

## TC78H660FTG/FNG

### Usage considerations

#### **Summary**

The TC78H660 is a dual H Bridge motor driver IC.

TC78H660FTG: QFN16 package

TC78H660FNG: TSSOP16 package

It can control two DC motors or one stepping motor.

\* Contents in this application note are only for reference to evaluate products. Therefore, they are not guaranteed. As for details, please refer to the data sheet.

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## 1. Power supply voltage

### 1.1. Power supply voltage and operating range

In using the TC78H660, the voltage should be applied to the VM and VREF pins.

The maximum rating of VM supply voltage is 18 V (active). The usage range is 2.5 to 16 V.

The slew rate in inputting a power supply should be used 0.05V/ $\mu$ s or less.

A regulator is embedded for internal logic power supply, and the IC operates with only applying voltage to VM pin.

In using constant current PWM control, the usage range of VREF is 0 to 1.8V.

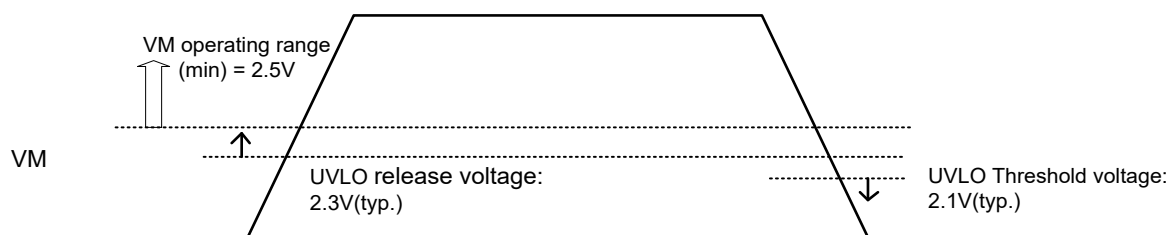


Figure 1.1 VM operation range and UVLO threshold

### 1.2. Power supply sequence

This IC realizes the single power supply drive by the internal regulator. Additionally, the under voltage lockout (UVLO) is embedded to prevent a malfunction at low voltage.

However, under the unstable state of inputting the power supply (VM) and shutdown (transient area), setting the motor operation to OFF state is recommended. After the power supply is in the stable state, the motor should be operated by switching the input signal.

## 2. Output current

Motor usage current should be 2.0A or less. The maximum current of the actual usage is limited depending on the usage conditions (the ambient temperature, the wiring pattern of the board, the radiation path, and the exciting design). Configure the most appropriate current value after calculating the heat and evaluating the board under the operating environment.

## 3. Control input

When the logic input signal is inputted under the condition that the voltage of VM is not supplied, the electromotive force by inputting signal is not generated. However, configure the input signal low level before the power supply.

Input signals of the 1.8 V system can also be acceptable to control the IC because VIN (H) is 1.5 V and VIN (L) is 0.7 V. Pull down resistor of 100 k $\Omega$  (typ.) is incorporated.

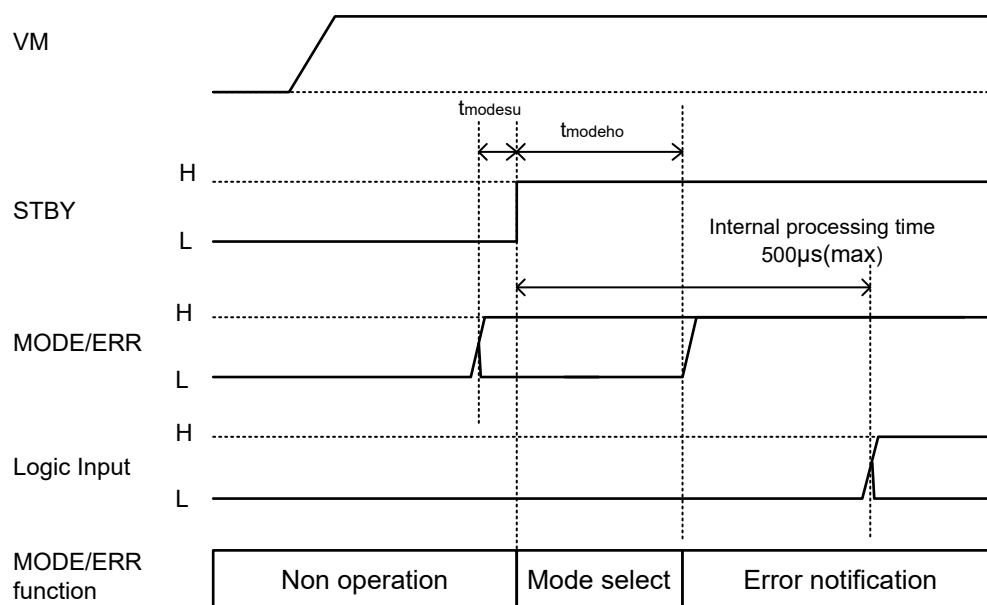
### 3.1. Control Mode Select Function

The TC78H660 can be selected IN input mode or Phase input mode.

The control mode is set up by the input state of the MODE pin after releasing standby mode.

**Table 3.1 Control mode select function**

MODE pin input	Function
L	IN input mode
H	Phase input mode



**Figure 3.1 Mode selection**

**Table 3.2 Mode select AC characteristics**

Characteristics	Symbol	Test condition	Min	Typ.	Max	Unit
Mode select Setup time	$t_{modesu}$	To STBY edge	1	—	—	µs
Mode select Data hold time	$t_{modeho}$	From STBY edge	100	—	—	µs

Note: When using Phase input mode (MODE=H) or Error function, please set the MODE/ERR pin to High level via a pull-up resistor.

### 3.2. Input / Output function

#### 3.2.1. IN Input Mode (MODE=L)

Table 3.3 IN Input Mode

STBY	IN1A	IN2A	IN1B	IN2B	OUT_A+	OUT_A-	OUT_B+	OUT_B-	Mode
H	H	H	H	H	L	L	L	L	Short brake
H	H	L	—	—	H	L	—	—	Forward
H	L	H	—	—	L	H	—	—	Reverse
H	—	—	H	L	—	—	H	L	Forward
H	—	—	L	H	—	—	L	H	Reverse
H	L	L	L	L	Hi-Z	Hi-Z	Hi-Z	Hi-Z	Stop
L	—	—	—	—	Hi-Z	Hi-Z	Hi-Z	Hi-Z	Standby

Note: Current path; Forward rotation (OUT\_X+ to OUT\_X-), Reverse rotation (OUT\_X- to OUT\_X+). X = A or B.

Note: Dual H-Bridge can be programmed and operate simultaneously.

Note: — are Don't Care.

#### 3.2.2. Phase Input Mode (MODE=H)

Table 3.4 Phase Input Mode

STBY	Phase A	Enable A	Phase B	Enable B	OUT_A+	OUT_A-	OUT_B+	OUT_B-	Mode
H	H	H	—	—	H	L	—	—	Forward
H	L	H	—	—	L	H	—	—	Reverse
H	—	—	H	H	—	—	H	L	Forward
H	—	—	L	H	—	—	L	H	Reverse
H	—	L	—	L	Hi-Z	Hi-Z	Hi-Z	Hi-Z	Stop
L	—	—	—	—	Hi-Z	Hi-Z	Hi-Z	Hi-Z	Standby

Note: Current path; Forward rotation (OUT\_X+ to OUT\_X-), Reverse rotation (OUT\_X- to OUT\_X+). X = A or B.

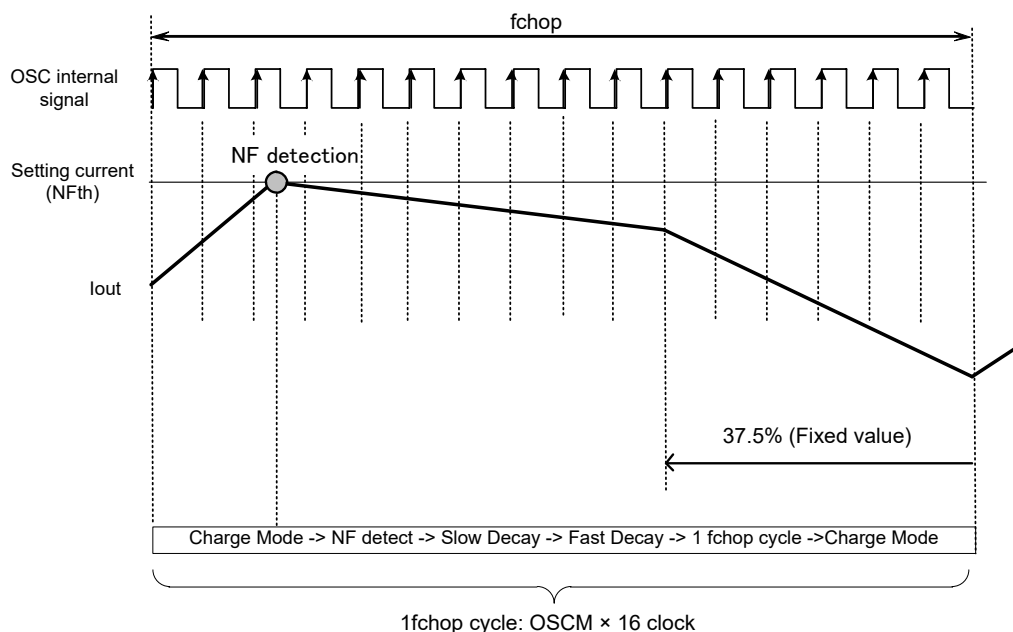
Note: Dual H-Bridge can be programmed and operate simultaneously.

Note: — are Don't Care.

## 4. Constant Current Control

The TC78H660 has the constant current control of Mixed Decay Mode.

In the case of constant current control, the rate of Mixed Decay Mode which determines the current ripple is fixed to 37.5%. Peak current is set by the voltage value of VREF pin.



**Figure 4.1 Waveform in Mixed Decay Mode**

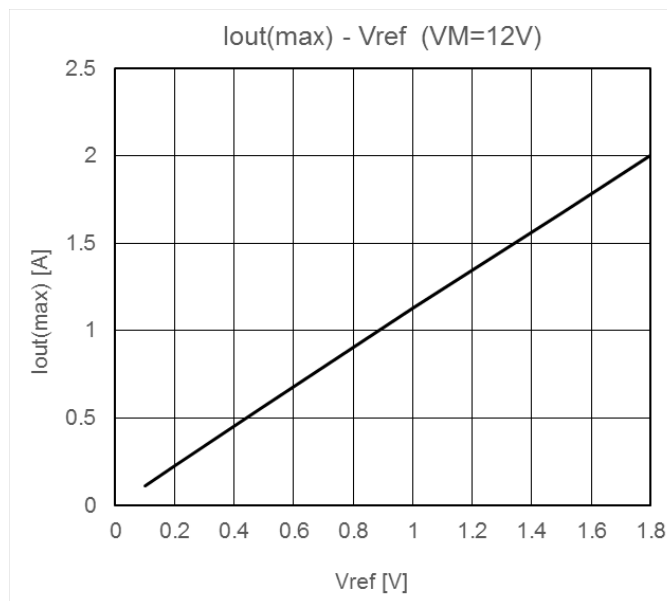
Note: The blanking time is also set to prevent an incorrect operation in the NF detection (the motor current reaches the set current value (NFth)).

Note: Timing charts may be simplified for explanatory purpose.

### 4.1. Calculation of the Predefined Output Current

TC78H660 can configure the constant current value only by the input voltage to the VREF pin. External current detection resistor is not required. The Setting current value:  $I_{out(max)}$  can be set, as follows:

$$I_{out(max)} = 1.1 \times V_{ref} (V)$$



**Figure 4.2 Setting current value vs VREF input voltage**

Note: Characteristics shown above are reference values and not guaranteed.

## 4.2. OSCM Oscillation Frequency and Chopping Frequency

The OSCM oscillation frequency ( $f_{\text{OSCM}}$ ) and chopping frequency ( $f_{\text{chop}}$ ) can be adjusted by the external resistor ( $R_{\text{OSC}}$ ) connecting to OSCM pin.

**Table 4.1 Relation of  $R_{\text{OSC}}$  and Internal oscillation frequency, chopping frequency**

$R_{\text{OSC}}[\text{k}\Omega]$	$f_{\text{OSCM}} [\text{kHz}](\text{typ.})$	$f_{\text{chop}}[\text{kHz}](\text{typ.})$
18	3290	206
22	2691	168
30	1982	124
39	1526	95
47	1266	79
56	1064	66
75	795	50
91	656	41

If chopping frequency is raised, Ripple of current will become small and wave-like reproducibility will improve.

However, the gate loss inside IC goes up and generation of heat becomes large.

By lowering chopping frequency, reduction in generation of heat is expectable. However, Ripple of current may become large.

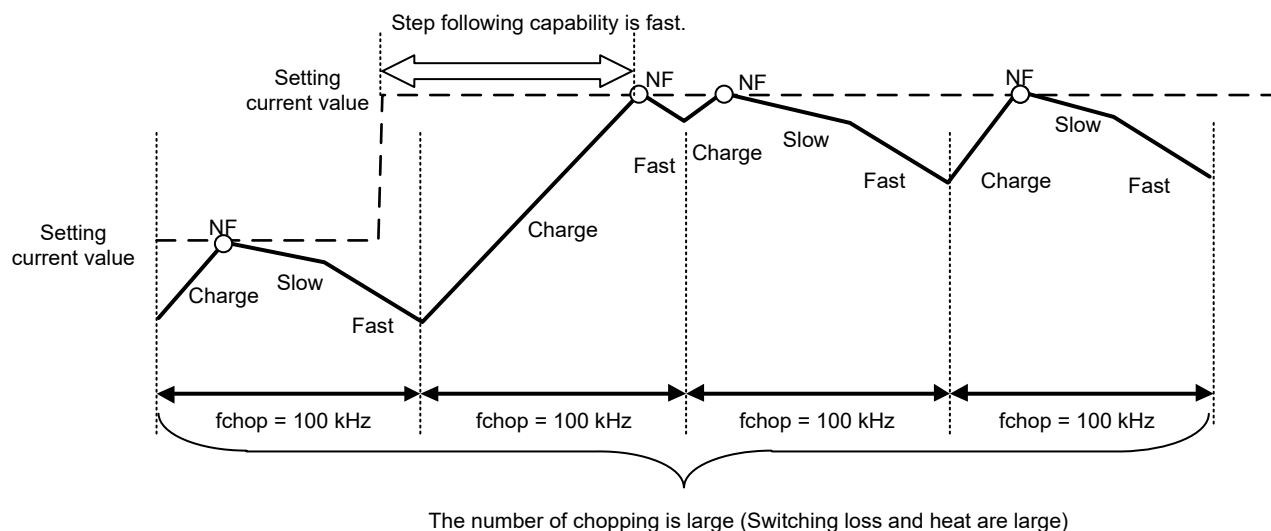
It is a standard about 70 kHz. A setup in the range of 50 kHz to 100 kHz is recommended.



### 4.3. Constant current waveform when chopping frequency changes

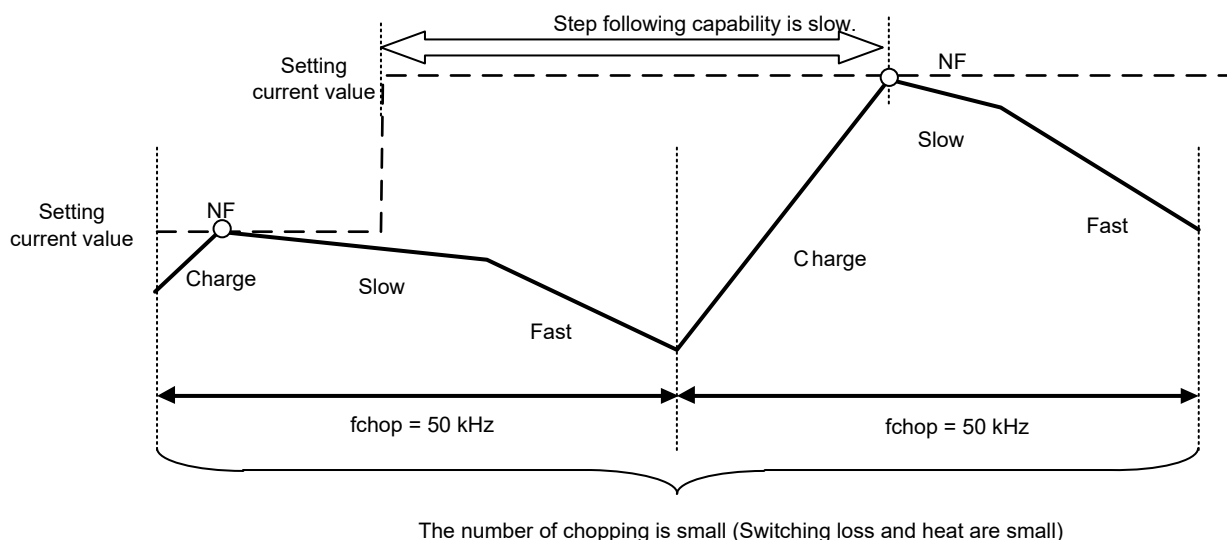
Chopping frequency ( $f_{chop}$ ) is recommended to set about 70 kHz in using the IC. When the chopping frequency is increased, ripple current of the motor is decreased and the waveform quality is improved. However, the heat generates because the increased chopping frequency enhances the switching loss. 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 4.3 Constant current waveform ( $f_{chop} = 100$  kHz)**

Example 2: When chopping frequency ( $f_{chop}$ ) = 50 kHz,



**Figure 4.4 Constant current waveform ( $f_{chop} = 50$  kHz)**

## 5. Output switching characteristics

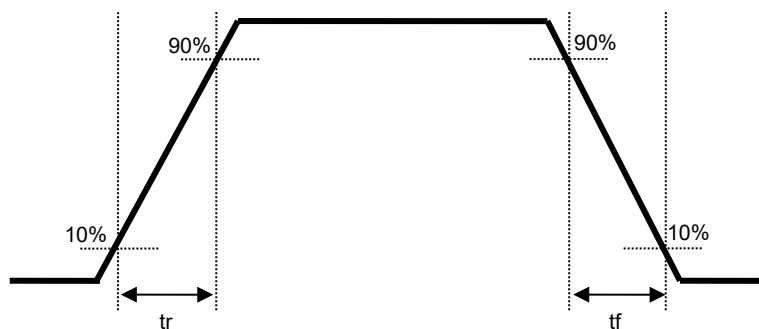


Figure 5.1 Output switching characteristics

Table 5.1 Output switching characteristics

$T_a = 25^\circ\text{C}$ ,  $V_M = 12\text{V}$ ,  $6.8\text{ mH}/5.7\ \Omega$

Item	Typ.	Unit
$t_r$	20	ns
$t_f$	20	ns

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

## 6. Error detection circuit

### • Thermal shutdown (TSD)

When the junction temperature of the device reaches 165°C (typ.), the TSD circuit is triggered; the internal reset circuit then turns off the output transistors. Once the TSD circuit is triggered, the device will set output pin to Hi-Z, and can be cleared by reasserting the VM power source, or setting the STBY pins to standby mode. The TSD circuit is a backup function to detect a thermal error, therefore, is not recommended to be used aggressively.

### • Under voltage lockout (UVLO)

When the supply voltage to VM pin is 2.1 V or less (typ.), the internal circuit is triggered; the internal reset circuit then turns off the output transistors. Once the UVLO is triggered, it can be cleared by reasserting the VM supply voltage to 2.3 V or more (typ.)

### • Over current detection (ISD)

When the output current reaches the threshold, the ISD circuit is triggered; the internal reset circuit then turns off the output transistors. It has a dead band time of 1.2  $\mu$ s (typ.) to avoid ISD false triggering by switching noise. Once the ISD circuit is triggered, the device will set output pins to Hi-Z, and can be cleared by reasserting the VM power source, or setting the STBY pins to standby mode.

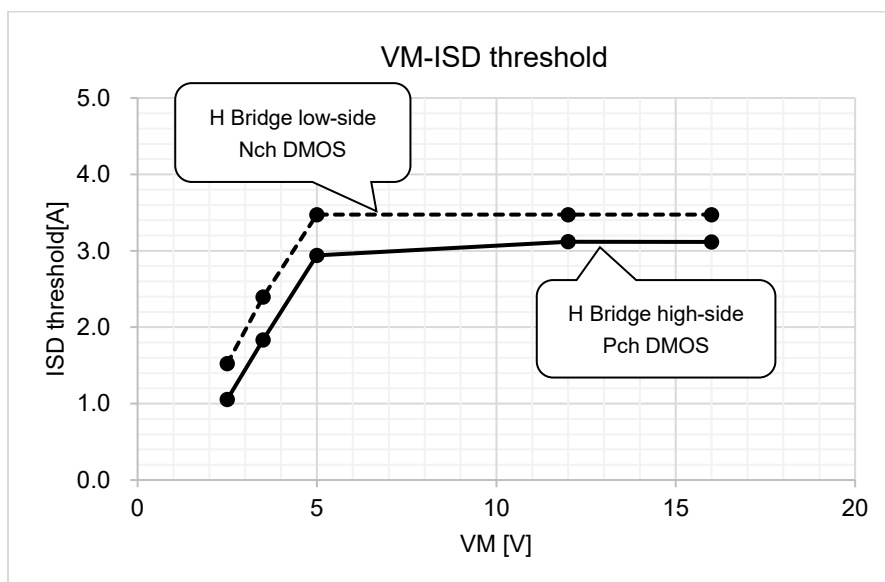


Figure 6.1 VM – ISD threshold

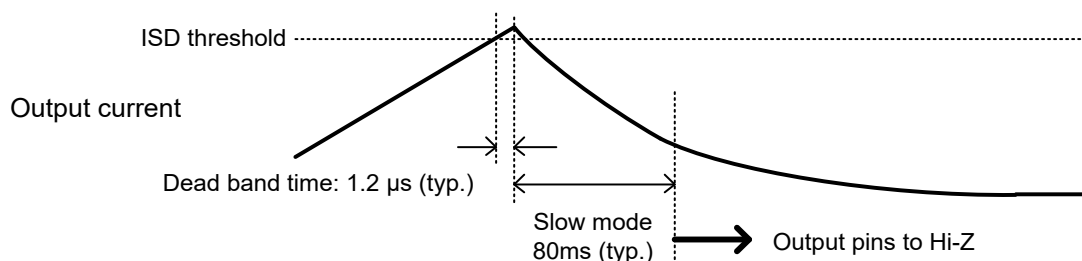


Figure 6.2 ISD operation

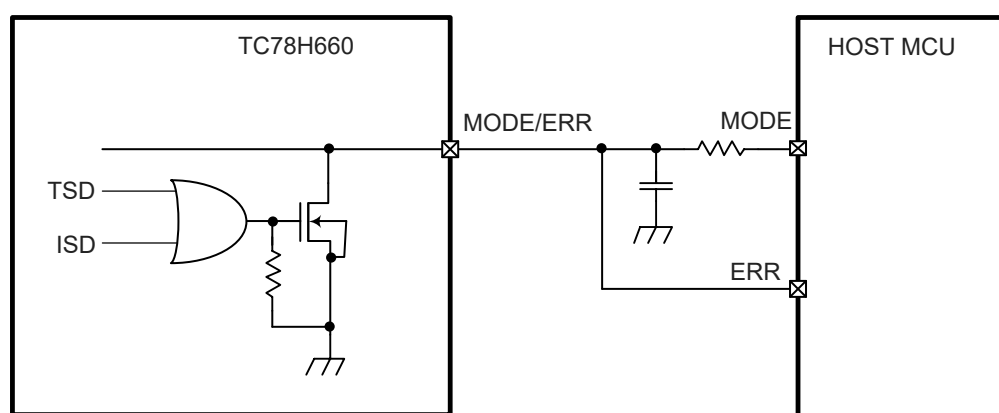
Note: Above ISD operation threshold value and band times are reference values, and are not guaranteed.

## 7. Error Function (Error Detect Flag Output)

When TC78H660 detects some errors, ERR pin outputs low level to peripheral block.

Since ERR pin and MODE pin share the function, the below peripheral circuit between TC78H660 and HOST MCU should be inserted. In normal status, since the internal MOSFET is OFF, the level of ERR pin is equal to the MODE control voltage from outside. When the thermal shutdown (TSD), Over current (ISD), occurs, ERR pin will become Low (the internal MOSFET is ON). When using this function, please set the MODE/ERR pin to High level with a pull-up resistor after setting up control mode.

When the error detection is released by reasserting the VM power supply or setting the device to STANDBY mode, ERR pins show "normal status".



**Figure 7.1 Example of MODE/ERR connection**

Note: This figure may be simplified for explanatory purpose.

**Table 7.1 Error Function**

ERR pin output	Function
H (Pull-up)	Normal status (Normal operation)
L	Detect error status (ISD or TSD)

After detecting TSD detection: TC78H660 draws out currents of motor by Fast mode. If the output current is zero-detected or for 1 ms at maximum, the outputs become Hi-Z.

After detecting ISD detection: In H Bridge high side (Pch DMOS) detection, TC78H660 draws out currents of motor by lower side Slow mode. The output after 80 ms becomes Hi-Z. In H Bridge lower side (Nch DMOS) detection, it draws out by high side Slow mode.

Note: Above times are reference values, and are not guaranteed.

## 8. Power consumption of the IC

Power of the IC is consumed by the transistor of the output block and that of the logic block mainly.

$$P_D = P_D(\text{out}) + P_D(\text{bias})$$

### • Power consumption of the motor output block

Power of the output block ( $P_D(\text{out})$ ) is consumed by MOSFET of upper and lower H-Bridge.

$$P_D(\text{out}) = \text{Number of H-Bridge} \times I_{\text{out}}(\text{A}) \times V_{\text{DS}}(\text{V}) = 2(\text{ch}) \times I_{\text{out}}(\text{A})^2 \times R_{\text{on}}(\Omega) \dots\dots\dots(1)$$

When  $R_{\text{on}} = 0.48 \Omega$ ,  $I_{\text{out}}(\text{max}) = 1.0 \text{ A}$ ,  $V_M = 12 \text{ V}$

$$P_D(\text{out}) = 2(\text{ch}) \times 1.0(\text{A}) \times 1.0(\text{A}) \times 0.48(\Omega) = 0.24(\text{W}) \dots\dots\dots(2)$$

\*  $R_{\text{on}}$ : On-resistance (Upper + lower) of MOSFET to configure the H-Bridge circuit

Please keep in mind that this value has the characteristic depending on power supply voltage and temperature although it is defined as  $0.48 \Omega$  in the above-mentioned formula.

Please refer to the following graph about the characteristics of  $R_{\text{on}}$  at  $V_M=5\text{V}$  or less.

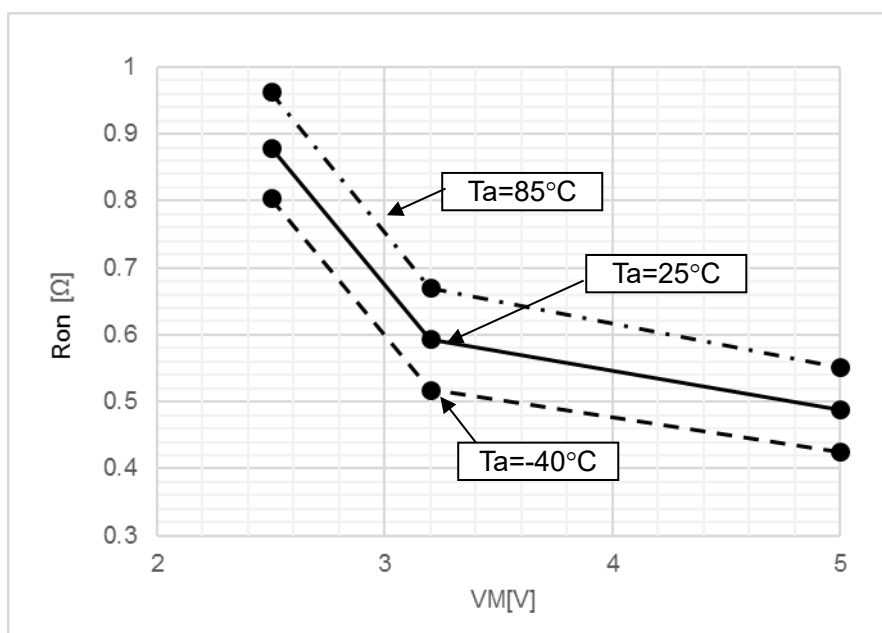


Figure 8.1 Ron characteristics (IOUT=0.5A)

Note: The values shown in the above graphs are reference, not design values.

- **Power consumption of logic and IM systems.**

The power consumption of the control block ( $P_D(\text{bias})$ ) is calculated from following formula.

$$P_D(\text{bias}) = V_M (\text{V}) \times I_M (\text{A})$$

$I (IM3) = 3.3 \text{ mA (typ.)}$  : Operating (fPWM = 18.75 kHz)

$I (IM2) = 2.8 \text{ mA (typ.)}$  : Stopping (Break mode)

When  $V_M = 12 \text{ V}$ , following equation is gained.

$$P_D(\text{bias}) = 12 (\text{V}) \times 0.0033 (\text{A}) = 0.04 (\text{W}) \dots\dots\dots (3)$$

- **Power consumption**

Total power consumption  $P_D(\text{total})$  is calculated from the values of formula (2) and (3).

$$P_D = P_D(\text{out}) + P_D(\text{bias}) = 0.96 + 0.04 = 1.00 (\text{W})$$

The power consumption in non-operation mode (stopping) of the motor is calculated as follows;

$$P_D = 12 (\text{V}) \times 0.0028 (\text{A}) = 0.034 (\text{W})$$

Additionally, the power consumption can be reduced by stopping the operation with the standby mode.

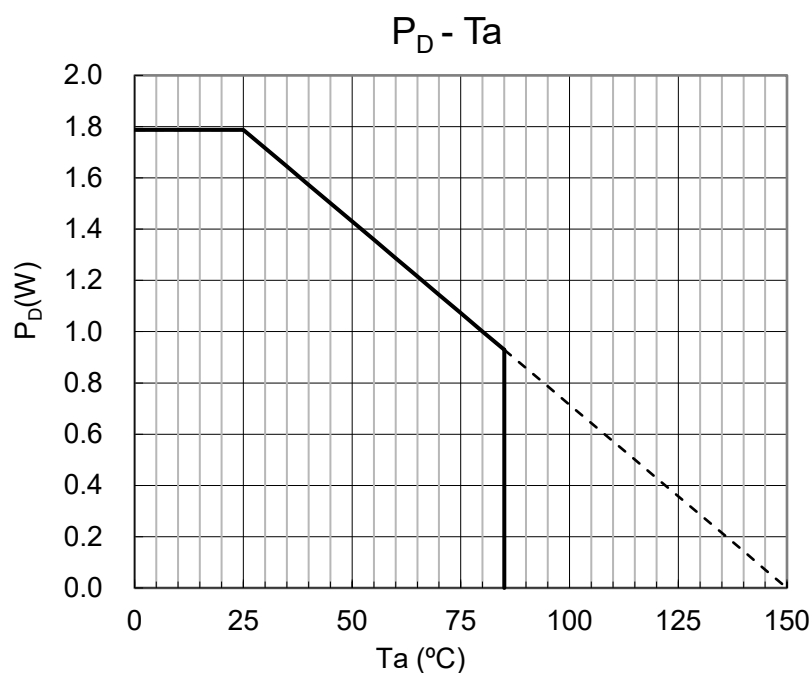
$$I_{M1} = 0.1 \mu\text{A (max)}$$

In actual motor operation, the average current becomes lower than the calculated value because of transition time of the current steps and the ripple of the constant current PWM. Refer to the above equations, evaluate the heat design of the board by the actual board enough, and configure the appropriate margin.

## 9. Power dissipation

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

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



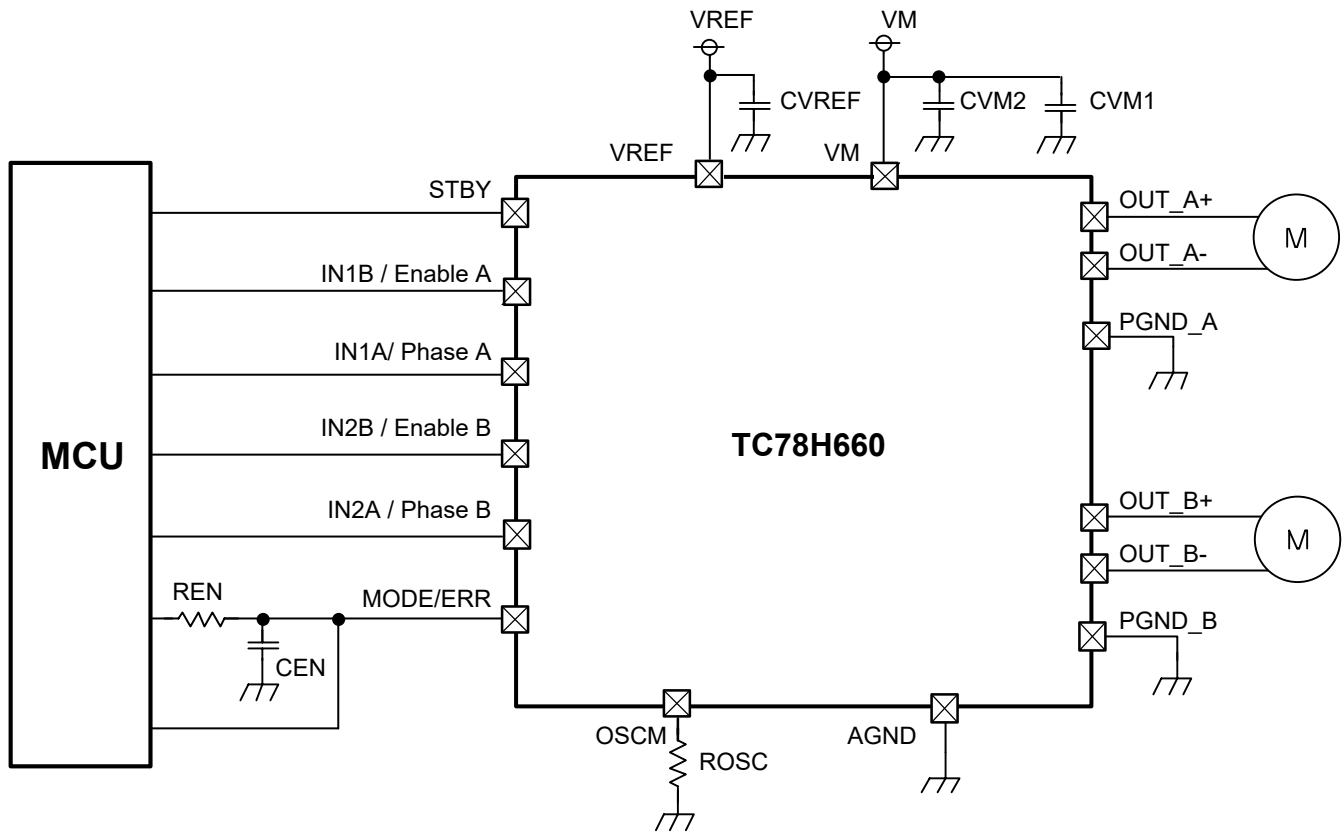
When mounted on the board (JEDEC 4 layers)

**Figure 9.1 Relation between power dissipation ( $P_D$ ) and ambient temperature ( $T_a$ )**

Note: Characteristics shown above are reference values and not guaranteed.

Pay attention that  $T_a$ ,  $R_{th(j-a)}$ , and  $P_D$  depend on the usage environment. When ambient temperature is high, the allowable power consumption decreases.

## 10. Example of application circuit



**Figure 10.1 Example of application circuit**

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



### 10.1. Capacitor for power supply terminal

To stabilize the power supply voltage of the IC and reduce the noise, connect the appropriate capacitor to each terminal. It is recommended to connect the capacitor as close to the IC as possible. Especially, by connecting the ceramic capacitor near the IC, the fluctuation of the power supply at the high frequency range and the noise can be reduced.

**Table 10.1 Recommended capacitor values for power supply terminal**

Item	Parts	Typ.	Recommended range
VM-GND	Electrolytic capacitor	47 $\mu$ F	47 to 100 $\mu$ F
	Ceramic capacitor	0.1 $\mu$ F	0.01 to 1 $\mu$ F
VREF-GND	Ceramic capacitor	0.1 $\mu$ F	0.01 to 1 $\mu$ F

\* VREF-GND: Connect the capacitor by necessity, depending on the usage environment.

\* It is possible to use the capacitor, which is not the recommended capacitor, depending on the motor load condition and the design pattern of the board.

### 10.2. Wiring pattern for power supply and GND

Since large current may flow in the pattern to VM pin, AGND pin, PGND\_x pin, OUT\_x+ pin, and OUT\_x- pin (x = A or B) especially, design the appropriate board in order to avoid the influence of wiring impedance. It is very important for surface mounting package to radiate the heat from the heat sink back side to the GND. So, design the pattern by considering the heat design.

### 10.3. 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 detection 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 abnormal state, use the fuse for the power supply line.

## 11. Reference Land Pattern

P-VQFN16-0303-0.50-001

Unit: mm

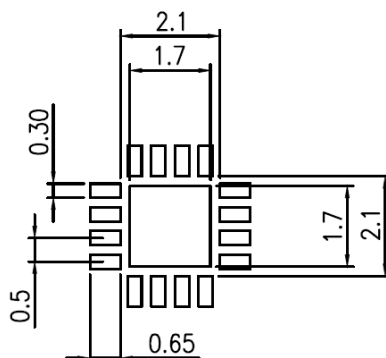


Figure 11.1 Reference Land Pattern(QFN16)

P-TSSOP-0505-0.65-001

単位: mm

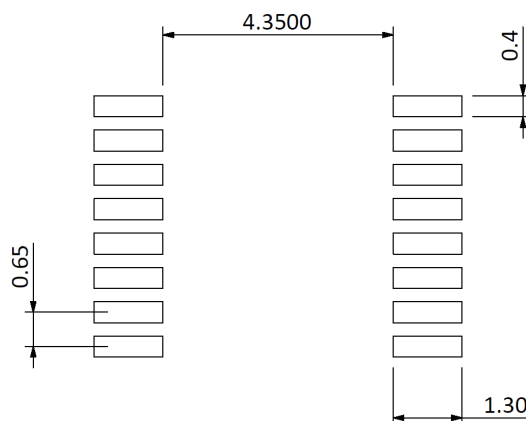


Figure 11.2 Reference Land Pattern(TSSOP16)

The land pattern is provided for reference purposes only, and are not guaranteed for mass production. In determining the size of mounting board, design the most appropriate pattern by considering the solder bridge, the solder connecting strength, the pattern accuracy in making board, and the mounting accuracy of the IC board.

## 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.

Toshiba does not grant any license to any industrial property rights by providing these examples of application circuits.

## 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 terminals of power supplies are connected properly. Otherwise, the current or power consumption may exceed the absolute maximum rating, and exceeding the rating(s) may cause the device breakdown, damage or deterioration, and may result injury by explosion or combustion.  
In addition, do not use any device that is applied the current with inserting in the wrong orientation or incorrectly even just one time.
- (3) Use an appropriate power supply fuse to ensure that a large current does not continuously flow in case of over current and/or IC failure. The IC will fully break down when used under conditions that exceed its absolute maximum ratings, when the wiring is routed improperly or when an abnormal pulse noise occurs from the wiring or load, causing a large current to continuously flow and the breakdown can lead smoke or ignition. To minimize the effects of the flow of a large current in case of breakdown, appropriate settings, such as fuse capacity, fusing time and insertion circuit location, are required.
- (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 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, overcurrent or IC failure can cause smoke or ignition. (The over current can 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, such as exceeding absolute maximum ratings can cause the over current protection circuit to not operate properly or IC breakdown before operation. In addition, depending on the method of use and usage conditions, if over current continues to flow for a long time after operation, the IC may generate heat resulting in breakdown.

**(2) Thermal Shutdown Circuit**

Thermal shutdown circuits do not necessarily protect ICs under all circumstances. If the thermal shutdown circuits operate against the over temperature, clear the heat generation status immediately.

Depending on the method of use and usage conditions, such as exceeding absolute maximum ratings can cause the thermal shutdown circuit to not operate properly or IC breakdown before operation.

**(3) Heat Radiation Design**

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

**(4) Back-EMF**

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

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