

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

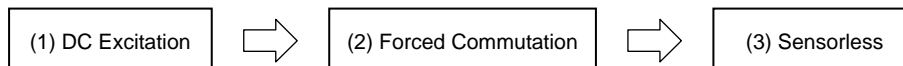
Note 2: Pins operating at  $V_{IN2}$ : WAVEP and WAVEM

**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.



**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.

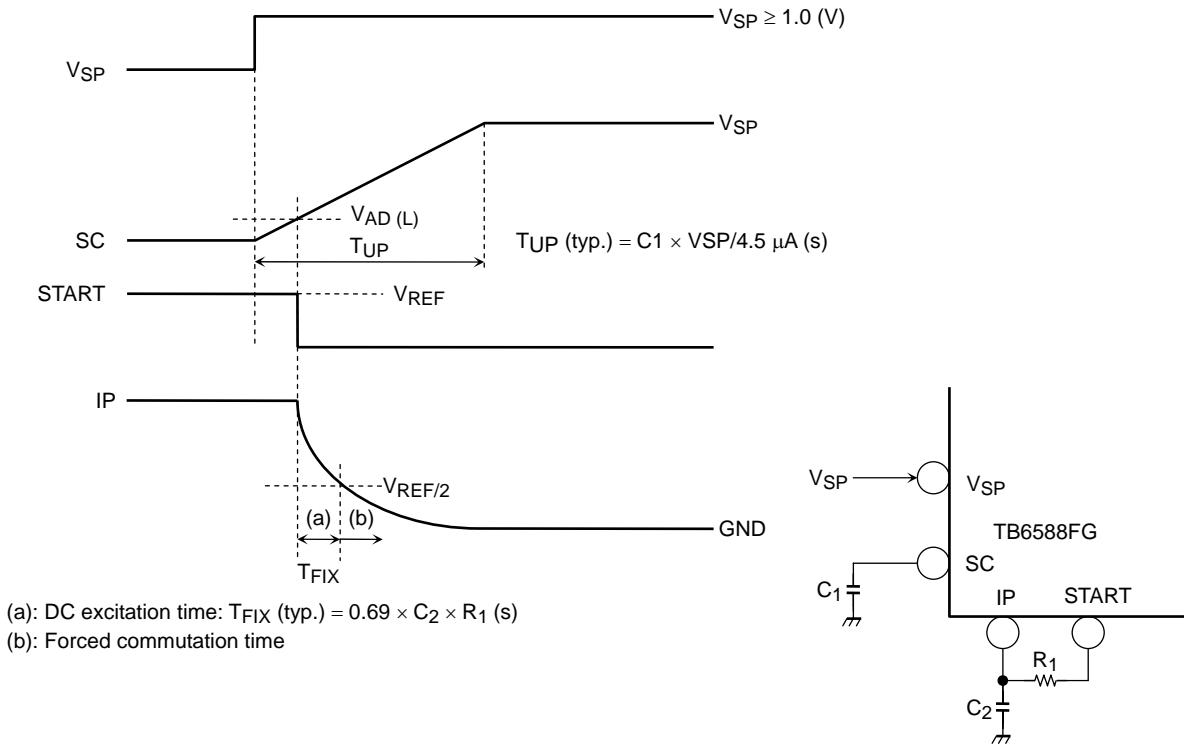
**(1) DC Excitation Mode Settings**

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 VSP 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.



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  $C_2$  and  $R_1$ . 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 VSP 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  $f_{ST} \approx f_{osc}/(6 \times 2^{16})$   
 FST2 : FST1 = High : Low, Open = Forced commutation frequency  $f_{ST} \approx f_{osc}/(6 \times 2^{17})$   
 FST2 : FST1 = Low, Open : High = Forced commutation frequency  $f_{ST} \approx f_{osc}/(6 \times 2^{18})$   
 FST2 : FST1 = Low, Open : Low, Open = Forced commutation frequency  $f_{ST} \approx f_{osc}/(6 \times 2^{19})$

The forced commutation frequency is determined by the internal frequency  $f_{osc}$  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.

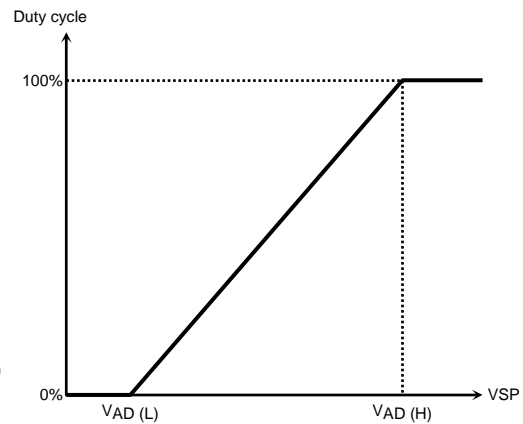
- Motor speed control pin (VSP)

An analog voltage applied to the VSP 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 VSP input.)

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

$V_{AD} (L) = 1.2 \text{ V (typ.)}$   
 (FPWM = L, OSC\_C = 100pF, OSC\_R = 20 kΩ)  
 $V_{AD} (H) = 4.1 \text{ V (typ.)}$   
 (FPWM = L, OSC\_C = 100 pF, OSC\_R = 20 kΩ)



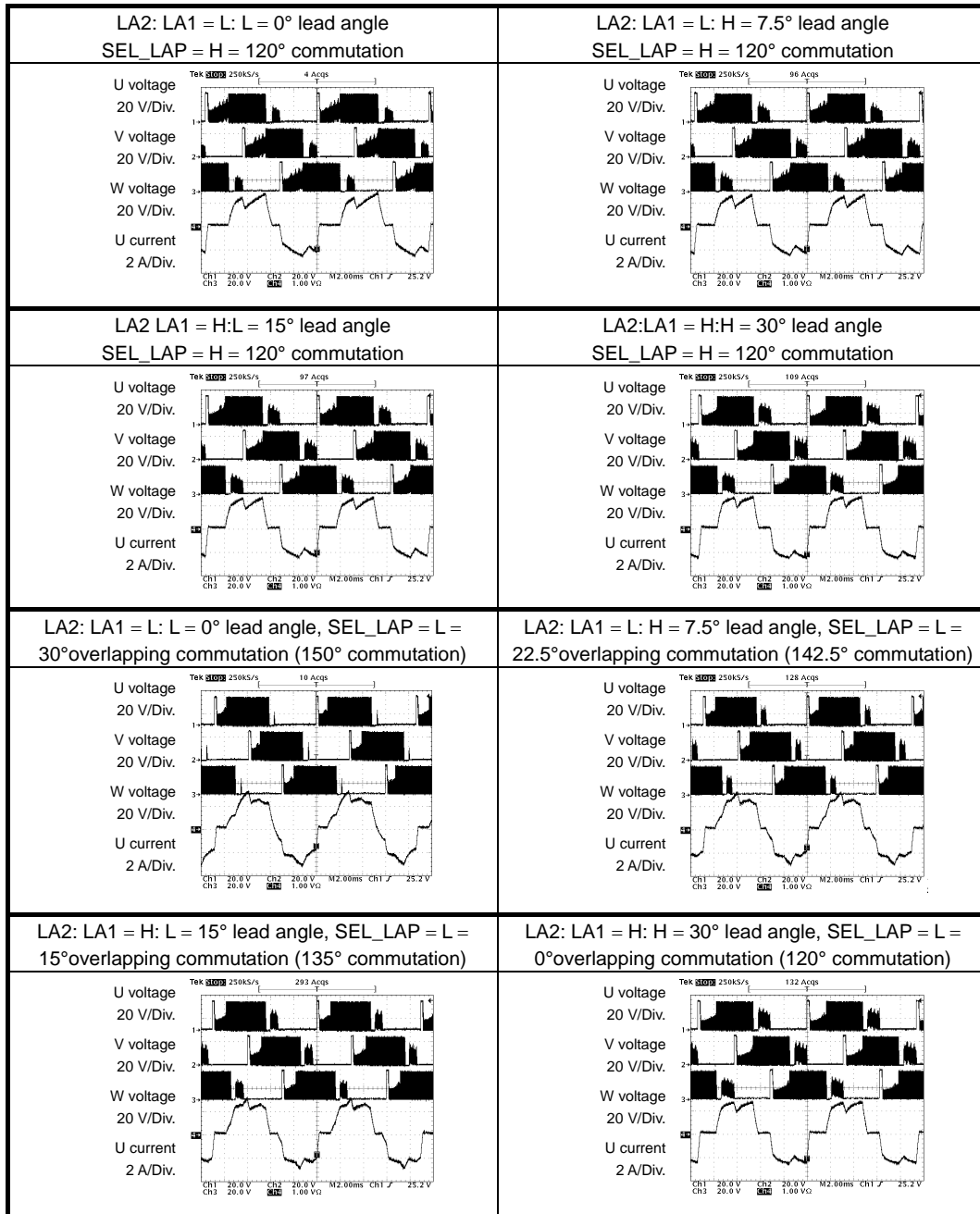
Note: The analog input voltage applied to the VSP pin should be adjusted so that the duty cycle becomes large enough to allow the voltage induced by the motor rotation in forced commutation mode to exceed the WAVE pin voltage ( $V_M/2$ ). If the duty cycle is too small, the induced voltage in the motor 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.

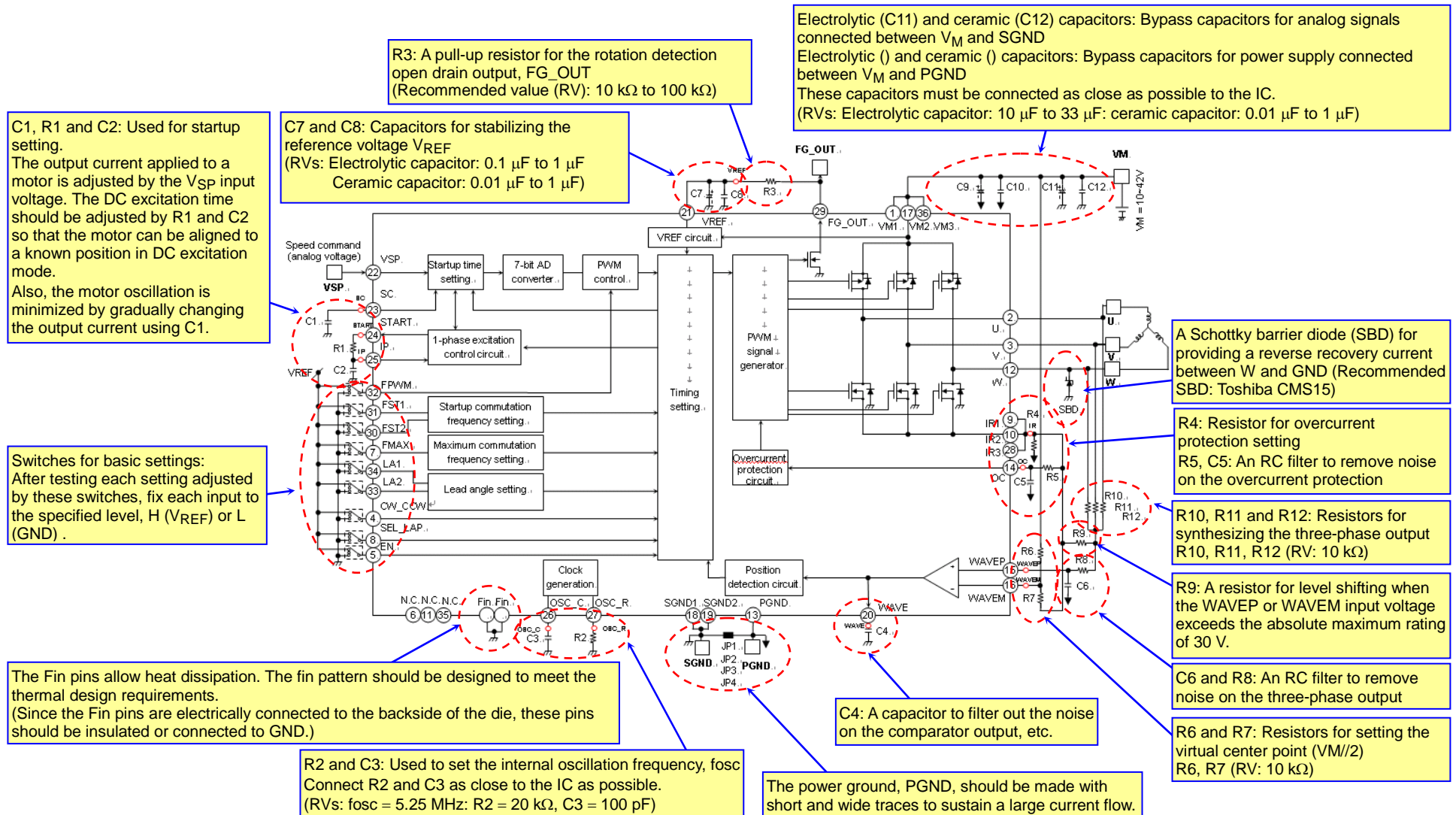
- Settings of lead angle select pins
  - LA2: LA1 ≈ High, Open : High, Open ≈ 30° lead angle
  - LA2: LA1 ≈ High, Open : Low ≈ 15° lead angle
  - LA2: LA1 ≈ Low : High, Open ≈ 7.5° lead angle
  - LA2: LA1 ≈ Low : Low ≈ 0° lead angle
- Settings of overlapping commutation select pins
  - SEL\_LAP = High,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

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



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

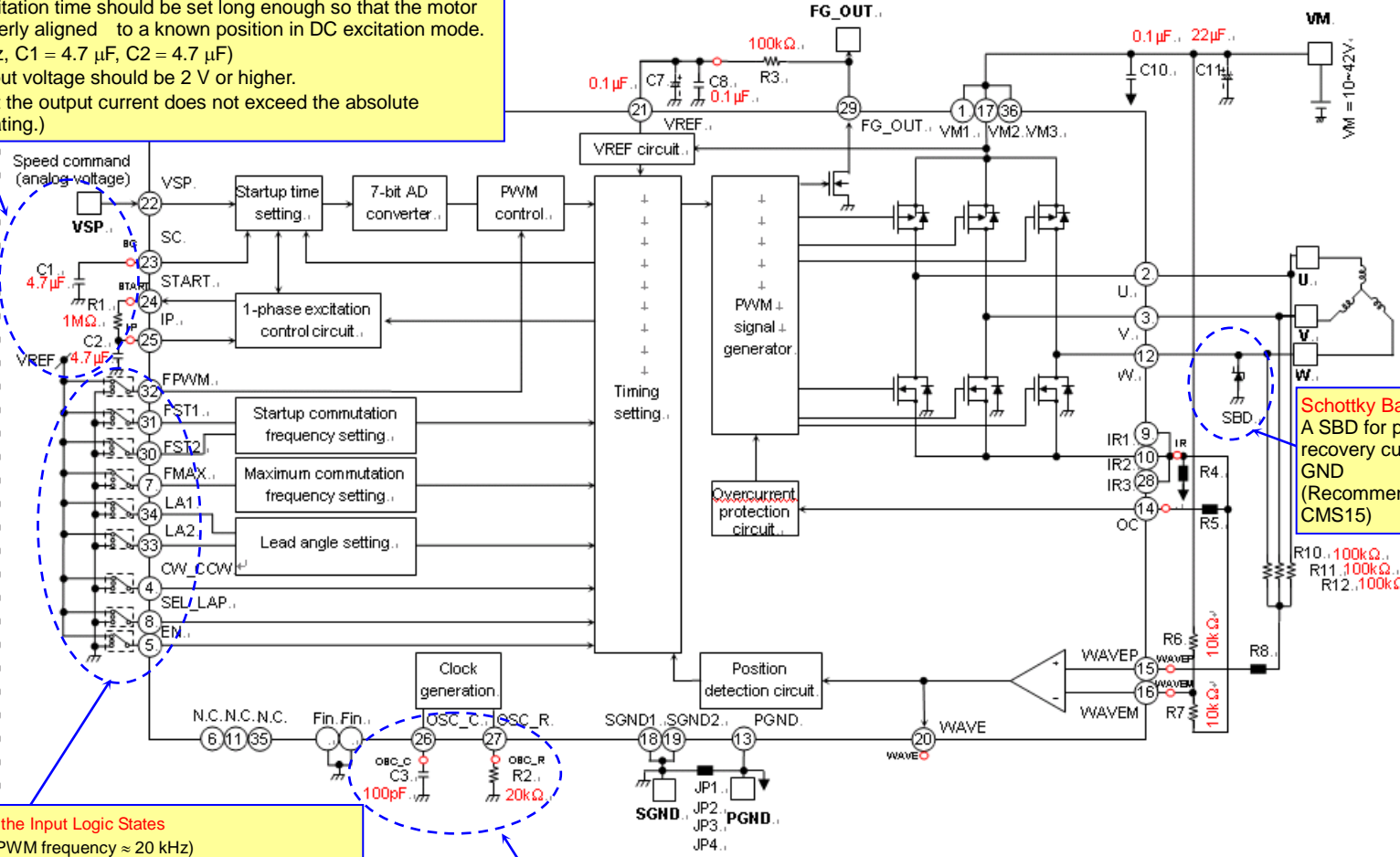


Note: Please refer to the Technical Data Sheet for the settings on the fault protection operation and the overcurrent protection.

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

**Startup Adjustment**

The DC excitation time should be set long enough so that the motor can be properly aligned to a known position in DC excitation mode. (R1 = 1 M $\Omega$ , C1 = 4.7  $\mu$ F, C2 = 4.7  $\mu$ F)  
 The V<sub>SP</sub> input voltage should be 2 V or higher.  
 (Ensure that the output current does not exceed the absolute maximum rating.)



**Schottky Barrier Diode**  
 A SBD for providing a reverse recovery current between W and GND  
 (Recommended SBD: Toshiba CMS15)

**Adjustment of the Input Logic States**

- FPWM = L (PWM frequency  $\approx$  20 kHz)
- FST2: FST1 = L: H (Forced commutation frequency  $\approx$  3 Hz)
- FMAX = H (Maximum commutation frequency  $\approx$  0.8 kHz)
- LA2: LA1 = H: H (About 30° lead angle)
- CW\_CCW = H (Forward rotation: U  $\rightarrow$  V  $\rightarrow$  W)
- SEL\_LAP = H (120° commutation)
- EN = L (Protection circuitry disabled)

**Internal Oscillation Frequency Adjustment**  
 Internal oscillation frequency (fosc)  $\approx$  5.25 MHz  
 (R2 = 20 k $\Omega$ , C3 = 100 pF)

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).

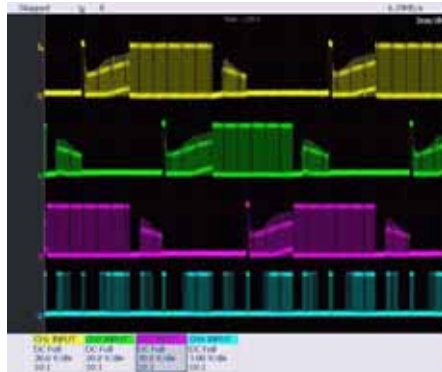
The back-EMF (induced while a diode for providing a reverse recovery current is enabled) is masked when the position detection signal is recognized inside the IC. In applications whose mask period is shorter than the period during which the diode is enabled, the motor malfunctions and cannot rotate properly.

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.

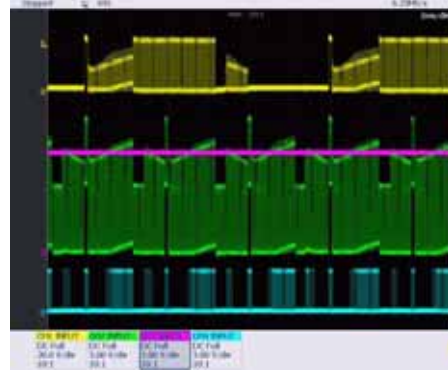
**Waveforms of Motor Driving Signals (provided as a guide)  $V_M = 24\text{ V}$ ,  $V_{SP} = 2.5\text{ V}$**

- 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%

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

### In PWM Mode

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

The junction temperature, T<sub>j</sub>, is calculated as follows. T<sub>j</sub> must be kept below 150°C.

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

\* R<sub>th</sub> (j-a): Junction-to-ambient thermal resistance

\* T<sub>a</sub>: Ambient temperature

The higher the ambient temperature, the lower the power dissipation, as shown in the following graph. Keep in mind that R<sub>th</sub> (j-a) varies with the use environment such as the pc board.

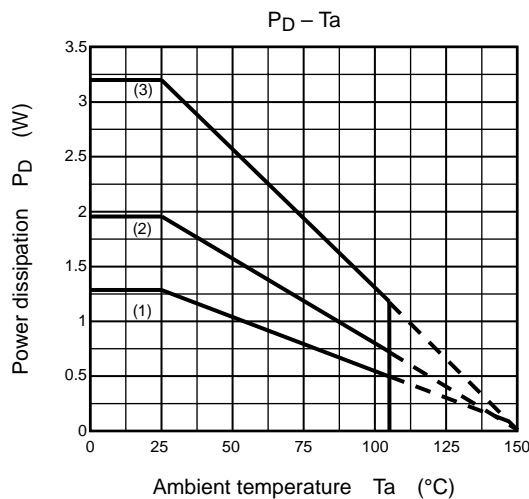
The above calculation should be considered only as a guide. The rise in temperature must be measured empirically for appropriate thermal design.

### Example:

Conditions: V<sub>M</sub> = 24 V, I<sub>OUT</sub> = 1 A, I<sub>M</sub> (opr) = 8 mA(max), R<sub>ON</sub> (H) = 0.35 Ω (max),  
R<sub>ON</sub> (L) = 0.35 Ω (max), T<sub>a</sub> = 25°C, PWMDuty = 100%, chip-only R<sub>th</sub> (j-a) : 96°C/W

$$P = 24 \text{ V} \times 8 \text{ mA} + 1 \text{ A}^2 \times (0.35 \text{ } \Omega + 0.35 \text{ } \Omega) = 0.192 + 0.7 = 0.892 \approx 0.9 \text{ W}$$

$$\text{Hence, } T_j = 0.9 \text{ W} \times 96^\circ\text{C/W} + 25^\circ\text{C} = 111.4^\circ\text{C}$$



(1) Chip-only R<sub>th</sub> (j-a): 96°C/W

(2) R<sub>th</sub> (j-a) when mounted on a pc board (114 mm × 75 mm × 1.6 mm, Cu 20%): 65°C/W

(3) R<sub>th</sub> (j-a) when mounted on a pc board (140 mm × 70 mm × 1.6 mm, Cu 50%): 39°C/W

\* Infinite heat sink: R<sub>th</sub> (j-c): 8.5°C/W

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