

TB67S128FTG

Usage considerations

Main Specifications

Product number	TB67S128FTG
Control I/F	CLOCK-IN / Serial
Absolute maximum ratings	50 V, 5 A
Package	QFN64
Step resolution	Full, Half, Quarter, 1/8, 1/16, 1/32, 1/64 and 1/128 step resolution
Other features	128 micro step Adoption of AGC, ADMD, and ACDS architectures Built-in error detection functions (thermal shutdown, over current protection, under voltage lock out, and motor load open detection) Built-in error detection signal output function Support the power-on sequence by the single power drive Automation oscillation circuit which does not require components

Toshiba Electronic Devices & Storage Corporation

The contents described in the application note are reference for evaluating the product. Therefore, the contents described cannot be guaranteed. As for the detailed materials, please check the data sheet.

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1. Overview

TB67S128FTG can control a single 2-phase bipolar stepping motor.

This IC supports from 12 V to 42 V power supply and large-current drive for motors by adopting 50 V monolithic analog process (BiCD: Bipolar CMOS DMOS).

CLK-In Decoder for 128 micro stepping drive is incorporated, allowing motors to drive with sine-wave current by inputting CLK signals. It realizes fast and accurate current following with ADMD (Advanced Mixed Decay Mode). Also, it can switch to the conventional Mixed Decay control.

Also, external components can be eliminated by adopting ACDS (Advanced Current Detection System) and the component-elimination mode of the internal oscillation circuit. The greatest feature of the IC is adopting AGC (Active Gain Control: anti-stall function) technology. It can achieve high efficient motor drive, while preventing motor stalls.

Usage methods and notes in using the IC are described from the next section.

2. Power Supply Voltage

2.1. Power supply voltage and operation range

In using TB67S128FTG, the voltage should be applied to the pins of VM (VMA, VMB) and VREF (VREFA, VREFB).

Built-in VCC regulator for internal logic power supply enables the IC to operate with a single power supply. Applying an external voltage is unnecessary. The maximum rating of the motor supply voltage is 50 V. Its operation voltage range is 6.5 V to 44 V.

The maximum voltage rating, which is applied to VREF pin for PWM threshold, is 5 V. Its operation range is 0 to 3.6 V.

VREF is configured by voltage of VCC regulator and can be set by dividing voltage in necessary.

However, if the current value exceeds the capability of the VCC regulator, the output voltage may not be kept.

Therefore, when VREF is applied by dividing VCC, the voltage-dividing resistance (combined resistance of VCC and GND) should be in the range of 10 k Ω to 100 k Ω .

Table 2.1 Operation ranges of power supply voltage (Ta=-20 to 85°C)

Item	Symbol	Absolute maximum ratings	Operation range	Unit	Remarks
Motor power supply voltage	VM	50	6.5 to 44	V	—
Setting voltage for PWM threshold	VREF	5.0	0 to 3.6	V	—
Voltage for internal logic power supply	VCC	6.0	4.75 to 5.25	V	Supplied by internal regulator

3. Power Supply Sequence

There are no special procedures between power sources in powering on and shutdown because TB67S128FTG can operate with a single power supply by the VCC regulator. Moreover, built-in under voltage detections (UVLO and power on reset function (POR)) avoid malfunction, which occurs at the UVLO/POR detection threshold or less. While POR is activated, the internal logic is initialized. The UVLO/POR detection threshold is as follows; $6.0\text{ V} \pm 0.3\text{ V}$.

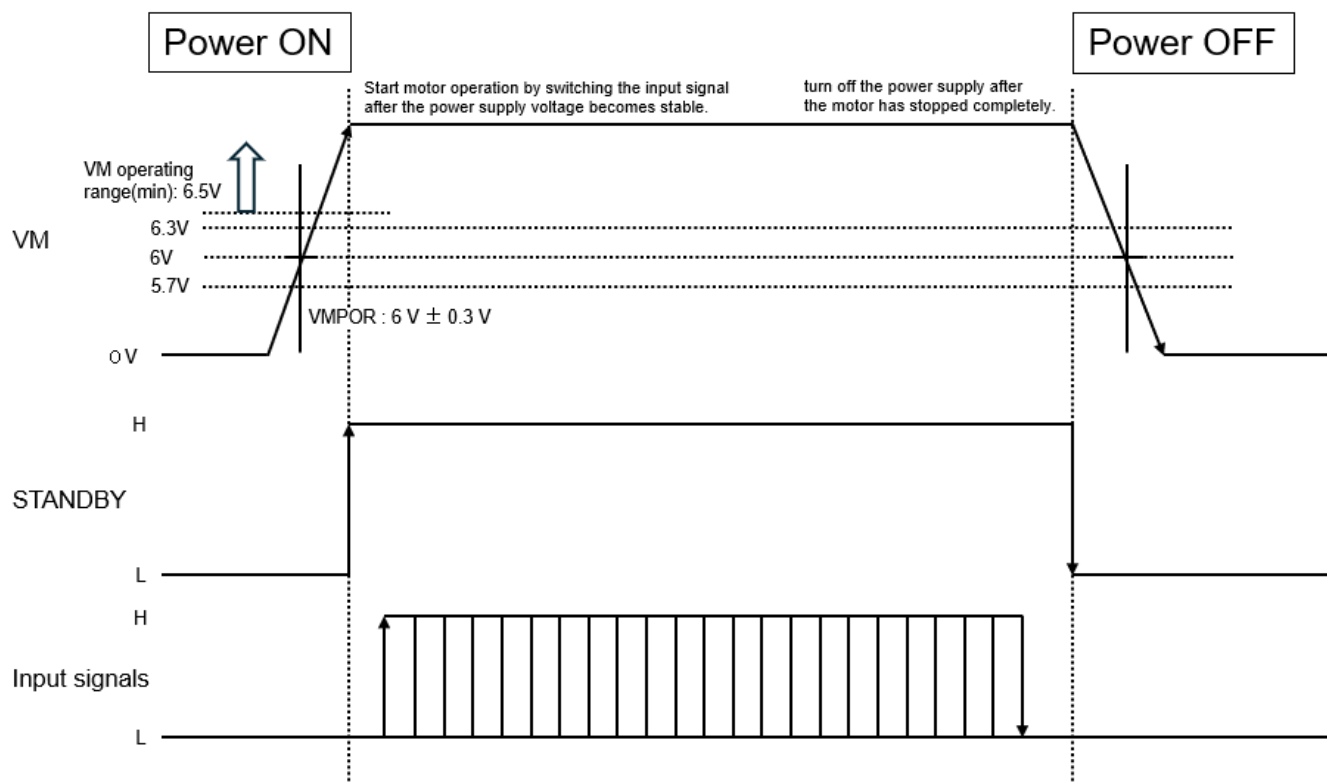


Figure 3.1 Power Supply Sequence

4. Output Current

Output current value for the motor depends on the power consumption that refers to the voltage drop at the on resistance of the output circuit. From the above, the absolute maximum current rating of each IC is as follows; 5 A. These ratings must not be exceeded, even for a moment.

The actual-usage maximum current is limited depending on the usage conditions (the ambient temperature, the wiring pattern of the board, the radiation path, the exciting design, etc.). Therefore, configure the most appropriate current value after calculating the heat and evaluating the board under the operating environment.

Moreover, the IC drives the motor with a constant-current control by ACDS technology. Recommended lower current limit for appropriate motor operation is as follows; $V_{ref}=0.7V$ over. When the configured current is too small in using large-current drive devices, malfunctions such as offset may occur. In that case, please use the RS resistance mode and adjust with the sense resistance value.

5. Control Logic Input

The IC can avoid malfunction occurred by the electromotive force, which generates when the control logic signal is input without VM voltage.

However, it is recommended to set the control logic signal low level while VM is not supplied.

Configure the control logic signal low level during powering on and shutdown (refer to “3.1 Power Supply Sequence”) and input the operation signal after VM and VREF reach the operation voltage range.

6. PWM Control

6.1. Setting PWM threshold

TB67S128FTG can configure the constant current PWM threshold only by the applied voltage to the VREF pin. External current detection resistor is not required. (ACDS technology)

The current value (I_{out}) can be approximated from below formulas.

$$I_{out} = V_{REF} \times 1.56 \text{ (GAIN_SEL pin=L)}$$

$$I_{out} = V_{REF} \times 0.78 \text{ (GAIN_SEL pin=H)}$$

For example, when GAIN_SEL = L and a voltage of 2 V is input to VREF pin, setting current is as follows;

$$I_{out} = 2 \text{ V} \times 1.56 = 3.12 \text{ A (typ.)}$$

6.2. Setting internal oscillation frequency (f_{OSCM}) and constant current PWM (chopping) frequency (f_{chop})

TB67S128FTG can set the internal oscillation frequency (f_{OSCM}) and the PWM (chopping) frequency (f_{chop}) with the constant numbers of the external components (resistor and capacitor), which are connected to OSCM pin.

The internal oscillation frequency can be set by connecting the resistor (R_{OSC}) between VCC and OSCM pin, and connecting the capacitor (C_{OSC}) between OSCM pin and GND. Please set it by changing the R_{OSC} value, while fixing the C_{OSC} value to 270 pF.

The relational expression of the internal oscillation frequency (f_{OSCM}) and the external resistance (R_{OSC}) is as follows ($C_{\text{OSC}} = 270 \text{ pF}$);

$$f_{\text{OSCM}} = 4.0 \times R_{\text{OSC}}^{-0.8}$$

Note: In the above equation, the unit of f_{OSCM} is MHz, and the unit of R_{OSC} is k Ω .

Refer to the following graph (Figure 11.1, Figure 11.2) for the relation of the external component and the measured data of the internal oscillation frequency (reference data).

The relational expression of the internal oscillation frequency (f_{OSCM}) and the constant current PWM (chopping) frequency (f_{chop}) is as follows;

$$f_{\text{chop}} = f_{\text{OSCM}} / 16$$

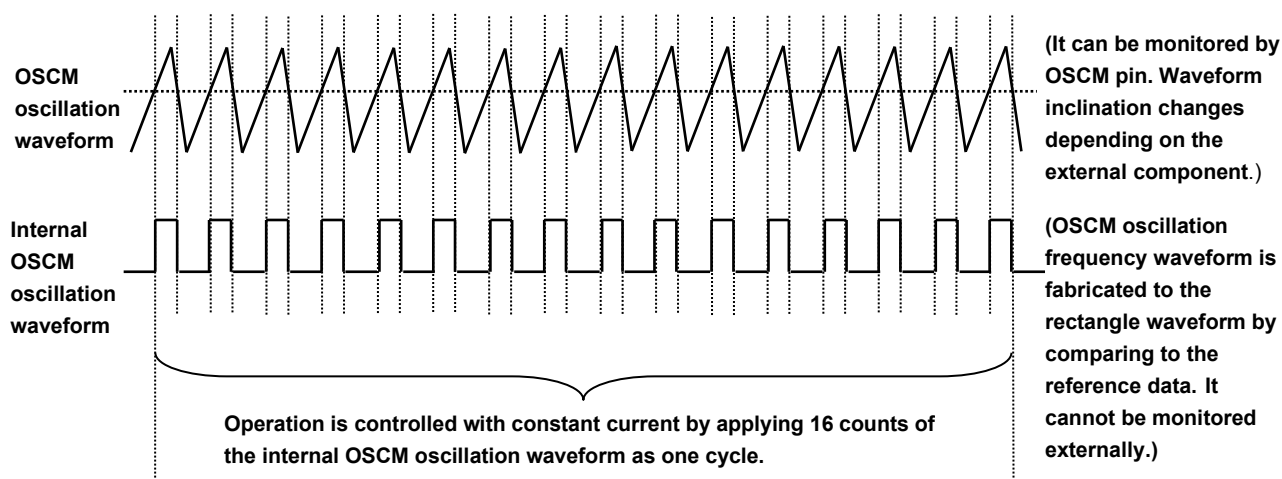


Figure 6.1 Relation of OSCM pin oscillation waveform and internal OSCM oscillation waveform

6.3. Constant current waveform when chopping frequency changes

Chopping frequency (f_{chop}) is recommended to set about 67 kHz in using the IC. When the chopping frequency is increased, ripple current of the motor is decreased and the waveform quality is improved. However, the heat generates because the increased chopping frequency enhances the switching loss. To improve the waveform quality, increase the chopping frequency. To reduce the heat generation, decrease the frequency.

Example 1: When chopping frequency (f_{chop}) = 100 kHz,

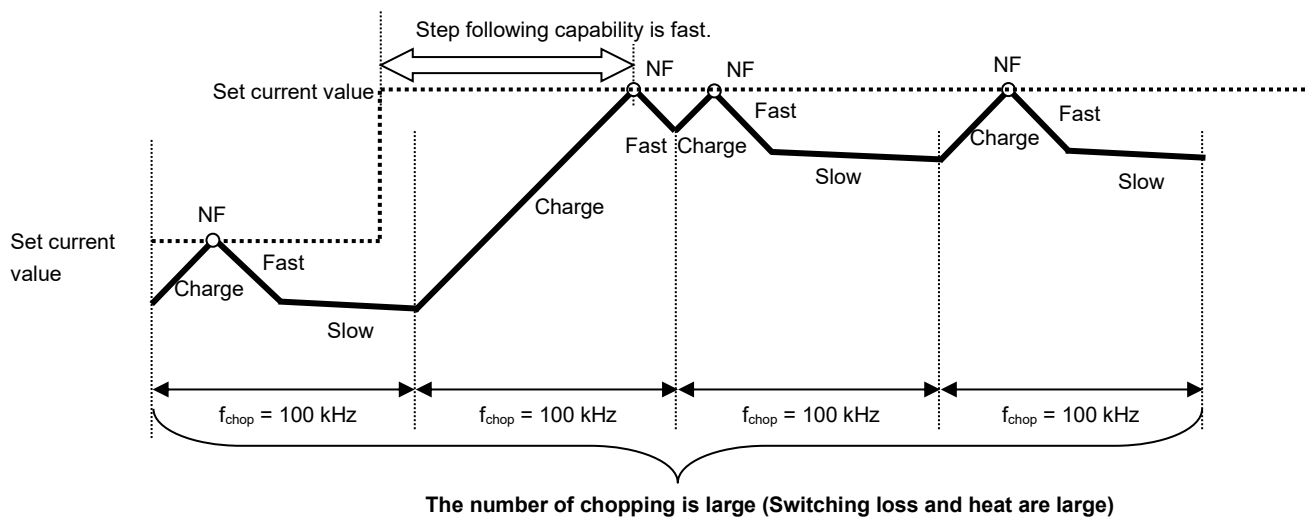


Figure 6.2 Chopping frequency (100 kHz)

Example 2: When chopping frequency (f_{chop}) = 72 kHz,

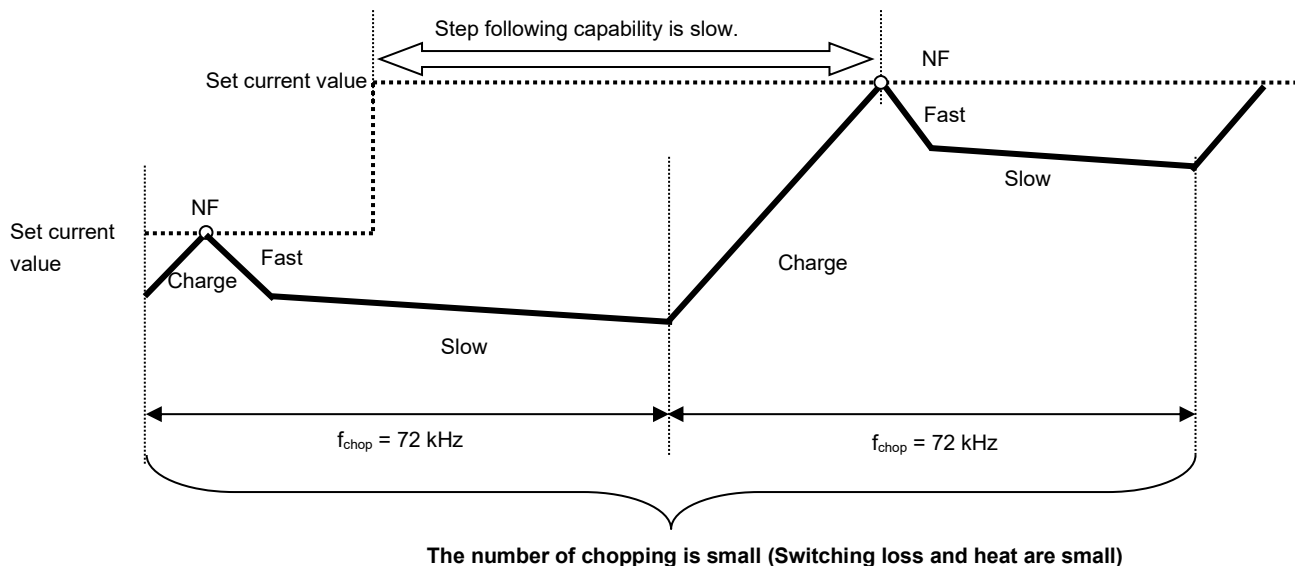


Figure 6.3 Chopping frequency (72 kHz)

Generally, it is recommended to use the IC with the frequency range of 50 kHz to 120 kHz based on 67 kHz as a typical value.

7. Output Switching Characteristics

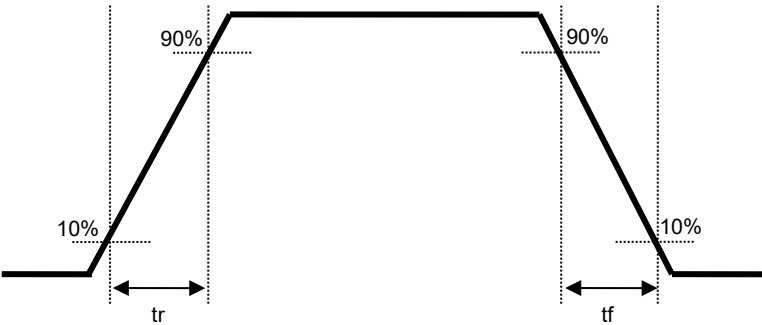


Figure 7.1 Switching characteristics

Table 7.1 Switching characteristics

Ta = 25°C, VM = 24 V, No load

Item	Typ.	Unit
tr	80	ns
tf	90	ns

Note. Confirm the electrical characteristics of the data sheet for each value.

8. IC Function Explanation 1 (CLK mode, IF_SEL pin = L)

This chapter describes the basic functions of stepping motors.

8.1. CLK function

An electrical angle advances one unit according to the driving mode, which is configured by each pulse of CLK signal. Each signal is reflected at upper edge of CLK signal.

The analog filter of 200 ns ($\pm 20\%$) is implemented for CLK pin to avoid malfunction due to noise.

Duty of CLK signal is not necessary to set 50 %. However, pay attention to configure the maximum frequency of the CLK signal in considering this analog filter of 200 ns.

When the state of inputting upper edge signal continues due to noise, upper edge signal is reflected after the filtering period. In this case, the motor may stall because the electrical angle advances according to the below function regardless of the signal reflecting state. Pay attention to design the wiring layout for CLK pin not to be influenced by noise.

In addition, when the input CLK frequency is increased by high-resolution microstepping, it is possible to switch with the EDG_SEL signal so that the electrical angle is advanced at both edges of CLK. (MCU load can be reduced.)

Table 8.1 CLK function

CLK	Function	
	EDG_SEL=L	EDG_SEL=H
rising edge	Shifts the electrical angle and current step per each upper edge.	Shifts the electrical angle and current step per each upper edge.
Down edge	— (no change, maintain former state)	Shifts the electrical angle and current step per each down edge.

8.2. ENABLE function

This function switches ON and OFF of the output circuit of the IC. Motor operation (i.e., current outputting) starts when this function is enabled. Motor operation stops when it is disabled. (In OFF mode, all of output MOSFETs are turned off and become the high impedance state.) To prevent the motor from operating outside the VM operating voltage range, following ENABLE pin setting is recommended. Configure ENABLE pin to low level in powering on and shutdown, and switch it to high level after VM voltage is stabilized at the usage voltage.

Table 8.2 ENABLE function

ENABLE	Function
High	Motor operation: ON (Normal operation)
Low	Motor operation: OFF (Hi-Z)

8.3. CW/CCW function (Output logic at charge start)

This function controls the rotation direction of the stepping motor. When CW/CCW pin is set to high level, OUT (+) pin outputs a high level signal and OUT (-) pin outputs a low level signal in the charge starting. When CW/CCW pin is set to low level, OUT (+) pin outputs a low level signal and OUT (-) pin outputs a high level signal in the charge starting.

Table 8.3 CW/CCW function

CW/CCW	Function
High	Clock-wise: The current of Ach leads the current of Bch by 90-degree phase difference.
Low	Counter clock-wise: The current of Bch leads the current of Ach by 90-degree phase difference.

8.4. RESET function

This function initializes the internal electrical angle. The standby mode can be configured by setting STANDBY pin low level.

Note: Built-in digital filter of 0.625 μ s (± 20 %) is adopted to RESET pin.

Table 8.4 RESET function

RESET	Function
High	Initializes the internal electrical angle
Low	Normal operation

When the electrical angle is initialized by setting RESET pin to high level, the relation of the current setting for each H-bridge (Ach and Bch) and the electrical angle is shown below. In the case the MO pin level is pulled up, it shows low level (internal open-drain MOSFET turns on) when the electrical angle is initialized.

Table 8.5 Phase current at RESET

Step resolution	Ach current	Bch current	Electrical angle
Full step setting	100%	100%	45°
Half step setting	71%	71%	45°
Quarter step setting	71%	71%	45°
1/8 step setting	71%	71%	45°
1/16 step setting	71%	71%	45°
1/32 step setting	71%	71%	45°
1/64 step setting	71%	71%	45°
1/128 step setting	71%	71%	45°

8.5. Torque function

The torque can be changed without changing the Vref voltage using the TORQE0, TORQE1, and TORQE2.

Table 8.6 Torque function

TORQE2	TORQE1	TORQE0	Function
L	L	L	Torque : 100%
L	L	H	Torque : 85%
L	H	L	Torque : 70%
L	H	H	Torque : 60%
H	L	L	Torque : 50%
H	L	H	Torque : 40%
H	H	L	Torque : 25%
H	H	H	Torque : 10%

8.6. RS function

ACDS mode or external RS resistance mode can be selected. If accuracy is important where output current is low, it is recommended to use the external RS resistance mode.

Table 8.7 RS function

RS_SEL	Function
L	ACDS (RS resistance less) mode
H	External RS resistance mode

Note: Create a board pattern according to the RS function.

In ACDS mode, connect the RS pin to GND. In external RS resistance mode, connect a resistor according to the set current.

8.7. Gain function

Vref (gain) value can be selected from 1/5 or 1/10. It is recommended that GAIN_SEL = H be set when the output current is set to a maximum of 1A or less.

Table 8.8 Gain function

GAIN_SEL	Function
L	Vref(gain) = 1/5
H	Vref(gain) = 1/10

8.7.1. External RS resistance mode

The peak output current value (set current value) can be determined by setting the sense resistor (RS) for sensing current and the reference voltage (Vref).

$$I_{out}(\max) = Vref(\text{gain}) \times \frac{Vref(V)}{RS(\Omega)}$$

When Vref = 3.0 (V), Torque = 100%, RS = 0.22 Ω , and Vref(gain) = $\frac{1}{5}$ (typ.) (When GAIN_SEL pin = L),

motor constant current (Setting current value) will be calculated by the following expressions.

$$I_{out}(\max) = \frac{1}{5} \times \frac{3(V)}{0.22(\Omega)} = 2.73 A$$

8.7.2. RS Resistor Less Mode (ACDS)

The $I_{out}(\max)$ will be calculated by the following expressions.

When Vref(gain) = $\frac{1}{5}$ (typ.) (GAIN_SEL = L)
 $I_{out}(\max) = 1.56 \times Vref(V)$

When Vref(gain) = $\frac{1}{10}$ (typ.) (GAIN_SEL = H)
 $I_{out}(\max) = 0.78 \times Vref(V)$

8.8. Selectable Mixed Decay function

The Selectable Mixed Decay can adjust the current regeneration amount during the period of current regeneration (Decay) using pins.

Though the Mixed Decay is determined by controlling 2 different types of decay (Fast Decay and Slow Decay), this function enables the user to select the ratio of the Mixed Decay using MDT0 and MDT1 pin. (2bit, 4 function)

Table 8.9 Selectable Mixed Decay function

MDT1	MDT0	Function
L	L	Fast Decay: 37.5% (Fast Decay = $OSCM \times 6$)
L	H	Fast Decay: 50% (Fast Decay = $OSCM \times 8$)
H	L	Fast Decay only
H	H	ADMD

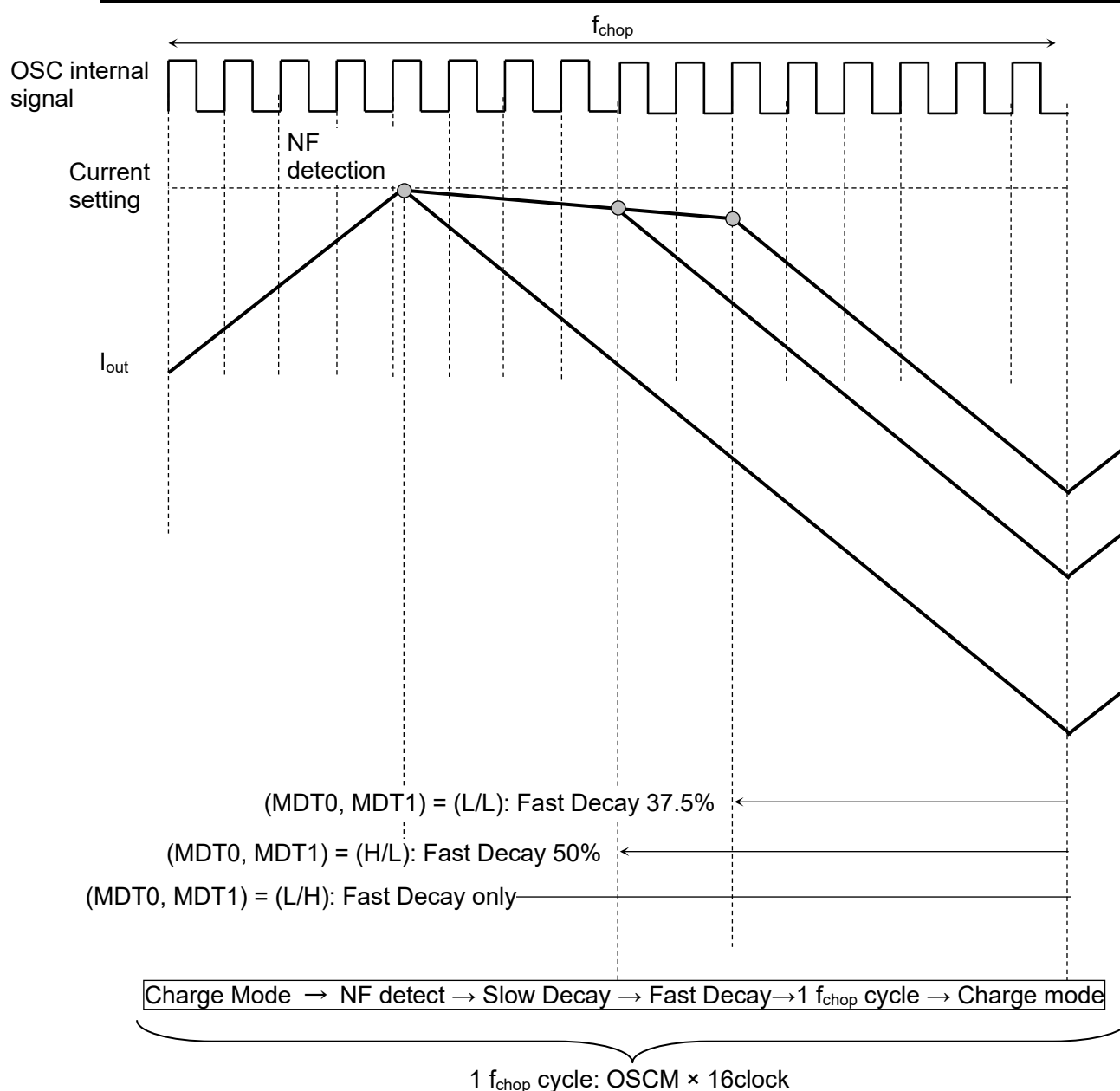


Figure 8.1 Selectable Mixed Decay function

Note: Timing charts may be simplified for explanatory purpose.

8.9. MO (Monitor Output: electrical angle output) function

MO pin outputs an internal initial electrical angle as a signal. Since MO pin is an open drain type pin, please pull up this pin to the power supply such as VCC to enable this function. (The pull-up resistor value should be set between 10 kΩ and 100 kΩ.)

MO pin outputs high level with the pulled-up state because it is in high impedance (Hi-Z) state during the normal operation. When the internal electrical angle corresponds to the initial angle, the pin level becomes low (internal open-drain MOSFET turns on) as shown below.

In case MO pin is not used, leave the pin open state or connect it to GND.

Table 8.10 MO function

MO	Function
High (Hi-Z)	Electrical angle is not at the initial position
Low	Electrical angle is at the initial position

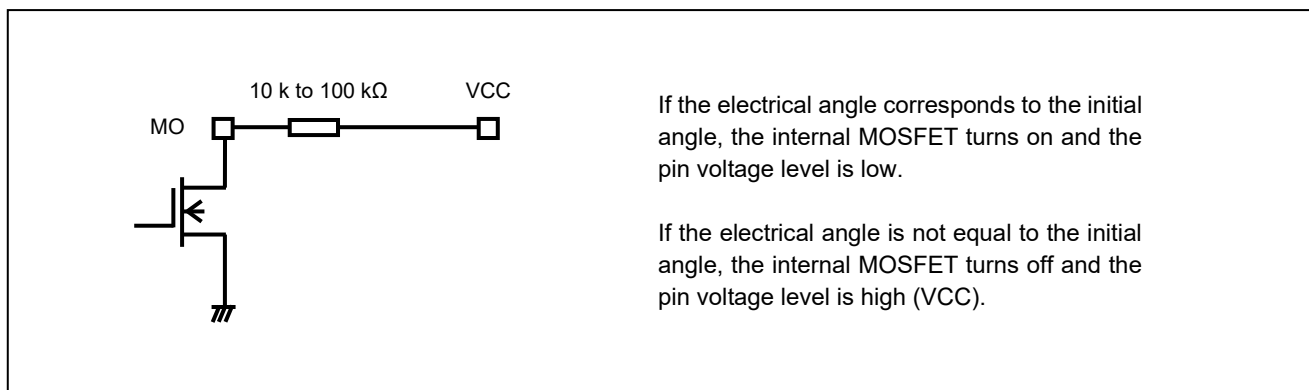


Figure 8.2 MO function Equivalent Circuit

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

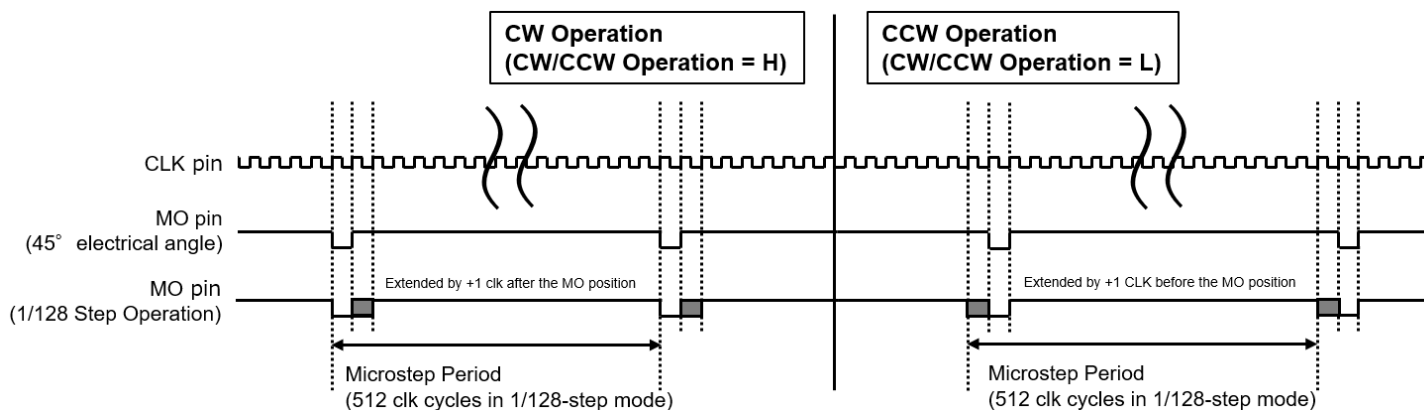


Figure 8.3 MO Pulse Width During CW/CCW Operation

Note: Only in 1/128-step mode, the MO output pulse is extended by one CLK cycle from its original position. As a result, the MO pulse width becomes equivalent to two CLK cycles. In CW operation, the pulse is extended after the original MO position, while in CCW operation, it is extended before the original MO position.

8.9.1. Step resolution setting**Table 8.11 DMODE function**

DMODE0	DMODE1	DMODE2	Function
Low	Low	Low	Full step resolution
Low	Low	High	Half step resolution
Low	High	Low	Quarter step resolution
Low	High	High	1/8 step resolution
High	Low	Low	1/16 step resolution
High	Low	High	1/32 step resolution
High	High	Low	1/64 step resolution
High	High	High	1/128 step resolution

Note: After the standby mode is released, do not input a motor driving signal until the internal circuit becomes stable. (Indication time is 1 ms after the release of the standby mode.)

8.10. AGC (Active Gain Control)

AGC is an abbreviation for Active Gain Control that is our original driving technology. When required motor torque is lower than the configured constant current value, the motor can drive efficiently by decreasing driving current. When higher torque is required, motor stall can be prevented by increasing the constant current value.

8.10.1. AGC functions

AGC pin switch ON/OFF of the Active Gain Control (AGC).

When AGC pin is set to high level, AGC turns on. The motor current is decreased according to the load torque. Upper current limit is determined by VREF.

When AGC pin is set to low level, AGC is turned off. The IC can be used as a constant current driver because it operates with the current, which is set by VREF.

The difference between the configurations of (AGC0, AGC1) = (Low, Don't Care) and (AGC0, AGC1) = (High, Low) is waveforms in full step resolution.

AGC monitors the state of each output pin where the current value continues to be zero, and use this monitoring result for internal signal detection. However, in full step resolution drive, continuous period of zero-level current does not exist in principle. Therefore, the IC generates the judging period by controlling a certain period of zero-level current. This period is automatically generated by the IC, so users do not need to control the period externally.

Table 8.12 AGC functions

AGC	Function
L	AGC: OFF
H	AGC: ON

Note: Built-in digital filter of 0.625 μ s ($\pm 20\%$) is adopted to AGC pin.

8.10.2. CLIM (AGC bottom current limit) function

AGC judges the required torque value and decreases the current value from the constant current, which is set by VREF.

In order to avoid stalls including motor-system stalls, this constant current value should have enough margins.

Since actual required current value for motor driving is generally lower than this set current value, the motor driving current is reduced to the minimum required value (torque value) when AGC is enabled. However, in the case that the load torque is very small, the set current itself becomes very small. And when the required torque becomes high due to the load fluctuates, its current difference may be very big. In this case, following problems generate; it takes longer time to increase the current to the required level, and delay of torque following (depending on motor characteristics) occurs stalling. As a counter measure for above problems, CLIM (Current limit) function prevents the current value from falling too much compared to the set constant current value.

CLIM0 and CLIM1 pins can set the lower current limit in 8 levels. CLIM0 is a 2 stated logic input, and CLIM1 is a 4 stated logic input.

Usually, it is effective to start the evaluation from the ' $I_{out} \times 80\%$ ' condition and lower the current limit to determine the margin limit that allows the system operation. This evaluation can be performed by using CLIM0 and CLIM1 setting combinations.

Even when operating the IC with ' $I_{out} \times 80\%$ ' condition, the power consumption can be saved greatly because it is proportional to the square of I_{out} .

Built-in digital filter of $0.625 \mu s$ ($\pm 20\%$) is adopted to CLIM0 and CLIM1 pins.

This function is disabled when AGC is not used.

Table 8.13 CLIM function

CLIM0	CLIM1	Function
High	Connected to VCC	AGC bottom current limit: $I_{out} \times 80\%$
	Pulled up to VCC with 100 k Ω -resistor	AGC bottom current limit: $I_{out} \times 75\%$
	Pulled down to GND with 100 k Ω -resistor	AGC bottom current limit: $I_{out} \times 70\%$
	Connected to GND	AGC bottom current limit: $I_{out} \times 65\%$
Low	Connected to VCC	AGC bottom current limit: $I_{out} \times 60\%$
	Pulled up to VCC with 100 k Ω -resistor	AGC bottom current limit: $I_{out} \times 55\%$
	Pulled down to GND with 100 k Ω -resistor	AGC bottom current limit: $I_{out} \times 50\%$
	Connected to GND	AGC bottom current limit: $I_{out} \times 45\%$

8.10.3. BOOST (current boost) function

BOOST pin sets the current boost level (i.e., return to the initial constant current setting value) when the load torque increases. BOOST pin is a 4 stated logic input pin, setting the compensation value in accordance with the existence of the 100 k Ω -resistor.

In the following table, Mode 1 has the fastest current recovery, and Mode 4 has the slowest one. The "step" of the function in the table means the number of divisions of the current change, indicating that the smaller this value is, the faster the current boosts (i.e., recovers).

Determination of the mode depends on the load torque change of the used system. For example, in using the system with rapid torque fluctuations, Mode 1 is suitable. In using the system with slow torque fluctuations, Mode 3 or Mode 4 can be adopted. In general, it is recommended to evaluate the operation by using Mode 1 as the standard and shift to Mode 2 and Mode 3 to verify whether the torque-following is possible or not.

Table 8.14 BOOST function

Mode	BOOST	Function	Recovery speed
1	Connected to VCC	Takes 5 steps in maximum to reach 100 % current (design value)	Fast
2	Pulled up to VCC with 100 k Ω -resistor	Takes 7 steps in maximum to reach 100 % current (design value)	Slightly fast
3	Pulled down to GND with 100 k Ω -resistor	Takes 9 steps in maximum to reach 100 % current (design value)	Slightly slow
4	Connected to GND	Takes 11 steps in maximum to reach 100 % current (design value)	Slow

Note: Built-in digital filter of 0.625 μ s ($\pm$ 20%) is adopted to BOOST pin.

8.10.4. FLIM (AGC frequency limit) function

FLIM pin sets the bottom frequency (frequency limit) for AGC to be active. Since AGC uses an induced voltage in operating, some motors have unstable AGC operation when the motor rotation is very slow. Also, the motor's own resonance frequency influences on the AGC operation. Thereby, the lower frequency limit for AGC activation is necessary to avoid above and can be set by FLIM pin.

FLIM pin is a 4 stated logic input. Built-in digital filter of 0.625 μ s ($\pm 20\%$) is adopted to FLIM pin.

Table 8.15 FLIM function

Mode	FLIM	Function
1	Connected to VCC	Frequency limit: ON, AGC is invalid when f_{CLK} is less than 675 Hz
2	Pulled up to VCC with 100 k Ω -resistor	Frequency limit: ON, AGC is invalid when f_{CLK} is less than 450 Hz
3	Pulled down to GND with 100 k Ω -resistor	Frequency limit: ON, AGC is invalid when f_{CLK} is less than 225 Hz
4	Connected to GND	Frequency limit: OFF

When connected to GND, the operation is not limited by the limiter circuit of the IC. The induced voltage of the motor, which is used in AGC, is generated by the rotation of the motor. Therefore, the frequency threshold for AGC activation is unique to the motor.

The frequency threshold for AGC activation shown in the above table is the case of full step resolution. When using other step resolutions (micro step resolution), the thresholds are different. In micro stepping, the thresholds are roughly equivalent to conversion of the full step resolution. Please refer to the table below.

Table 8.16 Frequency limit threshold

FLIM	Full step resolution	Half step resolution	Quarter step resolution	1/8 step resolution	1/16 step resolution	1/32 step resolution	1/64 step resolution	1/128 step resolution
Connected to VCC	675 Hz	1.35 kHz	2.7 kHz	5.4 kHz	10.8 kHz	21.6 kHz	43.2 kHz	86.4 kHz
Pulled up to VCC with 100 k Ω -resistor	450 Hz	900 Hz	1.8 kHz	3.6 kHz	7.2 kHz	14.4 kHz	28.8 kHz	57.6 kHz
Pulled down to GND with 100 k Ω -resistor	225 Hz	450 Hz	900 Hz	1.8 kHz	3.6 kHz	7.2 kHz	14.4 kHz	28.8 kHz
Connected to GND	Frequency limit: OFF							

8.10.5. LTH (AGC detection threshold) function

LTH pin sets AGC detection threshold.

Torque detection sensitivity can be set by changing the connected resistor value. When lowering the resistor value, the detection sensitivity increases but the constant current value may become unstable for some motors. Therefore, caution should be exercised.

The resistor can be lowered to about 10 k Ω . Connect a 100 k Ω -resistor in the normal usage.

Table 8.17 LTH function

LTH	Function
Pulled down with 100 k Ω -resistor	Standard configuration for AGC detection threshold
Pulled down with 10 k Ω -resistor	Upper limit configuration for AGC detection threshold

8.11. LO1, LO2 (Error Output: Error detect flag output) function

LO1 pin and LO2 pin output signals when the error state of the IC or its environment is detected. Both pins are open drain type like MO pin, therefore to use the function properly, they should be pulled up to the power supply (3.3 V/5 V) such as VCC.

Use the pull-up resistor in the range of 10 kΩ to 100 kΩ.

During normal operation, they are high-impedance (Internal open-drain MOSFETs turn off and pin voltage is VCC). Once the error detect function (thermal shutdown (TSD), over current protection (ISD), or motor load open (OPD)) operates, pin voltage becomes low level (Internal open-drain MOSFETs turn ON).

When the error detection is released by reasserting the VM power supply or using the standby mode, LO1 pin and LO2 pin show “normal operation” status again. If this function is not used, leave the pins open or connect them to GND.

Table 8.18 LO1, LO2 function

LO1	LO2	Function
High (Hi-Z)	High (Hi-Z)	Normal state (Normal operation)
High (Hi-Z)	Low	Detects motor load open (OPD)
Low	High (Hi-Z)	Detects over current (ISD)
Low	Low	Detects over thermal (TSD)

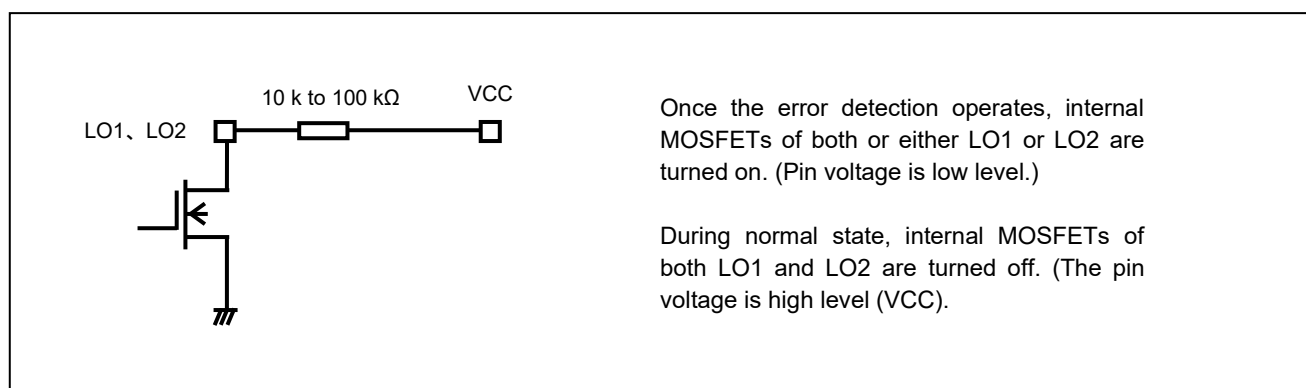


Figure 8.4 LO function Equivalent Circuit

Note: The equivalent circuit diagrams may be simplified or omitted for explanatory purposes.

9. IC Function Explanation 2 (Serial mode, IF_SEL pin = H)

When IF_SEL pin = H, the interface is serial input. It performs setting and motor control in the following 32 bit format.

When BANK_EN pin is L, initial setting is performed. When the BANK_EN pin is H, the motor is controlled.

For the motor control, each current value is set in the serial setting, and the output is updated to the set current value at the timing of the LATCH signal.

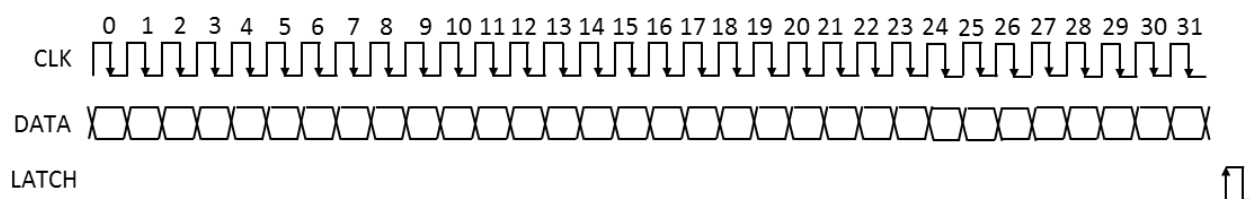


Figure 9.1 LATCH signal timing

Table 9.1 BANK_EN = L: Initial setting

D0	D1	D2	D3	D4	D5	D6	D7	D8	D9	D10	D11	D12	D13	D14	D15
0	0	AGC	CLIM0	CLIM1	CLIM2	FLIM0	FLIM1	BST0	BST1	0	0	RSSEL	GAINSEL	0	0

D16	D17	D18	D19	D20	D21	D22	D23	D24	D25	D26	D27	D28	D29	D30	D31
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Note: The data which has a same name as a pin name in CLK mode performs as same as the pin in CLK mode.

Table 9.2 BANK_EN = H: Motor controlling

D0	D1	D2	D3	D4	D5	D6	D7	D8	D9	D10	D11	D12	D13	D14	D15
0	0	TORQE0	TORQE1	TORQE2	0	MDT_A0	MDT_A1	PHA	CA0	CA1	CA2	CA3	CA4	CA5	CA6

D16	D17	D18	D19	D20	D21	D22	D23	D24	D25	D26	D27	D28	D29	D30	D31
CA7	CA8	CA9	MDT_B0	MDT_B1	PHB	CB0	CB1	CB2	CB3	CB4	CB5	CB6	CB7	CB8	CB9

Note: Every issuing a command, the current setting transfers by one step.

9.1. Registers When BANK_EN pin = H

The registers when BANK_EN pin = H are shown below.

9.1.1. PHx (x = A and B)

The polarity of the output current can be selected by PHx register for each channels.

Table 9.3 PHx (x = A and B)

PHx register setting	Function
L	Setting the direction of the output current to minus
H	Setting the direction of the output current to plus

9.1.2. Cx0 to Cx9 (x = A or B)

The output of each channel's DAC for current limitation can be set by Cx0 to Cx9.

The relation between Setting DAC and the output current (I_{out}) are shown below.

A) External Sense Resistor mode

$$I_{out}(\max) = V_{ref}(\text{gain}) \times \frac{V_{ref}(V)}{RS(\Omega)} \times \frac{Cx[9:0]}{1023} \times \text{Setting torque by the torque function (\%)} \\ (x = A \text{ or } B)$$

B) RS Resistor Less Mode (ACDS)

$$V_{ref}(\text{gain}) = \frac{1}{5} \text{ (typ.) (when GAIN_SEL pin = L)}$$

$$I_{out}(\max) = 1.56 \times V_{ref}(V) \times \frac{Cx[9:0]}{1023} \times \text{Setting torque by the torque function (\%)}$$

$$V_{ref}(\text{gain}) = \frac{1}{10} \text{ (typ.) (when GAIN_SEL pin = H)}$$

$$I_{out}(\max) = 0.78 \times V_{ref}(V) \times \frac{Cx[9:0]}{1023} \times \text{Setting torque by the torque function (\%)} \\ (x = A \text{ or } B)$$

9.2. Serial setting example when driving a motor

Serial setting example for motor operation is shown below.

1. Set the BANK_EN pin L. Initial setting for AGC, etc. is performed under this condition.
2. Then, set the BANK_EN pin H and configure the motor control to turn on the output transistors.
3. Transmit the 1st to 4th commands repeatedly by keeping the BANK_EN pin level H. The motor operates with full step resolution.

Table 9.4 Serial setting example when driving a motor

1st command

D0	D1	D2	D3	D4	D5	D6	D7	D8	D9	D10	D11	D12	D13	D14	D15
0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1

D16	D17	D18	D19	D20	D21	D22	D23	D24	D25	D26	D27	D28	D29	D30	D31
1	1	1	0	0	1	1	1	1	1	1	1	1	1	1	1

2nd command

D0	D1	D2	D3	D4	D5	D6	D7	D8	D9	D10	D11	D12	D13	D14	D15
0	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1

D16	D17	D18	D19	D20	D21	D22	D23	D24	D25	D26	D27	D28	D29	D30	D31
1	1	1	0	0	1	1	1	1	1	1	1	1	1	1	1

3rd command

D0	D1	D2	D3	D4	D5	D6	D7	D8	D9	D10	D11	D12	D13	D14	D15
0	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1

D16	D17	D18	D19	D20	D21	D22	D23	D24	D25	D26	D27	D28	D29	D30	D31
1	1	1	0	0	0	1	1	1	1	1	1	1	1	1	1

4th command

D0	D1	D2	D3	D4	D5	D6	D7	D8	D9	D10	D11	D12	D13	D14	D15
0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1

D16	D17	D18	D19	D20	D21	D22	D23	D24	D25	D26	D27	D28	D29	D30	D31
1	1	1	0	0	0	1	1	1	1	1	1	1	1	1	1

10. Application Circuit Example

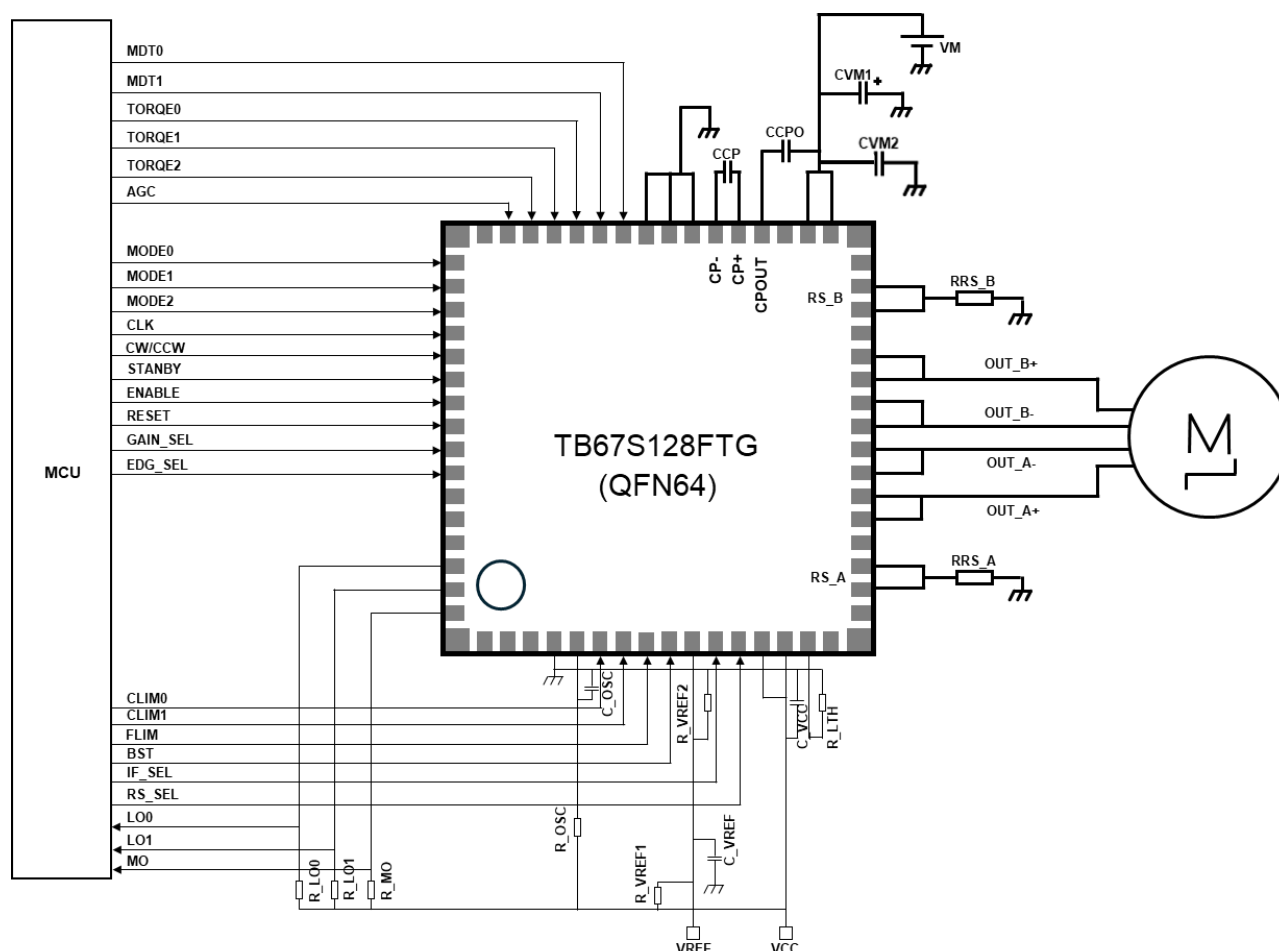


Figure 10.1 Application circuit example

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

Note: Above application circuit example is provided for reference purposes only, and is not guaranteed for mass production.

Table 10.1 Component constants (reference example)

Part Reference	Component	Value
CVM1	Electrolytic Capacitor	100 μ F (CVM1 $\geq$ 10 μ F)
CVM2	Ceramic Capacitor	(0.1 μ F)
CCP	Ceramic Capacitor	0.022 μ F
CCPO	Ceramic Capacitor	0.22 μ F
C_VCC	Ceramic Capacitor	0.1 μ F
R_osc	Resistor	5.1 k Ω (1.8 k Ω to 8.2 k Ω)
C_osc	Ceramic Capacitor	270 pF
R_VREF1, R_VREF2	Resistor	Arbitrary (10 k Ω $\leq$ R_VREF1 + R_VREF2 $\leq$ 50 k Ω)
C_VREF	Ceramic Capacitor	(0.1 μ F)
R_MO	Resistor	10 k Ω (10 k Ω to 100 k Ω)
R_LO0, R_LO1	Resistor	10 k Ω (10 k Ω to 100 k Ω)
R_LTH	Resistor	100 k Ω

Note: The constants in the table are reference examples, and parts outside the recommended range may be used depending on the operating conditions.

11. External Component Description

11.1. Capacitors for power supply pins

To stabilize the power supply voltage of the IC and reduce the noise, connect an appropriate capacitor to each pin.

It is effective and recommended to connect capacitors as close to the IC as possible.

However, be sure to consider the influence of the IC's heat generation.

Also, connecting the small-capacity ceramic capacitor (bypass capacitor) near the IC is effective to reduce power supply fluctuations and noise especially at the high frequency range. Generally, this can be adopted to dealing of CMOS LOGIC IC board.

Table 11.1 Recommended capacitor values for power supply pins

Item	Components	Typ.	Recommended range
Between VM pin and GND	Decoupling capacitor (CVM1)	100 μ F	22 to 100 μ F
Between VCC pin and GND	Bypass capacitor (CVCC)	0.1 μ F	0.01 to 1 μ F
Between VREF pin and GND	Bypass capacitor (CVF)	0.1 μ F	0.01 to 1 μ F

Connect the capacitor in necessary between VREF pin and GND in accordance with the usage environment.

It is possible to remove the capacitor and use other than the recommended one depending on the motor load condition and the designed pattern of the board. For example, in case of using two or more motors (the same number of driver ICs as the motors are used), the capacitor between VM pin and GND can be removed. Comprehensively, ensure the capacitor not to increase the ripple of the power supply.

11.2. Internal oscillation frequency

OSCM oscillation frequency can be adjusted by changing the constant numbers of external capacitor and resistor. In adjusting, it is recommended to change the resistor, while fixing the capacitor to 270 pF. Chopping frequency can be also changed by adjusting OSCM frequency. Please refer to below table in adjusting the chopping frequency.

Product name: TB67S279FTG, TB67S289FTG, and TB67S249FTG
 Board: Our company's evaluation board
 Power supply voltage: 24 V
 C_{osc} : 270 pF

Table 11.2 Relation of external resistor (R_{osc}) and internal oscillation frequency (f_{oscM}), chopping frequency (f_{chop}) (for reference only)

R_{osc}	f_{oscM}	f_{chop}
k Ω	MHz	kHz
1.5	2.63	164.38
1.8	2.37	148.13
2.0	2.23	139.38
2.2	2.08	130.00
2.7	1.80	112.50
3.0	1.67	104.38
3.3	1.55	96.88
3.9	1.34	83.75
4.7	1.15	71.88
5.1	1.07	66.88
5.6	0.98	61.25
6.8	0.83	51.88
8.2	0.70	43.75
10.0	0.58	36.25

Setting chopping frequency range 40 k Ω to 150 kHz

←Typical value

Note: Values in above table are reference data. They are not guaranteed.

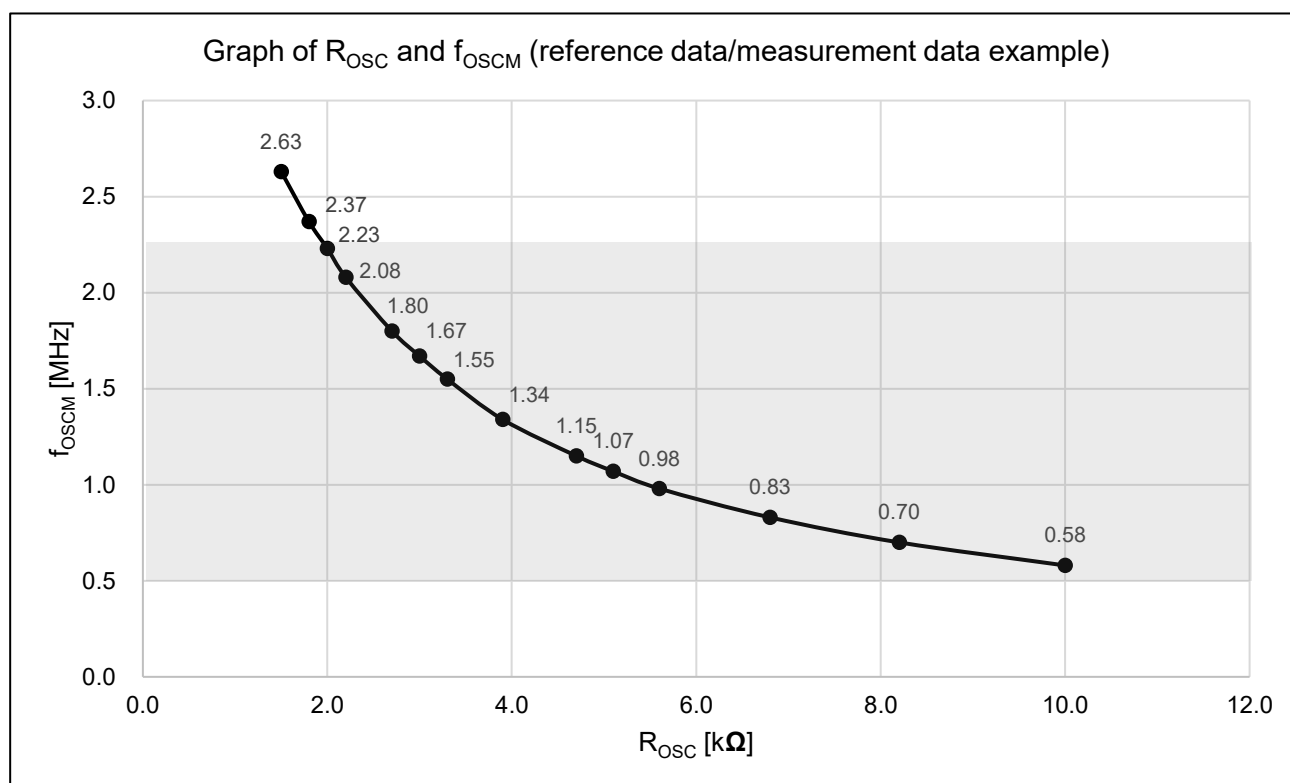


Figure 11.1 Graph of R_{OSC} and f_{OSC} (reference data/measurement data example)

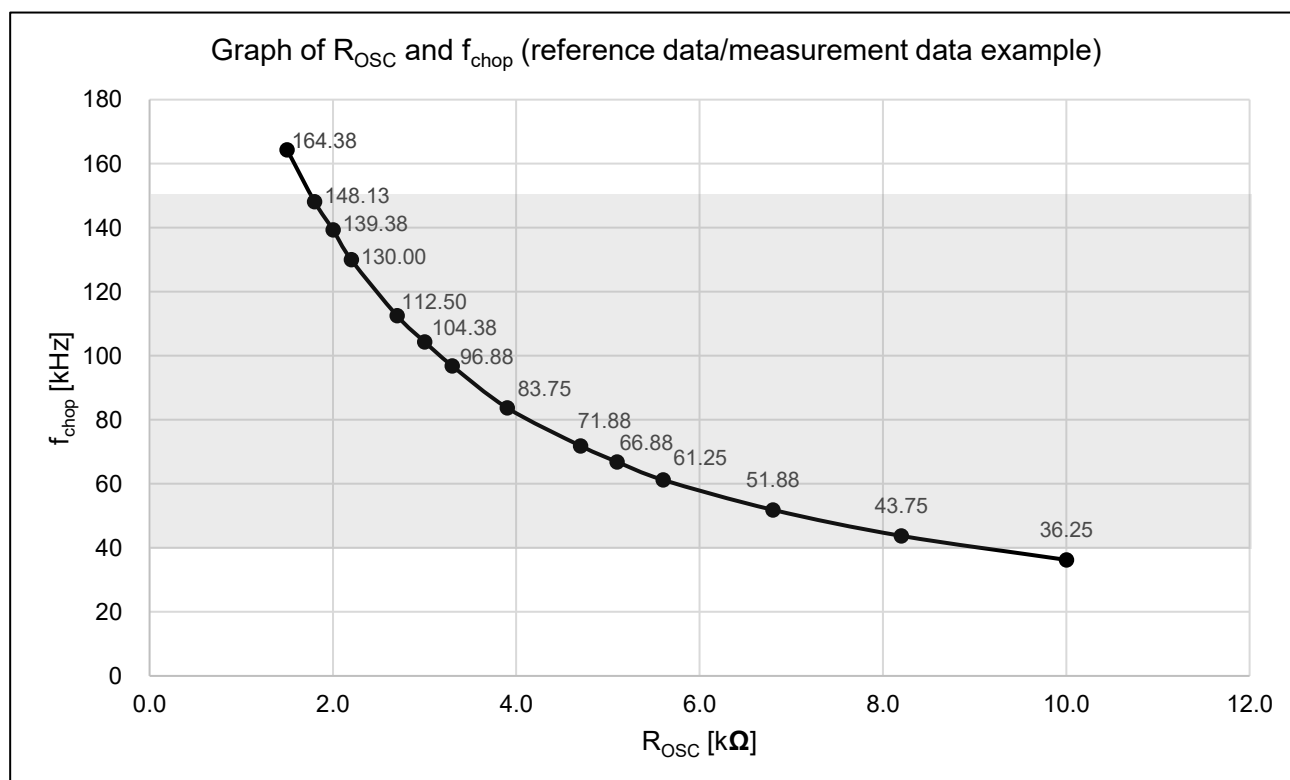


Figure 11.2 Graph of R_{OSC} and f_{chop} (reference data/measurement data example)

Note: Values in the graphs are reference data. They are not guaranteed.

11.3. Resistor for monitor pin

The IC has MO, LO1, and LO2 open-drain type pins to output some of the internal status of the IC. When internal open-drain MOSFETs turn off, these pins show high impedance. In using this function, they should be pulled up to the power supply (3.3 V/5 V) such as VCC. If this function is not used, leave the pins open or connect them to GND.

Table 11.3 Recommended resistor values for monitor pins

Item	Components	Typ.	Recommended range
Between (MO/LO1/LO2 pin) and power supply	Chip/Lead resistor	10 k Ω	10 k Ω to 100 k Ω

11.4. Layout pattern for power supply and GND

Since large current is assumed to flow in the pattern connected to VM, OUT, and GND pins in particular, design the appropriate board in order to avoid the influence of wiring impedance. It is very important for surface mounting packages such as QFN type to radiate the heat from the IC back side (the corner pad and the heat sink) to the GND (i.e., heat sink mounting area). So, design the pattern by considering the heat design.

11.5. Fuse

Use an appropriate power supply fuse for the power supply line to ensure that a large current does not continuously flow in the 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 to smoke or ignition. To minimize the effects of the flow of a large current in the case of breakdown, appropriate settings, such as fuse capacity, fusing time and insertion circuit location, are required.

This IC incorporates over current detection circuit (ISD) that turns off the output of the IC when over current is detected in the IC. However, it does not necessarily protect ICs under all circumstances. If the over current detection 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.

To avoid above IC destruction and malfunctions caused by noise, the over current detection circuit has a dead band time. So, it is concerned that the over current detection circuit may not operate depending on the output load conditions because of the dead band time. Therefore, in order to avoid continuing this over current state, use the fuse for the power supply line.

11.6. Error detection function

This IC incorporates a thermal shutdown circuit (TSD) and an over current protection (ISD), which are unique error detections to power ICs, in addition to a general UVLO function. Each function is described below.

11.6.1. Thermal shutdown circuit (TSD)

When the junction temperature of the IC reaches a preset specified value, the internal detection circuit operates to turn off the output block. The dead band time is provided to avoid a false detection, which is caused by switching and so on. While TSD is activated, the operation of the IC is in the standby mode continuously. To release this function, apply the power supply again or configure the standby mode by STANDBY pin. TSD function is activated when the IC is overheated irregularly. Therefore, do not use the TSD function often.

11.6.1.1. Dead band time of thermal shutdown circuit

This IC has a system clock ($f_{\text{osc}} = 6.4 \text{ MHz (typ.)}$) to count up a dead band time for the error detection. Thermal shutdown circuit can avoid a false detection by configuring the dead band time, which is counted by the system clock.

$$t_{\text{TSD}} = 5 \mu\text{s (typ.)}$$

11.6.2. Over current protection (ISD)

When the motor output current exceeds a specified value, over current protection circuit, which is implemented in the output block, operates to turn off the output block. The dead band time is provided to avoid a false detection, which is caused by switching and so on. While ISD is activated, the operation of the IC is in the standby mode continuously. To release this function, apply the power supply again or configure the standby mode by STANDBY pin.

11.6.2.1. Dead band time of over current protection

This IC has a system clock ($f_{\text{osc}} = 6.4 \text{ MHz (typ.)}$) to count up the dead band time for the error detection. Over current protection can avoid a false detection by configuring the dead band time, which is counted by the system clock.

$$t_{\text{ISD}} = 1.25 \mu\text{s (typ.)}$$

12. Power Consumption of the IC

Power of the IC is consumed mainly by the transistor of the output block and by the internal circuit, which includes the logic block.

$P(\text{total})$ = Power consumption of the IC

$P(\text{out})$ = Power consumption of the motor output block (MOSFET)

$P(\text{bias})$ = Power consumption of the internal circuit

$$P(\text{total}) = P(\text{out}) + P(\text{bias})$$

(1) Power consumption of the motor output block

The motor output block consumes the power ($P(\text{out})$) when the motor current flows in the output MOSFET. In case of driving stepping motors, two channels of H-SW (A-ch and B-ch) are controlled in parallel. Therefore, $P(\text{out})$ can be gained from below formula.

$$P(\text{out}) = \text{Number of H-SW (= 2ch)} \times \text{Motor current} \times \text{Motor current} \times \text{On resistance} \\ (\because P = V \times I = R(\text{on}) \times I(\text{out})^2) \quad \dots\dots\dots (1)$$

The power consumption above is gained under the condition that the motor current reaches the configured peak value. Actually, since the IC performs PWM constant current control, the peak current does not flow continuously. Hence, the average motor current is lower than the configured value due to the current ripple (in the constant PWM drive) and the current decay (in switching step resolution). Therefore, the power consumption above is only for reference.

Example) When motor current is 1 A, and the operation mode is full step resolution,

$$P(\text{out}) = 2 (\text{ch}) \times 1.0 (\text{A}) \times 1.0 (\text{A}) \times 0.35 (\Omega) = 0.7 (\text{W})$$

(2) Power consumption of the internal circuit

The power for the internal circuit ($P(\text{bias})$) including the logic block is continuously consumed by applying VM voltage for the motor operation (standby release mode). It is calculated from below formula.

$$P(\text{bias}) = \text{Motor power supply voltage} \times \text{Current consumption} = V_M \times I_M \quad \dots\dots\dots (2)$$

Example) When motor power supply voltage of 24 V is applied,

$$P(\text{bias}) = V_M \times I_{M3}, \text{ then } 24 (\text{V}) \times 0.0104(\text{A}) = 0.2496 (\text{W})$$

From above formula, the rough value of this IC power consumption is as follows;

$$P(\text{total}) = P(\text{out}) + P(\text{bias}) = 0.7 + 0.2496 = 0.9496 (\text{W})$$

The power consumption of the standby mode, which reduces bias current of the internal circuit, can be calculated from the formula (2) by substituting I_{M1} (standby mode) for I_M current consumption.

$$P(\text{bias}) = 24 (\text{V}) \times 0.0032 (\text{A}) = 0.0768(\text{W})$$

13. Power dissipation

Relation equation of the ambient temperature (T_a), the junction temperature (T_j), and the heat resistance ($R_{th(j-a)}$) between the junction temperature and the ambient temperature is as follows;

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

The IC adopts a surface mounting package, QFN64. QFN64 package radiates the heat mainly from the heat sink of the IC back side to the mounting board. So, $R_{th(j-a)}$ depends on the board design pattern, GND area, etc.

Electrode part (corner pad) for disabled pins of QFN package is connected to the heat sink in the IC. Connect this part to the board by soldering because heat can be radiated from the board surface.

Example of thermal calculation: If $R_{th(j-a)}$ is 25 °C/W when the IC is mounted on glass-epoxy 4-layer board, the junction temperature at ambient temperature ($T_a = 25$ °C) can be calculated from below formula. Conditions of the power consumption are as the same as the prior section 'Power Consumption of the IC'.

$$T_j = 25 \text{ (°C)} + 0.964 \text{ (W)} \times 25 \text{ (°C/W)} = 49.1 \text{ °C}$$

Reference) Relation of power dissipation and ambient temperature

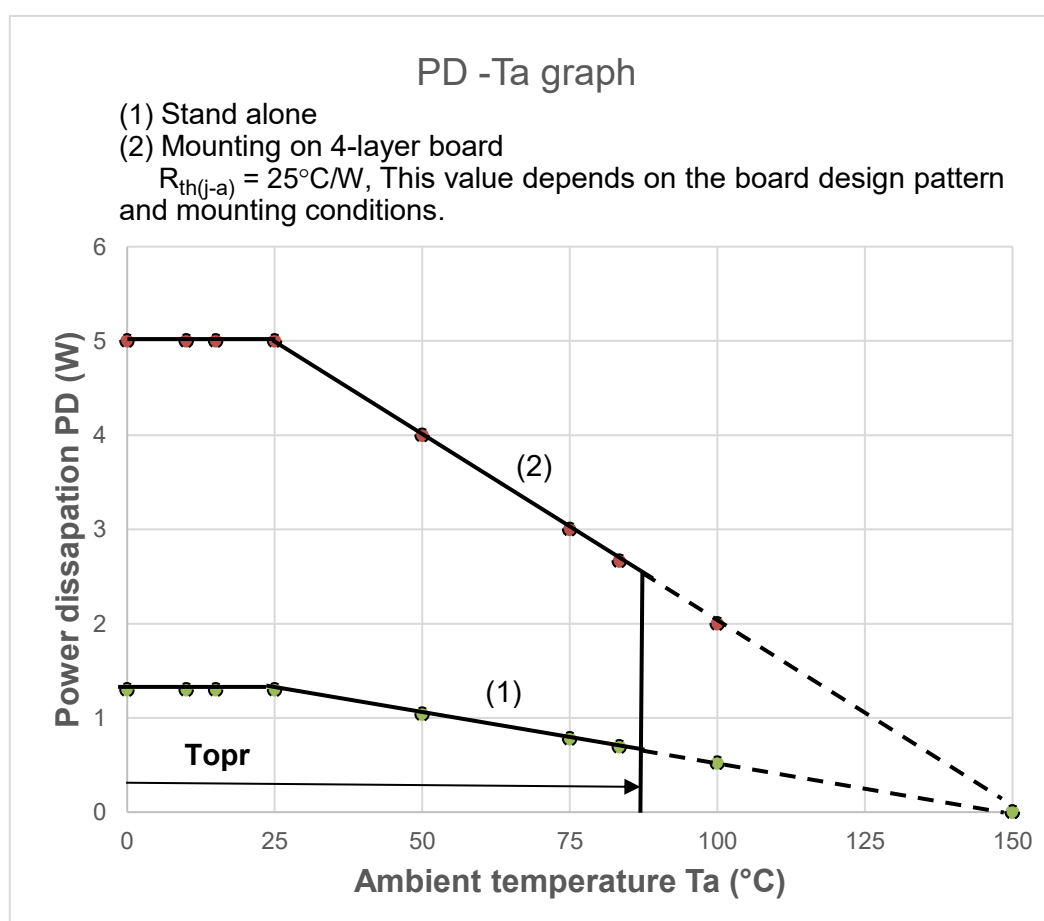


Figure 13.1 Power dissipation

Note: T_a , $R_{th(j-a)}$, and $P(\text{total})$ depend on the environment, in which the board and motor are used. If the ambient temperature is high, the allowable power consumption is reduced accordingly.

14. Foot Pattern Example

QFN64 foot pattern example

(unit: mm)

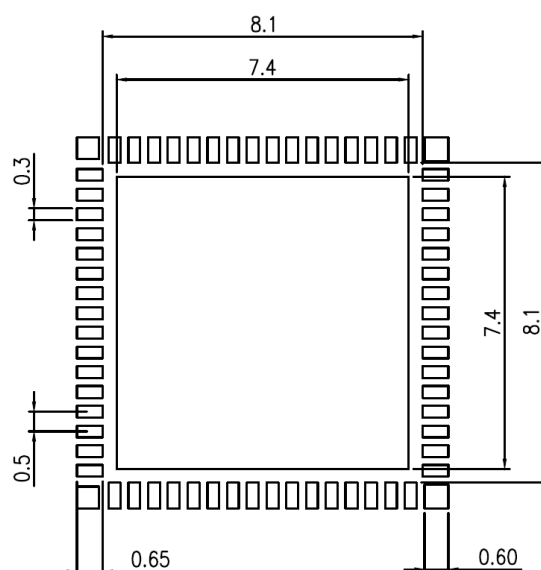


Figure 14.1 QFN64 foot pattern example

Note: The data is for reference only and not guaranteed for mass production. In designing the size of mounting board, determine the foot pattern by considering the solder bridge, the solder connecting strength, the pattern accuracy in making board, and the mounting accuracy of the IC board.

15.2. Main parts

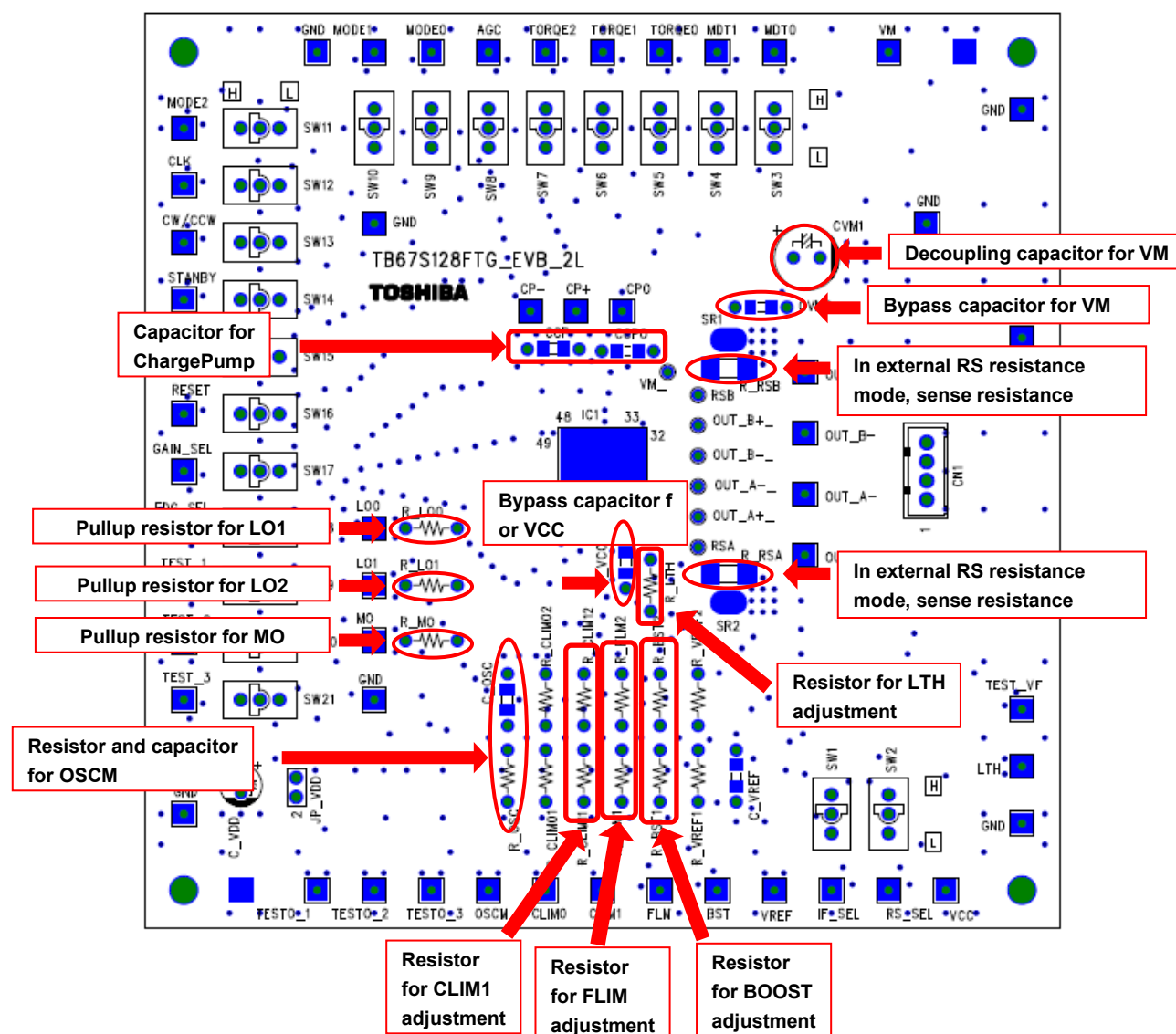


Figure 15.2 Main parts

Connect each external components referring to '10. Application Circuit Example'.

15.3. Options

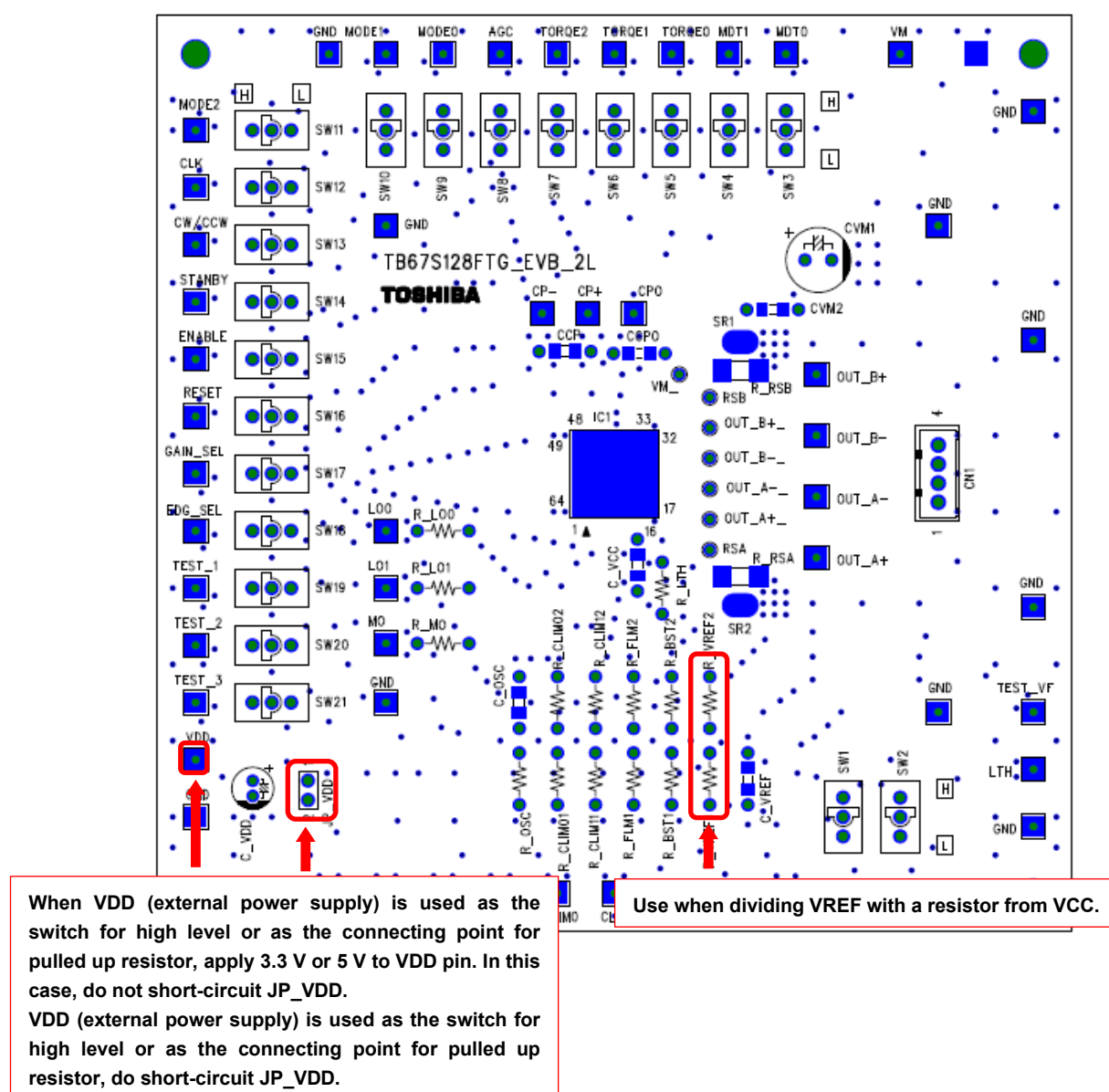


Figure 15.3 Options

Figure 15.4 Board circuit diagram

Notes on Contents**1. Block Diagrams**

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

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

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

Any license to any industrial property rights is not granted by provision of these application circuit examples.

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) Do not insert devices in the wrong orientation or incorrectly.
Make sure that the positive and negative pins 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 in 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.
- (3) Use an appropriate power supply fuse to ensure that a large current does not continuously flow in the 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 to smoke or ignition. To minimize the effects of the flow of a large current in the case of breakdown, appropriate settings, such as fuse capacity, fusing time and insertion circuit location, are required.
- (4) 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.
- (5) Carefully select external components (such as inputs and negative feedback capacitors) and load components (such as speakers), for example, power amp and regulator.
If there is a large amount of leakage current such as from input or negative feedback condenser, the IC output DC voltage will increase. If this output voltage is connected to a speaker with low input withstand voltage, over current or IC failure may cause smoke or ignition. (The over current may cause smoke or ignition from the IC itself.) In particular, please pay attention when using a Bridge Tied Load (BTL) connection type IC that inputs output DC voltage to a speaker directly.

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, exceeding absolute maximum ratings may cause the over current protection circuit to operate improperly or IC breakdown may occur 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, exceeding absolute maximum ratings may cause the thermal shutdown circuit to operate improperly or IC breakdown to occur before operation.

(3) Heat Radiation Design

When using an IC with large current flow such as power amp, regulator or driver, design the device so that heat is appropriately radiated, in order not to exceed the specified junction temperature (T_j) at any time or under any 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, when designing the device, take into consideration the effect of IC heat radiation with peripheral components.

(4) Back-EMF

When a motor rotates in the reverse direction, stops or slows abruptly, current flows back to the motor's power supply owing 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 the absolute maximum ratings. To avoid this problem, take the effect of back-EMF into consideration in system design.

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