the negative current resulting from the back electromotive force at power OFF. IC breakdown may cause injury, smoke or ignition.
Use a stable power supply with ICs with built-in protection functions. If the power supply is unstable, the protection function may not operate, causing IC breakdown. IC breakdown may cause injury, smoke or ignition.

(4) Do not insert devices in the wrong orientation or incorrectly.
Make sure that the positive and negative terminals of power supplies are connected properly.
Otherwise, the current or power consumption may exceed the absolute maximum rating, and exceeding the rating(s) may cause the device breakdown, damage or deterioration, and may result injury by explosion or combustion.
In addition, do not use any device that is applied the current with inserting in the wrong orientation or incorrectly even just one time.

Points to remember on handling of ICs

(1) Over current Protection Circuit
Over current protection circuits (referred to as current limiter circuits) do not necessarily protect ICs under all circumstances. If the Over current protection circuits operate against the over current, clear the over current status immediately.
Depending on the method of use and usage conditions, such as exceeding absolute maximum ratings can cause the over current protection circuit to not operate properly or IC breakdown before operation. In addition, depending on the method of use and usage conditions, if over current continues to flow for a long time after operation, the IC may generate heat resulting in breakdown.

(2) Thermal Shutdown Circuit
Thermal shutdown circuits do not necessarily protect ICs under all circumstances. If the thermal shutdown circuits operate against the over temperature, clear the heat generation status immediately.
Depending on the method of use and usage conditions, such as exceeding absolute maximum ratings can cause the thermal shutdown circuit to not operate properly or IC breakdown before operation.

(3) Heat Radiation Design
In using an IC with large current flow such as power amp, regulator or driver, please design the device so that heat is appropriately radiated, not to exceed the specified junction temperature (T_j) at any time and condition. These ICs generate heat even during normal use. An inadequate IC heat radiation design can lead to decrease in IC life, deterioration of IC characteristics or IC breakdown. In addition, please design the device taking into considerate the effect of IC heat radiation with peripheral components.

(4) Back-EMF
When a motor rotates in the reverse direction, stops or slows down abruptly, a current flow back to the motor’s power supply due to the effect of back-EMF. If the current sink capability of the power supply is small, the device’s motor power supply and output pins might be exposed to conditions beyond absolute maximum ratings. To avoid this problem, take the effect of back-EMF into consideration in system design.

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