TB6588FG Usage Considerations

The TB6588FG is a three-phase PWM driver for sensorless brushless DC (BLDC) motors.

In sensorless mode, the TB6588FG generates a commutation signal based on the rotor position that is detected by comparing the induced voltage of the motor and the V_M/2.

1. Absolute Maximum Ratings

Characteristic	Symbol	Rating	Unit
Absolute maximum supply voltage	V_M	50	V
Operating supply voltage range	V_M	7 to 42	V
Absolute maximum output current (peak)	I_{OUT}	2.5	A
Absolute maximum input voltage	V_{IN1} (Note 1)	−0.3 to V_{REF} + 0.3	V
	V_{IN1} (Note 2)	−0.3 to 30	V

Note 1: Pins operating at V_{IN1}: FPWM, FMAX, VSP, CW_CCW, LA1, LA2, OC, SEL_LAP, FST1, FST2 and EN

Note 2: Pins operating at V_{IN2}: WAVEP and WAVEM

2. Startup Settings

At startup, no induced voltage is generated due to the stationary motor, and the rotor position cannot be detected in sensorless mode. Therefore, the TB6588FG 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 rotor position can then be detected, and the operation mode is switched to the sensorless mode.

The driver output voltage applied to a motor (proportional to the PWM duty cycle) is determined by the V_{SP} input voltage.

The DC excitation time is determined by external capacitors and resistor. The forced commutation frequency is determined by the logic level of the FST1 and FST2 pins. The settings on the output voltage, the DC excitation time, and the forced commutation time vary depending on the motor type and load, so that they should be adjusted experimentally.

(1) DC Excitation ⇨ (2) Forced Commutation ⇨ (3) Sensorless

Recommended Startup Sequence

First, manually stop the rotor of the motor. Then, set up the configuration of the (2) forced commutation mode so that the operation mode can be properly switched to the sensorless mode. Lastly, set up the configuration of the (1) DC excitation mode so as to align the motor to a known position.

Programming Tip

(3) The FG_OUT output is kept Low and remains unchanged at startup until the operation mode is switched to (3) sensorless mode, and also during the operation under abnormal conditions. Therefore, if the operation mode remains in (1) DC excitation or in (2) forced commutation mode without being switched to (3) sensorless mode, FG_OUT remains Low. It is recommended that the TB6588FG be programmed to be restarted if the FG_OUT remains unchanged for a certain period of time, by using a microcontroller or any other device.

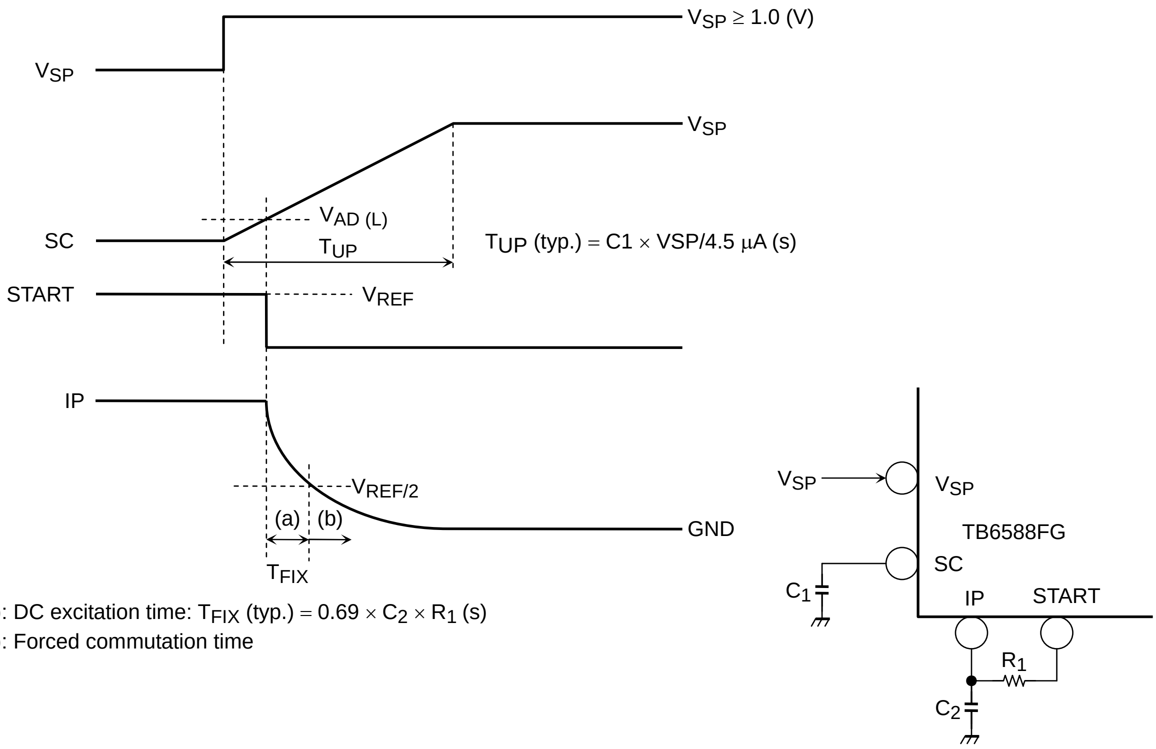
(1) DC Excitation Mode Settings

The driver output voltage applied to a motor (which is proportional to the PWM duty cycle) and the DC excitation time should be adjusted so that the motor can be aligned to a known position while the motor is in DC excitation mode.

The driver output voltage applied to a motor (PWM duty cycle) can be controlled by adjusting the analog input voltage on the V_{SP} pin.

The DC excitation time is determined by R1 and C2.

The motor vibration can be suppressed by gradually changing the driver output voltage applied to the motor (proportional to the PWM duty cycle), which can be achieved by gradually changing the SC voltage with C1.



(a): DC excitation time: T_{FIX} (typ.) = 0.69 × C_2 × R_1 (s)
(b): Forced commutation time

The rotor is aligned to a known position specified in DC excitation mode for the period of (a), during which the IP pin voltage decreases from V_{REF} to $V_{REF/2}$. The time constant for the period is determined by C2 and R1. Then, operation mode is switched to forced commutation mode for the period of (b) as shown above. The duty cycles for DC excitation and forced commutation modes are determined according to the SC pin voltage. When the motor rotation frequency exceeds the forced commutation frequency specified by FST1 and FST2, the operation mode is switched to the sensorless mode. The duty cycle for sensorless mode is determined by V_{SP}.

Note: The DC excitation time must be long enough so that a capacitor that determines the DC excitation time is properly charged by the V_M power supply. Thus, after turning on the V_M power supply, wait for a period of about four times the DC excitation time, then apply an appropriate voltage to the V_{SP} pin to start the motor operation.

(2) Forced Commutation Mode Settings

After driving the motor into forced commutation mode, the driver output voltage applied to a motor (which is proportional to the PWM duty cycle) and the forced commutation frequency should be adjusted so that the operation is switched to sensorless mode.

The driver output voltage applied to a motor (PWM duty cycle) can be controlled by adjusting the analog input voltage on the V_{SP} pin.

The forced commutation frequency can be adjusted by the logic level of the FST1 and FST2 pins.

- Settings of forced commutation frequency select inputs

FST2 : FST1 = High : High = Forced commutation frequency $f_{ST} \approx fosc/(6 \times 2^{16})$
FST2 : FST1 = High : Low, Open = Forced commutation frequency $f_{ST} \approx fosc/(6 \times 2^{17})$
FST2 : FST1 = Low, Open : High = Forced commutation frequency $f_{ST} \approx fosc/(6 \times 2^{18})$
FST2 : FST1 = Low, Open : Low, Open = Forced commutation frequency $f_{ST} \approx fosc/(6 \times 2^{19})$

The forced commutation frequency is determined by the internal frequency fosc and the logic level of the FST1 and FST2 pins.

Since the optimal frequency varies depending on the motor type and load, it must be adjusted experimentally.

The forced commutation frequency should be set higher as the number of motor magnetic poles increases.

The forced commutation frequency should be set lower as the inertia of the load increases.

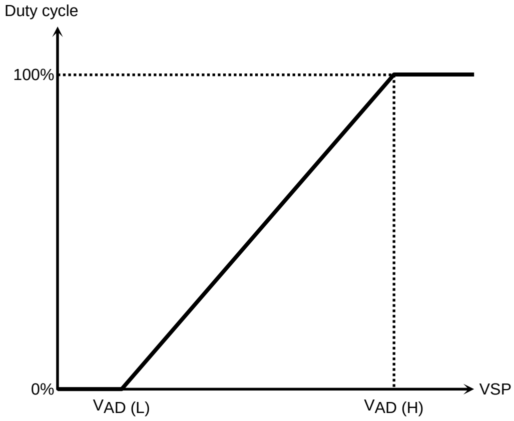
- Motor speed control pin (V_{SP})

An analog voltage applied to the V_{SP} pin is converted by a 7-bit AD converter and used to control the duty cycle of the PWM.

(The actual operation of the IC is determined by the voltage applied to the SC pin. The voltage at the SC pin equals the charging voltage of the capacitor C1, which is determined by the charging/discharging time of C1. This causes a delay in the SC voltage level relative to the V_{SP} input.)

$0 \le V_{DUTY} \le V_{AD\,(L)}$
→ Duty = 0%
$V_{AD\,(L)} \le V_{DUTY} \le V_{AD\,(H)}$
→ Figure on the right (1/128 to 127/128)
$V_{AD\,(H)} \le V_{DUTY} \le V_{REF}$
→ Duty = 100% (127/128)

$V_{AD\,(L)}$ = 1.2 V (typ.)
(FPWM = L, OSC_C = 100pF, OSC_R = 20 kΩ)
$V_{AD\,(H)}$ = 4.1 V (typ.)
(FPWM = L, OSC_C = 100 pF, OSC_R = 20 kΩ)



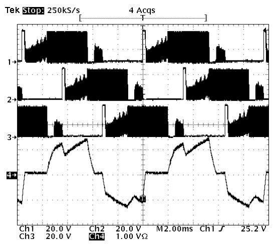
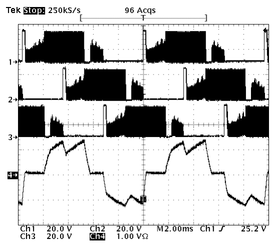
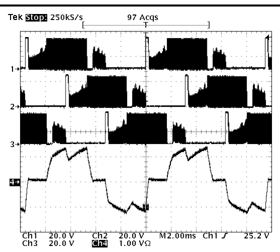
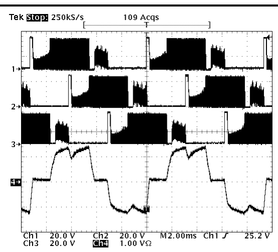
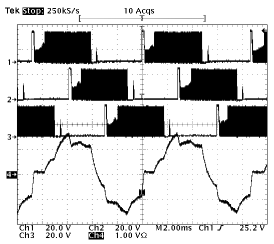
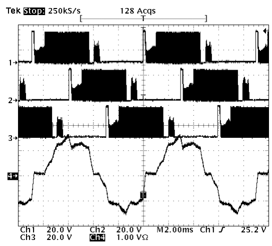
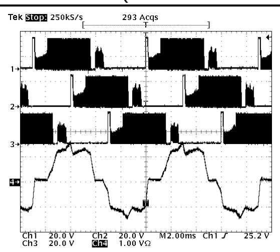
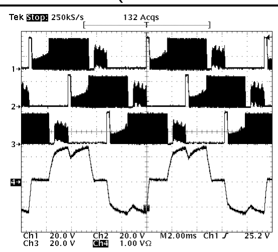
Note: The analog input voltage applied to the V_{SP} pin should be adjusted so that the duty cycle becomes large enough to allow the voltage induced by the motor rotation in forced commutation mode to exceed the WAVE pin voltage ($V_M/2$). If the duty cycle is too small, the induced voltage in the motor is filtered to less than the WAVE pin voltage ($V_M/2$) by the motor loads and external circuitry. Thus, the motor cannot enter sensorless mode.

(3) Sensorless Mode Settings

After the motor enters sensorless mode, the following settings should be determined so as to achieve efficient and silent drive of the motor: the lead angle setting using the LA1 and LA2 pins and the overlapping commutation angle setting using SEL_LAP.

- Settings of lead angle select pins
  LA2: LA1 ≈ High,Open : High, Open ≈ 30°lead angle
  LA2: LA1 ≈ High,Open : Low ≈ 15°lead angle
  LA2: LA1 ≈ Low : High,Open ≈ 7.5°lead angle
  LA2: LA1 ≈ Low : Low ≈ 0°lead angle
- Settings of overlapping commutation select pins
  SEL_LAP = High, Open = 120 commutation
- SEL_LAP = Low = Overlapping commutation

Waveforms of Motor Driving Signals in Each Setting (provided as a guide) V_M = 24 V, V_{SP} = 3.0 V

LA2: LA1 = L: L = 0° lead angle SEL_LAP = H = 120° commutation	LA2: LA1 = L: H = 7.5° lead angle SEL_LAP = H = 120° commutation
U voltage 20 V/Div. V voltage 20 V/Div. W voltage 20 V/Div. U current 2 A/Div. 	U voltage 20 V/Div. V voltage 20 V/Div. W voltage 20 V/Div. U current 2 A/Div. 
LA2 LA1 = H:L = 15° lead angle SEL_LAP = H = 120° commutation	LA2:LA1 = H:H = 30° lead angle SEL_LAP = H = 120° commutation
U voltage 20 V/Div. V voltage 20 V/Div. W voltage 20 V/Div. U current 2 A/Div. 	U voltage 20 V/Div. V voltage 20 V/Div. W voltage 20 V/Div. U current 2 A/Div. 
LA2: LA1 = L: L = 0° lead angle, SEL_LAP = L = 30°overlapping commutation (150° commutation)	LA2: LA1 = L: H = 7.5° lead angle, SEL_LAP = L = 22.5°overlapping commutation (142.5° commutation)
U voltage 20 V/Div. V voltage 20 V/Div. W voltage 20 V/Div. U current 2 A/Div. 	U voltage 20 V/Div. V voltage 20 V/Div. W voltage 20 V/Div. U current 2 A/Div. 
LA2: LA1 = H: L = 15° lead angle, SEL_LAP = L = 15°overlapping commutation (135° commutation)	LA2: LA1 = H: H = 30° lead angle, SEL_LAP = L = 0°overlapping commutation (120° commutation)
U voltage 20 V/Div. V voltage 20 V/Div. W voltage 20 V/Div. U current 2 A/Div. 	U voltage 20 V/Div. V voltage 20 V/Div. W voltage 20 V/Div. U current 2 A/Div. 

Note: First, adjust the lead angle so that the motor does not malfunction. Then, enable or disable SEL_LAP for overlapping commutation control. The rotor position detection in sensorless mode is achieved by comparing the off-phase voltage with the reference voltage. The back-EMF (induced while the diode is enabled) is masked when the position detection signal is recognized inside the IC. In applications whose mask period is shorter than the period during which the diode is enabled, the motor malfunctions and cannot rotate properly. In such cases, a rotor position may not be properly detected and the lead angle should therefore be adjusted.

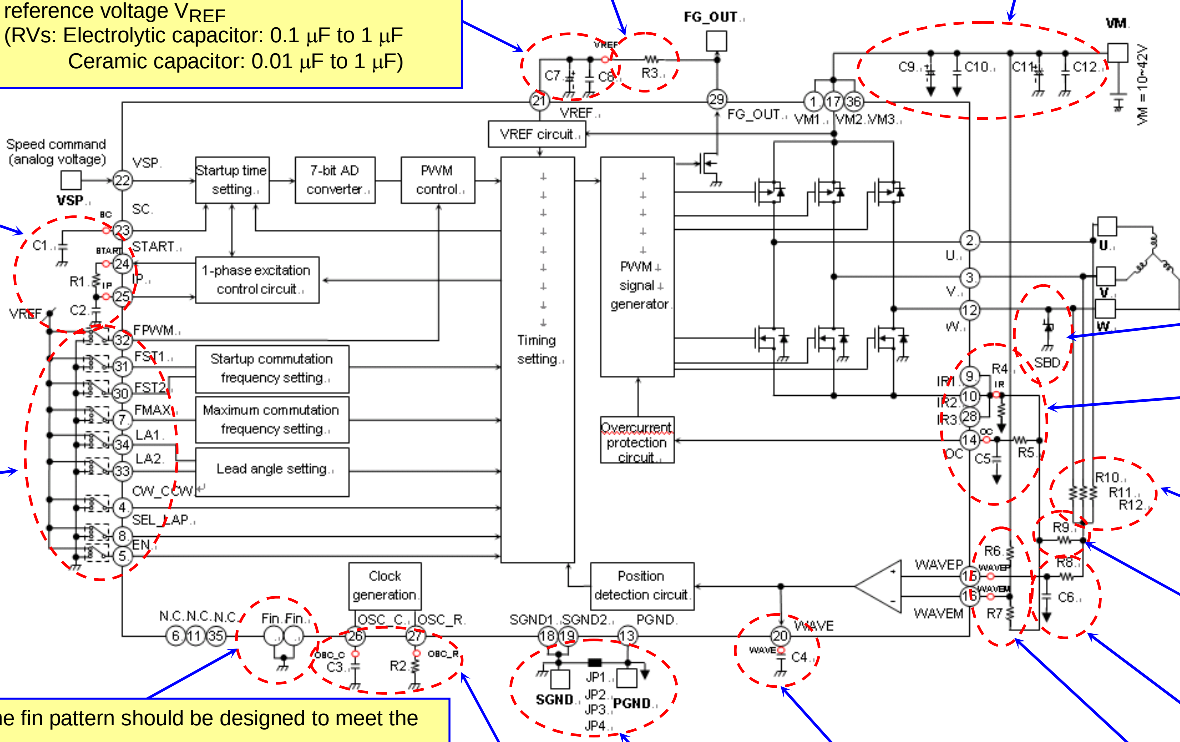
3. Setting Method for the Application Circuit

R3: A pull-up resistor for the rotation detection open drain output, FG_OUT
(Recommended value (RV): 10 kΩ to 100 kΩ)

Electrolytic (C11) and ceramic (C12) capacitors: Bypass capacitors for analog signals connected between V_M and SGND
Electrolytic () and ceramic () capacitors: Bypass capacitors for power supply connected between V_M and PGND
These capacitors must be connected as close as possible to the IC.
(RVs: Electrolytic capacitor: 10 μF to 33 μF: ceramic capacitor: 0.01 μF to 1 μF)

C1, R1 and C2: Used for startup setting.
The output current applied to a motor is adjusted by the V_{SP} input voltage. The DC excitation time should be adjusted by R1 and C2 so that the motor can be aligned to a known position in DC excitation mode.
Also, the motor oscillation is minimized by gradually changing the output current using C1.

C7 and C8: Capacitors for stabilizing the reference voltage V_{REF}
(RVs: Electrolytic capacitor: 0.1 μF to 1 μF
Ceramic capacitor: 0.01 μF to 1 μF)



A Schottky barrier diode (SBD) for providing a reverse recovery current between W and GND (Recommended SBD: Toshiba CMS15)

R4: Resistor for overcurrent protection setting
R5, C5: An RC filter to remove noise on the overcurrent protection

Switches for basic settings:
After testing each setting adjusted by these switches, fix each input to the specified level, H (V_{REF}) or L (GND) .

R10, R11 and R12: Resistors for synthesizing the three-phase output
R10, R11, R12 (RV: 10 kΩ)

R9: A resistor for level shifting when the WAVEP or WAVEM input voltage exceeds the absolute maximum rating of 30 V.

C6 and R8: An RC filter to remove noise on the three-phase output

The Fin pins allow heat dissipation. The fin pattern should be designed to meet the thermal design requirements.
(Since the Fin pins are electrically connected to the backside of the die, these pins should be insulated or connected to GND.)

C4: A capacitor to filter out the noise on the comparator output, etc.

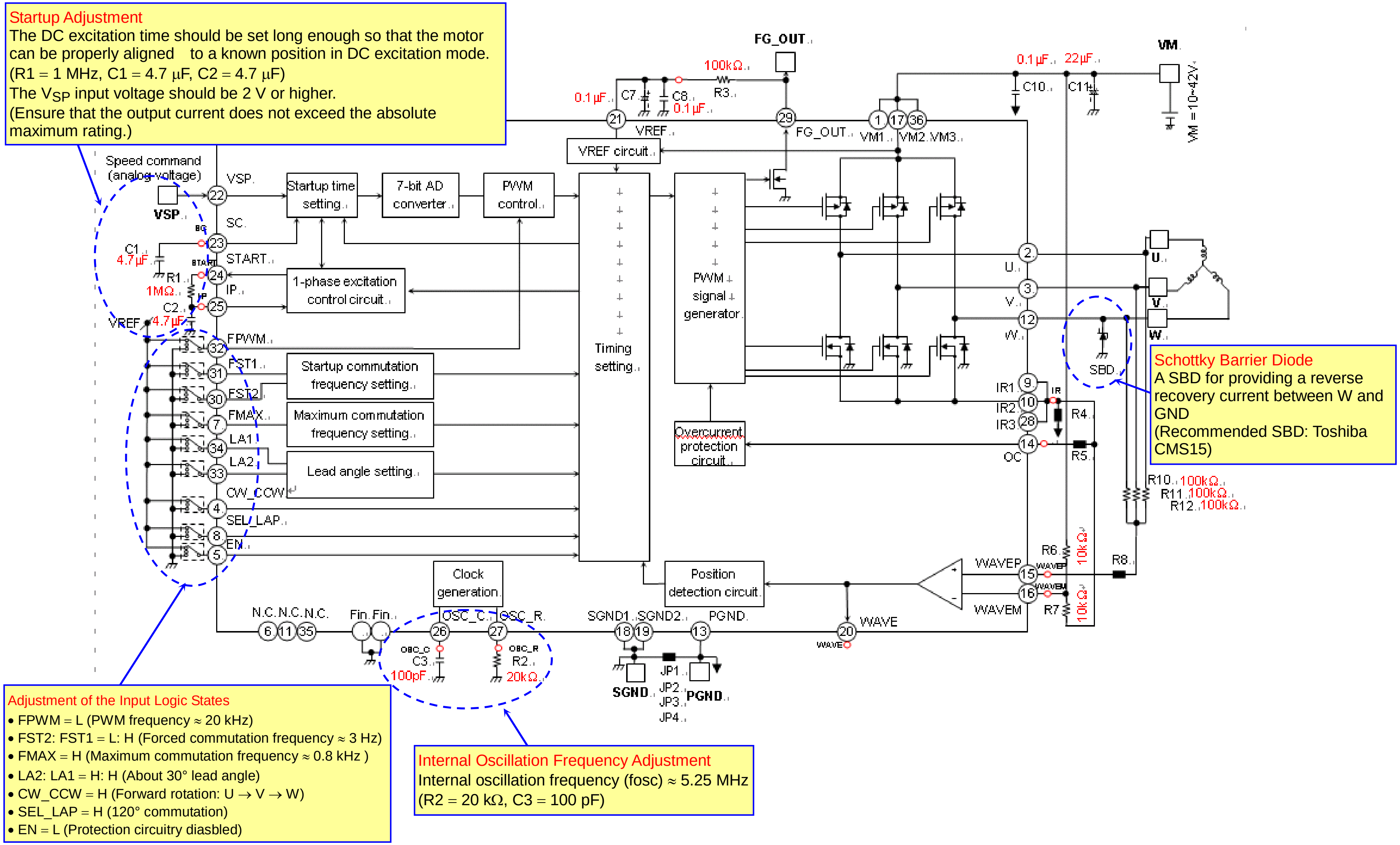
R6 and R7: Resistors for setting the virtual center point (VM//2)
R6, R7 (RV: 10 kΩ)

R2 and C3: Used to set the internal oscillation frequency, fosc
Connect R2 and C3 as close to the IC as possible.
(RVs: fosc = 5.25 MHz: R2 = 20 kΩ, C3 = 100 pF)

The power ground, PGND, should be made with short and wide traces to sustain a large current flow.

Note: Please refer to the Technical Data Sheet for the settings on the fault protection operation and the overcurrent protection.

4. Application Circuit Example (initial setting for trial operation)



Note: These settings may vary depending on the motor type and load, so that they should be adjusted experimentally.

5. Supplemental Information on Various Settings

To perform proper mode switching to sensorless mode, the position detection should be performed synchronized with the timing of the induced voltage, which is almost the same as the timing of the WAVE pin voltage waveform illustrated in Figure 2. The rotor position detection in sensorless mode is synchronized with the WAVE pin voltage, which is obtained by comparing the voltage change caused by the induced voltage in the turned-off phase (WAVEP pin voltage), with the reference voltage (WAVEM pin voltage).

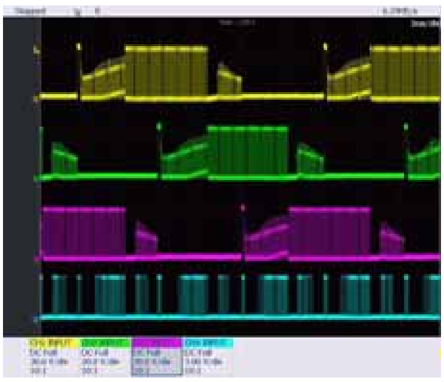
The back-EMF (induced while a diode for providing a reverse recovery current is enabled) is masked when the position detection signal is recognized inside the IC. In applications whose mask period is shorter than the period during which the diode is enabled, the motor malfunctions and cannot rotate properly.

In forced commutation mode at startup, rotation speed is low and the induced voltage cannot be detected easily. Also, due to the motor impedance, the voltage change caused by the induced voltage in the turned-off phase (WAVEP pin voltage) and the reference voltage (WAVE pin voltage) may deviate from the expected value. In such cases, the startup performance may be improved by adjusting the reference voltage (WAVEM pin voltage).

To properly detect the change of the WAVEP pin voltage (voltage change caused by the induced voltage in the turned-off phase) in forced commutation mode, the reference voltage VM/2 (WAVEM pin voltage) should be adjusted to the appropriate value with R6 and R7.

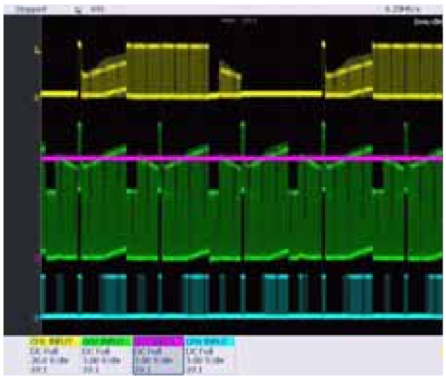
Waveforms of Motor Driving Signals (provided as a guide) V_M = 24 V, V_{SP} = 2.5 V

1 ch.
U
20 V/Div.
2 ch.
V
20 V/Div.
3 ch.
W
20 V/Div.
4 ch.
WAVE
5 V/Div.



1. Position Detection Timing Waveform

1 ch.
U
20 V/Div.
2 ch.
WAVEP
20 V/Div.
3 ch.
WAVEM
5 V/Div.
4 ch.
WAVE
5 V/Div.



2. Position Detection Timing Waveform

6. Damage Due to Short-Circuits Between Neighboring Pins

Short-circuits between pins 1 and 2, pins 3 and 4 and pins 12 and 13 cause permanent damage to the TB6588FG. As a result, a large current continuously flow into the device, leading to smoke and possibly fire. To avoid this, the device application should be designed and adjusted properly, including the external fail-safe mechanism, such as power supply fuses and overcurrent protection circuitry for power supply. To minimize the effect of such a current flow in case of damage, ensure that the fuse capacity, fusing time and overcurrent protection circuitry are properly adjusted.

Results of Short-Circuit Test on Neighboring Pins

No. of Shorted Pins	Respective Pin Names	Damage	Smoke or Fire	Remarks
1-2	VM1-U	Yes	Yes	The IC is damaged right after outputs are turned on, and keeps emitting smoke.
2-3	U-V	No	No	
3-4	V-CW_CCW	Yes	No	The IC is damaged right after outputs are turned on.
4-5	CW_CCW-EN	No	No	
5-6	EN-N.C.	No	No	
6-7	N.C.-FMAX	No	No	
7-8	FMAX-SEL_LAP	No	No	
8-9	SEL_LAP-IR1	No	No	
9-Fin	IR1-Fin	No	No	
Fin-10	Fin-IR2	No	No	
10-11	IR2-N.C.	No	No	
11-12	N.C.-W	No	No	
12-13	W-PGND	Yes	Yes	The IC is damaged right after outputs are turned on, and emits smoke for an instant.
13-14	PGND-OC	No	No	
14-15	OC-WAVEP	No	No	
15-16	WAVEP-WAVEM	No	No	
16-17	WAVEM-VM2	No	No	
17-18	VM2-SGND1	No	No	
18-19	SGND1-SGND2	No	No	
19-20	SGND2-WAVE	No	No	
20-21	WAVE-VREF	No	No	
21-22	VREF-VSP	No	No	
22-23	VSP-SC	No	No	
23-24	SC-START	No	No	
24-25	START-IP	No	No	
25-26	IP-OSC_C	No	No	
26-27	OSC_C-OSC_R	No	No	
27-Fin	OSC_R-Fin	No	No	
Fin-28	Fin-IR3	No	No	
28-29	IR3-FG_OUT	No	No	
29-30	FG_OUT-FST2	No	No	
30-31	FST2-FST1	No	No	
31-32	FST1-FPWM	No	No	
32-33	FPWM-LA2	No	No	
33-34	LA2-LA1	No	No	
34-35	LA1-N.C.	No	No	
35-36	N.C.-VM3	No	No	

7. Power Dissipation

The power dissipation, P, of the TB6588FG is approximately calculated as follows. (For the meanings of the symbols used in the equations, see the "Electrical Characteristics" table in the datasheet.)

When PWMDuty = 100%

$P = V_M \times I_{M\ (opr)} + I_{OUT}\text{^}2 \times (R_{ON\ (H)} + R_{ON\ (L)})$

In PWM Mode

$P = V_M \times I_{M\ (opr)} + I_{OUT}\text{^}2 \times (R_{ON\ (H)} + R_{ON\ (L)}) \times PWMduty$ (In actual use, switching loss occurs.)

The junction temperature, Tj, is calculated as follows. Tj must be kept below 150°C.

$Tj = P \times R_{th\ (j\text{-}a)} + Ta$

* $R_{th\ (j\text{-}a)}$: Junction-to-ambient thermal resistance
* Ta: Ambient temperature

The higher the ambient temperature, the lower the power dissipation, as shown in the following graph. Keep in mind that $R_{th\ (j\text{-}a)}$ varies with the use environment such as the pc board.

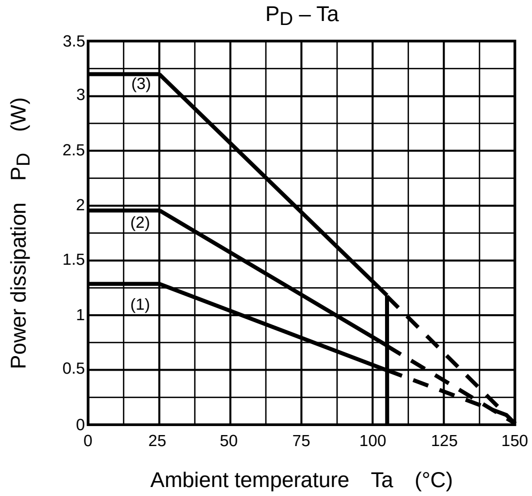
The above calculation should be considered only as a guide. The rise in temperature must be measured empirically for appropriate thermal design.

Example:

Conditions: V_M = 24 V, I_{OUT} = 1 A, $I_{M\ (opr)}$ = 8 mA(max), $R_{ON\ (H)}$ = 0.35 Ω (max), $R_{ON\ (L)}$ = 0.35 Ω (max), Ta = 25°C, PWMDuty = 100%, chip-only $R_{th\ (j\text{-}a)}$: 96°C/W

P = 24 V × 8 mA + 1 A^2 × (0.35 Ω + 0.35 Ω) = 0.192 + 0.7 = 0.892 ≈ 0.9 W

Hence, Tj = 0.9 W × 96°C/W + 25°C = 111.4°C



(1) Chip-only $R_{th\ (j\text{-}a)}$: 96°C/W

(2) $R_{th\ (j\text{-}a)}$ when mounted on a pc board (114 mm × 75 mm × 1.6 mm, Cu 20%): 65°C/W

(3) (3) $R_{th\ (j\text{-}a)}$ when mounted on a pc board (140 mm × 70 mm × 1.6 mm, Cu 50%): 39°C/W

* Infinite heat sink: $R_{th\ (j\text{-}c)}$: 8.5°C/W

RESTRICTIONS ON PRODUCT USE

- Toshiba Corporation, and its subsidiaries and affiliates (collectively “TOSHIBA”), reserve the right to make changes to the information in this document, and related hardware, software and systems (collectively “Product”) without notice.
- This document and any information herein may not be reproduced without prior written permission from TOSHIBA. Even with TOSHIBA’s written permission, reproduction is permissible only if reproduction is without alteration/omission.
- Though TOSHIBA works continually to improve Product’s quality and reliability, Product can malfunction or fail. Customers are responsible for complying with safety standards and for providing adequate designs and safeguards for their hardware, software and systems which minimize risk and avoid situations in which a malfunction or failure of Product could cause loss of human life, bodily injury or damage to property, including data loss or corruption. Before creating and producing designs and using, customers must also refer to and comply with (a) the latest versions of all relevant TOSHIBA information, including without limitation, this document, the specifications, the data sheets and application notes for Product and the precautions and conditions set forth in the “TOSHIBA Semiconductor Reliability Handbook” and (b) the instructions for the application that Product will be used with or for. Customers are solely responsible for all aspects of their own product design or applications, including but not limited to (a) determining the appropriateness of the use of this Product in such design or applications; (b) evaluating and determining the applicability of any information contained in this document, or in charts, diagrams, programs, algorithms, sample application circuits, or any other referenced documents; and (c) validating all operating parameters for such designs and applications. **TOSHIBA ASSUMES NO LIABILITY FOR CUSTOMERS’ PRODUCT DESIGN OR APPLICATIONS.**
- Product is intended for use in general electronics applications (e.g., computers, personal equipment, office equipment, measuring equipment, industrial robots and home electronics appliances) or for specific applications as expressly stated in this document. Product is neither intended nor warranted for use in equipment or systems that require extraordinarily high levels of quality and/or reliability and/or a malfunction or failure of which may cause loss of human life, bodily injury, serious property damage or serious public impact (“Unintended Use”). Unintended Use includes, without limitation, equipment used in nuclear facilities, equipment used in the aerospace industry, medical equipment, equipment used for automobiles, trains, ships and other transportation, traffic signaling equipment, equipment used to control combustions or explosions, safety devices, elevators and escalators, devices related to electric power, and equipment used in finance-related fields. Do not use Product for Unintended Use unless specifically permitted in this document.
- Do not disassemble, analyze, reverse-engineer, alter, modify, translate or copy Product, whether in whole or in part.
- Product shall not be used for or incorporated into any products or systems whose manufacture, use, or sale is prohibited under any applicable laws or regulations.
- The information contained herein is presented only as guidance for Product use. No responsibility is assumed by TOSHIBA for any infringement of patents or any other intellectual property rights of third parties that may result from the use of Product. No license to any intellectual property right is granted by this document, whether express or implied, by estoppel or otherwise.
- **ABSENT A WRITTEN SIGNED AGREEMENT, EXCEPT AS PROVIDED IN THE RELEVANT TERMS AND CONDITIONS OF SALE FOR PRODUCT, AND TO THE MAXIMUM EXTENT ALLOWABLE BY LAW, TOSHIBA (1) ASSUMES NO LIABILITY WHATSOEVER, INCLUDING WITHOUT LIMITATION, INDIRECT, CONSEQUENTIAL, SPECIAL, OR INCIDENTAL DAMAGES OR LOSS, INCLUDING WITHOUT LIMITATION, LOSS OF PROFITS, LOSS OF OPPORTUNITIES, BUSINESS INTERRUPTION AND LOSS OF DATA, AND (2) DISCLAIMS ANY AND ALL EXPRESS OR IMPLIED WARRANTIES AND CONDITIONS RELATED TO SALE, USE OF PRODUCT, OR INFORMATION, INCLUDING WARRANTIES OR CONDITIONS OF MERCHANTABILITY, FITNESS FOR A PARTICULAR PURPOSE, ACCURACY OF INFORMATION, OR NONINFRINGEMENT.**
- Do not use or otherwise make available Product or related software or technology for any military purposes, including without limitation, for the design, development, use, stockpiling or manufacturing of nuclear, chemical, or biological weapons or missile technology products (mass destruction weapons). Product and related software and technology may be controlled under the Japanese Foreign Exchange and Foreign Trade Law and the U.S. Export Administration Regulations. Export and re-export of Product or related software or technology are strictly prohibited except in compliance with all applicable export laws and regulations.
- Please contact your TOSHIBA sales representative for details as to environmental matters such as the RoHS compatibility of Product. Please use Product in compliance with all applicable laws and regulations that regulate the inclusion or use of controlled substances, including without limitation, the EU RoHS Directive. TOSHIBA assumes no liability for damages or losses occurring as a result of noncompliance with applicable laws and regulations.