TB9120AFTG Application Note

Introduction

This document is a reference document showing the product's technical information for engineers using TB9120AFTG. It mainly describes information and precautions useful for TB9120AFTG application. When using TB9120AFTG, always refer to the latest TB9120AFTG datasheet.

Contents

1. Product overview

TB9120AFTG is a stepping motor driver with PWM constant current control, 2-phase bipolar drive, and clock input, which directly drives an automotive stepping motor. It can be used in many applications for automotive stepping motor drives such as for the control of refrigerant circuit expansion valves, control of valve dampers for HVAC, angle adjustment of concave mirrors for HUDs, and valve control for two-wheel vehicles.
When using TB9120AFTG, always refer to the latest TB9120AFTG datasheet. You can download the datasheet from the following webpage:

https://toshiba.semicon-storage.com/ap-en/semiconductor/product/automotive-devices/detail.TB9120AFTG.html

Always comply with the information in the datasheet, including the notes.

2. Power supply

2.1 Power supply voltage range

- The VBAT pin supplies the power.
- Absolute maximum rating:
  - DC: $-0.3 \leq VBAT \leq 18$ V
  - For at most 1 minute: $VBAT \leq 30$ V
  - Transition voltage, for at most 0.5 seconds: $VBAT \leq 40$ V
  - Refer to "8. Absolute maximum rating" in the datasheet.
- Operating range: $4.5 \leq VBAT \leq 18$ V
  - However, for $4.5 \leq VBAT < 7$ V within the operating range, the specifications shown in the datasheet (such as electrical characteristics) are not guaranteed.
  - Refer to "9. Operation range" and "7.18 Operation outside the scope of the operation voltage range" in the datasheet.
- For the power supply low-voltage detection circuit, refer to "7.2 Power supply" in the datasheet.

2.2 Power ON and OFF

- Apply or shut off the voltage to VBAT under either condition BSTBY = L or ENABLE = L to prevent unexpected over-current from flowing into the motor coil.
- For the power supply rise/fall sequence, refer to "7.3 Power supply / control signal input sequence".

3. Input signal

3.1 Input signal priority

- As shown in Table 1, BSTBY, ENABLE, START, and CW/CCW have priority, in that order. For example, since BSTBY has higher priority than ENABLE, when BSTBY = L, the IC is in the standby state regardless of ENABLE.

Table 1. Truth table for BSTBY, CLK, ENABLE, CW/CCW, and START input signals

Input					Output state	Mode
CLK	CW/CCW	START	ENABLE	BSTBY		
↑ (rising edge)	H	L	H	H	CW (Clockwise)	Normal operation
↑ (rising edge)	L	L	H	H	CCW (Counterclockwise)	Normal operation
X	X	H	H	H	Initialization of electrical angle	Initial (Note 1)
X	X	X	L	H	High impedance	Enable OFF (Note 2)
X	X	X	X	L	High impedance	Standby

X: Don't Care

Note 1: Initial: Outputs the current level that is fixed to the initial electrical angle indicated by the START function.

Note 2: Enable OFF: The outputs enter a high-impedance state. On the other hand, when START = L and a signal is input to CLK, the internal counter proceeds.

3.2 BSTBY

- By setting the BSTBY pin to L, the IC enters the standby mode. Most circuits, such as the internal oscillation circuit and motor drive output MOSFET, cease operation.
- If no current flow through the motor is necessary for a long time, setting it to standby mode can reduce power consumption. In standby mode, no current flows through the load and VBAT current consumption is at most 10 μA.
- It takes at most 0.5 ms in the worst case for the system to go from standby cancellation (BSTBY = L → H) to VccOUT rise. Consequently, ensure that there is an interval of at least 0.5 ms from the BSTBY signal input to the ENABLE signal input.
- If the BSTBY pin shifts from H to L while ENABLE = H, the output pin enters a high-impedance state after a transitional period (regeneration period: Tregene), during which the regeneration operation is applied.
- Do not use the BSTBY pin for start or stop motor commands.
- The relationship between standby mode and electrical angle is as follows:
  - Since most of the circuits in the IC are in the OFF state during standby mode, when standby mode is canceled, operation cannot restart from the pre-standby mode electrical angle.
  - When standby mode is canceled, the electrical angle returns to its initial position. Due to it being at the initial position, MO outputs L. We recommend the following method to set the electrical angle to the initial position and control it precisely: after cancelling standby mode, first change START from H to L, then input the necessary number of pulses for CLK and set ENABLE to H.
- Refer to "7.1 BSTBY function" and "7.3 Power supply / control signal input sequence" in the datasheet.

3.3 CLK

- The electrical angle advances by 1 step for each CLK input.
- The system implements the signal at the next rising edge.
- The number of square waves input to the CLK pin per unit time (i.e., frequency) is proportional to the motor running speed.

- Use a signal to the CLK pin to start and stop the motor.
- To stop the running motor, gradually lower the frequency of the pulse to the CLK pin and finally fix the CLK pin to L or H.
- Refer to "7.4 CLK input" in the datasheet.

3.4 ENABLE

- This pin switches the current flowing through the motor ON and OFF. It switches the H-bridge directly connected to the motor coil ON and OFF.
- When ENABLE = H, the switch is ON, and current flows through the motor coil.
- When ENABLE = L, the switch is OFF, and the output pin enters a high-impedance state.
- Even when ENABLE = L and no current flows through the motor, commands from the CLK, START, and CW/CCW input pins are reflected in the internal counter. For example, if ENABLE = L, START = L, and pulses are input to the CLK pin, the counter in the IC advances. Consequently, the initial output current value depends on when ENABLE switches to H.
- When switching the power to ON, set ENABLE to L to prevent a large current from unintentionally flowing through the motor coil.
- When ENABLE = L, it cancels the latched state that follows detection of an over-temperature (TSD) or over-current (ISD) condition.
- When ENABLE = L, the DIAG pin is always in a high-impedance state.
- If the ENABLE pin shifts from H to L, the output pin enters a high-impedance state after the regeneration operation is applied.
- Refer to "7.5 ENABLE circuit” in the datasheet.

3.5 CW/CCW

- Switches the rotation direction of the stepping motor.
- The rotation direction of 2-phase stepping motor depends on which phase's current is output with a phase advance.
- When CW/CCW = H, the system outputs the current in phase A with a phase advance of 90° relative to that of phase B (defined as clockwise (CW)).
- When CW/CCW = L, the system outputs the current in phase B with a phase advance of 90° relative to that of phase A (defined as counterclockwise (CCW)).
- Refer to "7.6 CW/CCW control circuit” in the datasheet.

3.6 START

- When START is set to H, the internal counter initializes the electrical angle and sets it to the initial position.
- While START = H, the electrical angle is fixed to the initial position and the motor does not rotate. To rotate the motor, set START to L.
- While START = H, the MO pin outputs L.
- When the electrical angle reaches the initial position during motor rotation, the MO pin outputs L.
- A change in the state of the START pin is reflected in outputs as synchronized with the CLK input signal.
- Refer to "7.8 START function" in the datasheet.

3.7 Excitation mode

3.7.1 Excitation mode setting

- As shown in Table 2, DMODE0, DMODE1, and DMODE2 change step resolution.
- When DMODE0 = DMODE1 = DMODE2 = L, the current setting is fixed as phase A 71% and phase B 71%. At this time, the MO pin outputs L.

Table 2. Excitation mode setting with DMODE0, DMODE1, and DMODE2

DMODE0 input	DMODE1 input	DMODE2 input	Function
L	L	L	Phase A 71%, phase B 71%
L	L	H	Sets 2-phase excitation
L	H	L	Sets 1-2-phase excitation (a)
L	H	H	Sets W1-2-phase excitation
H	L	L	Sets 1-2-phase excitation (b)
H	L	H	Sets 2W1-2-phase excitation
H	H	L	Sets 4W1-2-phase excitation
H	H	H	Sets 8W1-2-phase excitation

- A change in excitation mode is reflected in outputs as synchronized with the CLK input signal.
- After power input, the first CLK input determines the excitation mode.
- Refer to "7.7 Excitation mode setting (DMODE)" in the datasheet.

3.7.2 Output current waveform of 8W1-2-phase excitation

- Figure 1 shows an example of an output current waveform for 8W1-2-phase excitation, which has the highest resolution.
- The quasi-sine wave waveform rotates the motor.

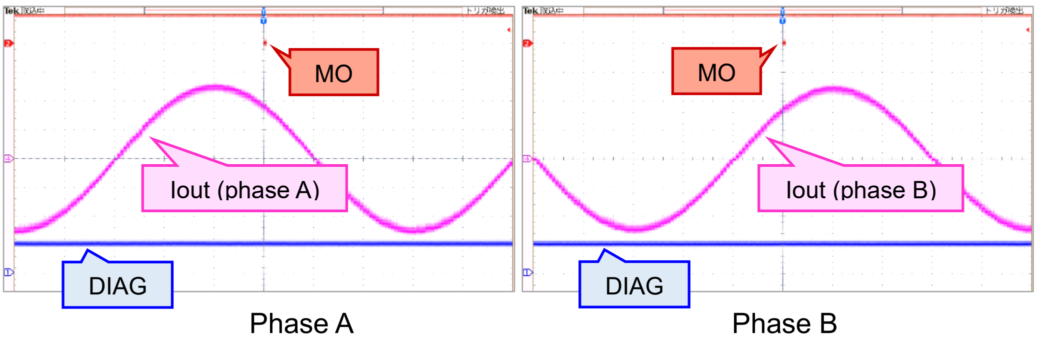


Figure 1. Output current waveform example of 8W1-2-phase excitation (for reference)

3.8 Weak excitation mode setting

- As shown in Table 3, use the TORQUE0 and TORQUE1 pin inputs to set a weak excitation mode.

Table 3. Weak excitation mode setting with TORQUE0 and TORQUE1

TORQUE0	TORQUE1	Function
L	L	Defined current value × 100%
H	L	Defined current value × 70%
L	H	Defined current value × 50%
H	H	Defined current value × 30%

- Normally, the 100% setting with TORQUE0 = TORQUE1 = L is used.
- When no square wave is input to the CLK pin, and CLK = H or CLK = L to stop motor rotation, the system applies a brake to prevent idle rotation of the motor's rotor. In this case, since the necessary torque to keep the brake applied is smaller than that for rotation, using weak excitation (e.g., setting the TORQUE pin to a reduced current of 30%) can keep the motor braked while keeping current consumption low. (Note)

  Note: Torque is proportional to current.

- Refer to the "TORQUE pin" section of "7.14 Constant current PWM control" in the datasheet.

4. MO

4.1 Electrical angle monitoring

- The MO pin monitors the electrical angle and outputs L at the initial state of the electrical angle (initial position).

4.2 Control by counting CLK pulses accurately

- For control using an accurate count of CLK pulses, combine the signals of the MO and START pins.
- After switching START from H to L, the pulse input to the CLK pin rotates the motor from the initial position. In this state, monitor the timing of the next instance that MO becomes L to know when the electrical angle completes a rotation (360°).
- The following illustrates a case where ENABLE = H and the CLK pin inputs square pulses of constant frequency.
  - When START = H, the electrical angle is fixed at the initial position, the motor stops rotating, and the MO pin outputs L.
  - Then, when START is set to L, MO changes to H, and the motor restarts its rotation at the next rising edge of CLK. Since the rotation starts at the initial position, count the number of CLK pulses that occur until the next initial position by detecting MO = L, which occurs at each full rotation of the electrical angle, to accurately determine the number of CLK pulses.
  - If the step is 1/8, for example, the necessary number of CLK pulses for each full rotation of the electrical angle is 32 (Note).

$$\text{Note: } 32 = \frac{1}{1/8\ (\text{step})} \times \frac{360°}{90°}$$

- Refer to "7.8 START function" and "7.9 MO output" in the datasheet.

5. Output current

5.1 Output current value setting with VREF

・The 100% current value for constant-current control is determined by the external resistor for motor current detection (RRS) and the reference voltage externally applied to the VREF pin (Vref).

・The following formula determines the current value:

$$\text{Iout (MAX)} = \text{Vrefgain} \times \frac{\text{Vref (V)}}{\text{RRS } (\Omega)}$$

Here, the following conditions are true:

・Compression ratio of the constant Vrefgain = 1/10 (typ.)

・Vref is the voltage applied to the VREF pin. Operating range: 0.3 V ≤ Vref ≤ 3.0 V

・Current-detecting resistors (RRS) are attached to the RSA and RSB pins to connect them with GND. The two resistors have the same resistance.

・If external voltage is split between two resistors to be applied to VREF, the resistance value between VREF pin and GND must be less than about 10 kΩ. If the current value is too small, noise may cause the voltage to fluctuate.

・Do not use the 5 V output from VccOUT as the voltage applied to VREF.

・Refer to the "Current value setting" section of "7.14 Constant-current PWM control" in the datasheet.

5.2 Upper limit of output current

・The absolute maximum rated output current for the OUTA+, OUTA, OUTB+, and OUTB pins is defined to be the same value as the over-current detection threshold.

・The over-current detection threshold is 1.5 A (min.), 2.0 A (typ.), and 2.5 A (max.) for each phase.

・Usage conditions such as the heat-dissipation capability of the circuit board and ambient temperature affect the current usable to drive the motor.

・Adequate thermal design and evaluation are required to keep the junction temperature (Tj) 150°C or lower. Inadequate thermal design may trigger overheat detection.

6. PWM chopping frequency setting

6.1 ROSCM

・This IC generates an output current waveform using constant-current PWM control.

・The value of ROSCM, which is an external resistor between the OSCM pin and GND, determines the PWM chopping frequency of this control.

・Refer to "7.12 OSC circuit" in the datasheet.

6.2

・Changing the PWM chopping frequency may change the ripple shape of current waveform and the magnitude of noise originating from the PWM control. Evaluate your design appropriately.

7. Test pin

7.1 TEST1 pin

・Always ground TEST1 to GND. This is a pin dedicated to the shipment test.

7.2 TEST2 pin

・Always keep TEST2 unconnected (open). This is a pin dedicated to the shipment test.

8. PWM constant-current control

8.1 Operation description of charge → slow → fast modes

・As shown in Figure 2, two types of operation occur depending on current direction.

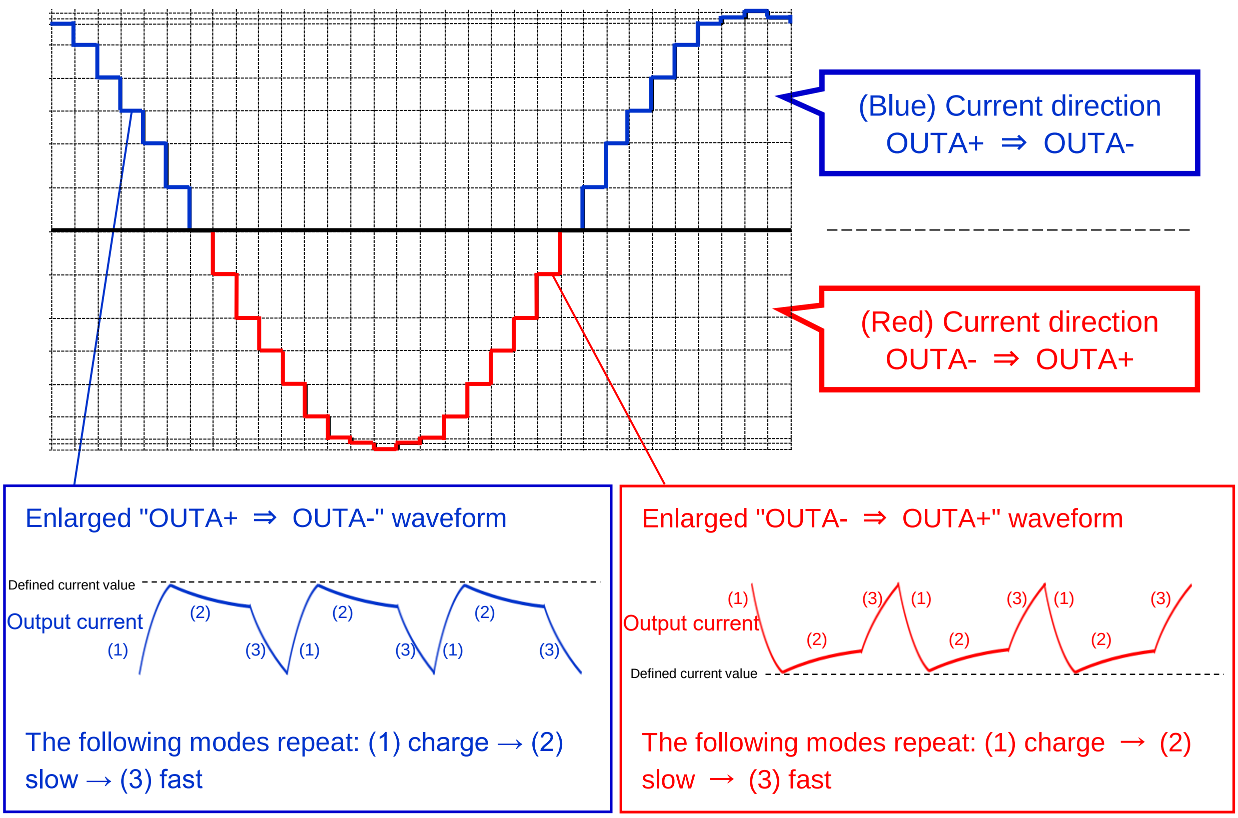


Figure 2. Definition of current direction: Example 2W1-2-phase excitation, phase A current waveform

・When the current direction is OUTA+ ⇒ OUTA-, operation is as shown in Figure 3.

Mode	U1	U2	L1	L2
Charge mode	ON	OFF	OFF	ON
Slow mode	OFF	OFF	ON	ON
Fast mode	OFF	ON	ON	OFF

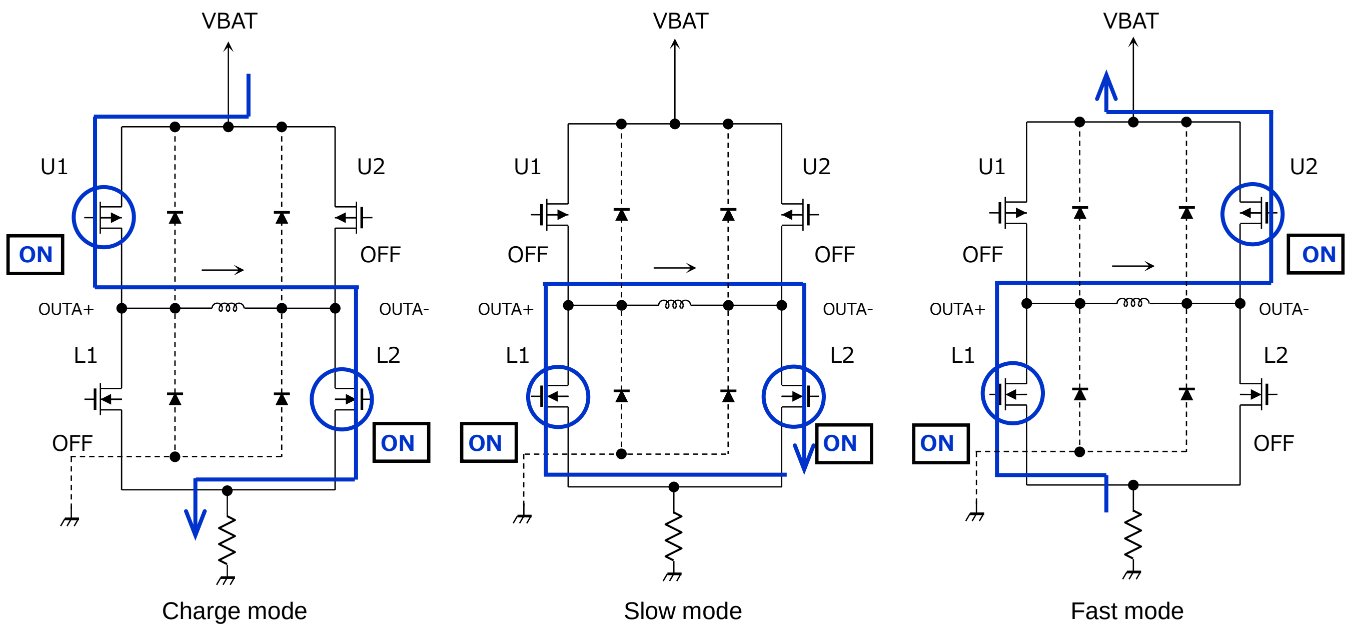


Figure 3. Operation showing charge → slow → fast modes with a current direction of OUTA+ ⇒ OUTA-

・When the current direction is OUTA- ⇒ OUTA+, operation is as shown in Figure 4.

Mode	U1	U2	L1	L2
Charge mode	OFF	ON	ON	OFF
Slow mode	OFF	OFF	ON	ON
Fast mode	ON	OFF	OFF	ON

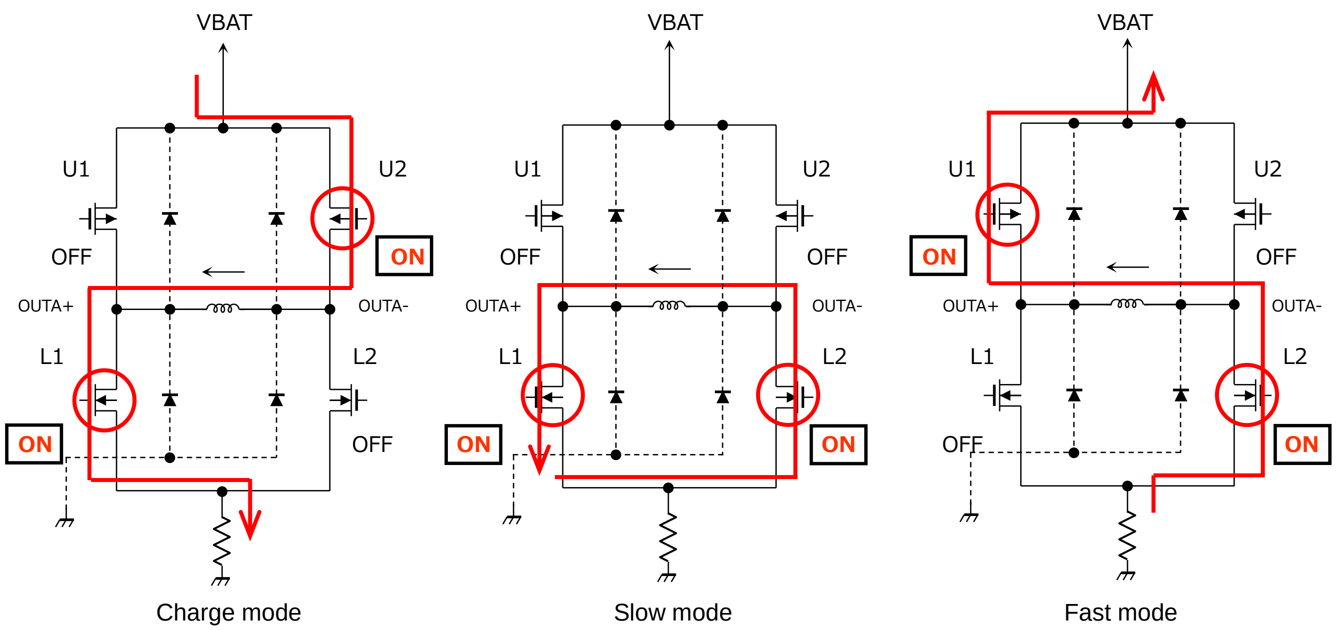


Figure 4. Operation showing charge → slow → fast modes with a current direction of OUTA- ⇒ OUTA+

・Phase B is the same.

8.2 Shoot-through current prevention time

・The control shown in Figures 5 and 6 prevents the pairs U1-L1 and U2-L2 from turning on simultaneously. The following case is for a current direction of OUTA+ ⇒ OUTA-.

		Time elapses →					
		Charge time	Dead time	Slow-decay time	Dead time	Fast-decay time	Dead time
OUTA+	Upper U1 (Pch)	ON	OFF	OFF	OFF	OFF	OFF
	Lower L1 (Nch)	OFF	OFF	ON	ON	ON	OFF
OUTA-	Upper U2 (Pch)	OFF	OFF	OFF	OFF	ON	OFF
	Lower L2 (Nch)	ON	ON	ON	OFF	OFF	OFF

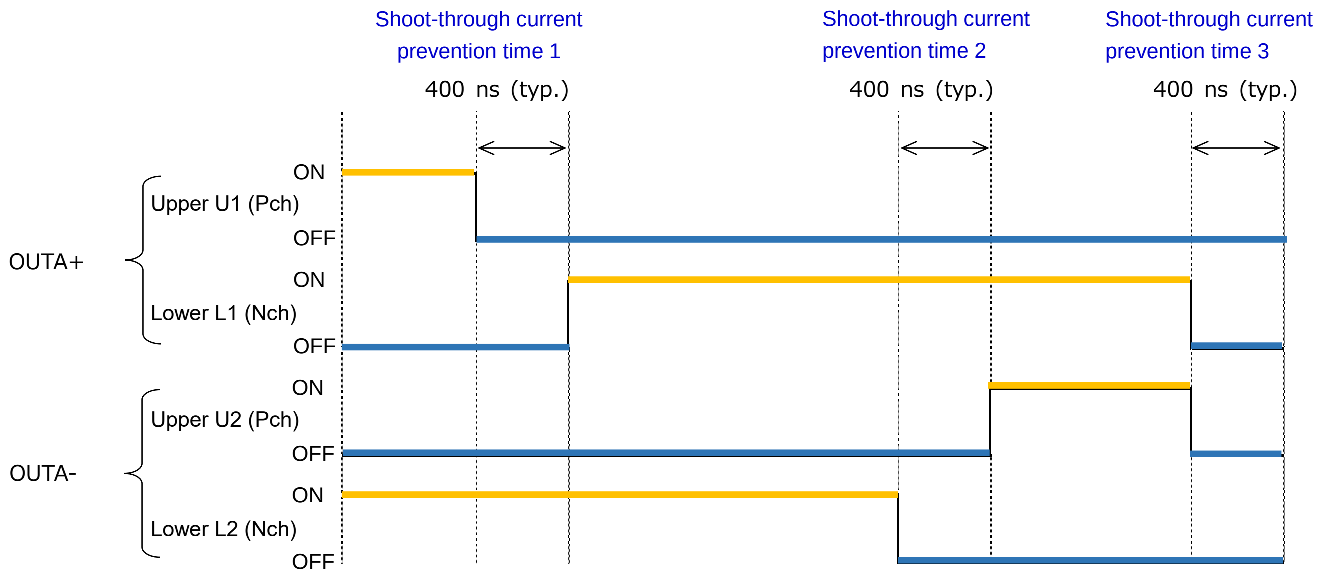


Figure 5. Shoot-through current prevention time illustrated by a waveform chart

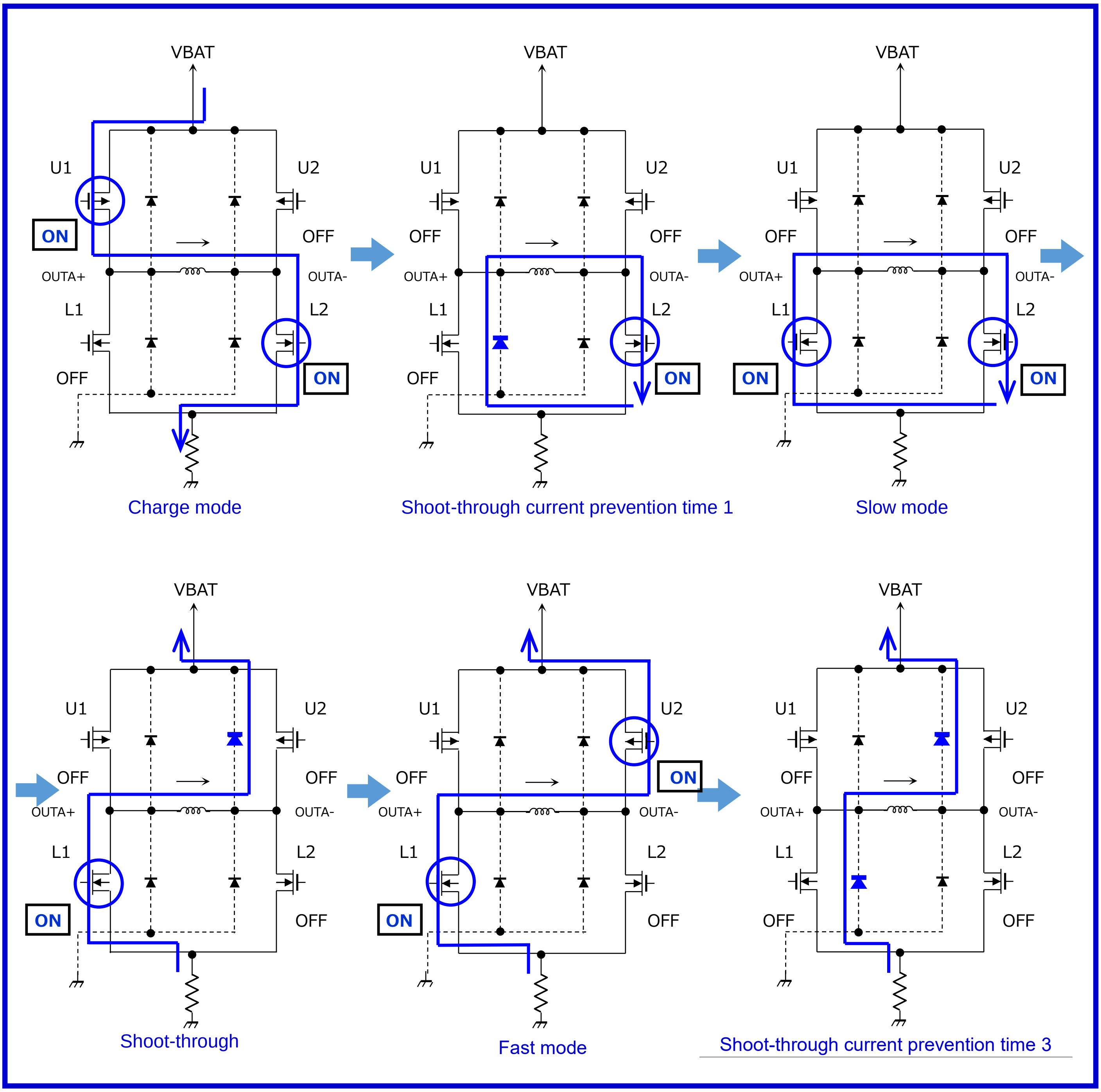


Figure 6. Shoot-through current prevention time illustrated by an H-bridge circuit diagram

- The system applies current to a diode during shoot-through current prevention time (400 ns (typ.))
- During shoot-through current prevention time, the system applies current to the diode shown in Figure 6 (blue).
- Figures 5 and 6 both show the case for a current direction of OUTA+ ⇒ OUTA-. If the current direction is OUTA- ⇒ OUTA+, current flows in the opposite direction and the current applied to the H-bridge is mirrored.

9. Anomaly detection

9.1 DIAG

- If the system detects an anomalous state (motor load open, over-current, or over-temperature), the DIAG pin outputs L.
- When ENABLE = L, anomaly detection is not active and the DIAG pin is always in a high-impedance state.
- If the DIAG pin is not used, keep the pin open.
- Refer to "7.10 DIAG function (Anomaly state diagnosis)" in the datasheet.

9.1.1 Load open detection

- If a motor load line comes off any of the connected output pins, the system detects that an output pin is open.
- If the system detects a load open, the DIAG pin outputs L.
- Even if the system detects a load open, the output remains ON.
- When you reconnect the load and restore the system to a normal state, the DIAG pin no longer outputs L.
- Refer to "7.15 Load open detection" in the datasheet.

9.1.2 Over-current detection

- If any of the output pins are short-circuited with power supply or ground, the system detects an over-current condition.
- If the system detects an over-current condition, the DIAG pin outputs L.
- If the system detects an over-current condition, the output changes to OFF. The OFF state is latched and fixed. No automatic recovery is applied. A manual recovery procedure is necessary to turn the output ON again.
- Re-inputting the VBAT power supply or applying L to the ENABLE pin cancels the latched state.
- Refer to "7.16 Overcurrent Detection (ISD)" in the datasheet.

9.1.3 Over-temperature detection

- If the IC chip temperature exceeds the set temperature, the system detects an over-temperature condition.
- If the system detects an over-temperature condition, the DIAG pin outputs L.
- If the system detects an over-temperature condition, the output changes to OFF. The OFF state is latched and is fixed. No automatic recovery is applied. A manual recovery procedure is necessary to turn the output ON again.
- Re-inputting the VBAT power supply or applying L to the ENABLE pin cancels the latched state.
- Refer to "7.17 Over temperature detection (TSD)" in the datasheet.

9.2 SD

- If the system detects a stall, the SD pin outputs L.
- If the stall detection function is not used, keep the SD pin open.

9.2.1 Stall detection

- If the system detects abnormal rotation (i.e., a stall), the SD pin outputs a stall-detection signal.

・A microcontroller can receive the stall-detection signal to feed it back to the system control.
・As shown in Figure 7, if the motor's induced voltage is below a certain level, the motor does not rotate sufficiently (i.e., a stall), and the SD pin outputs L.

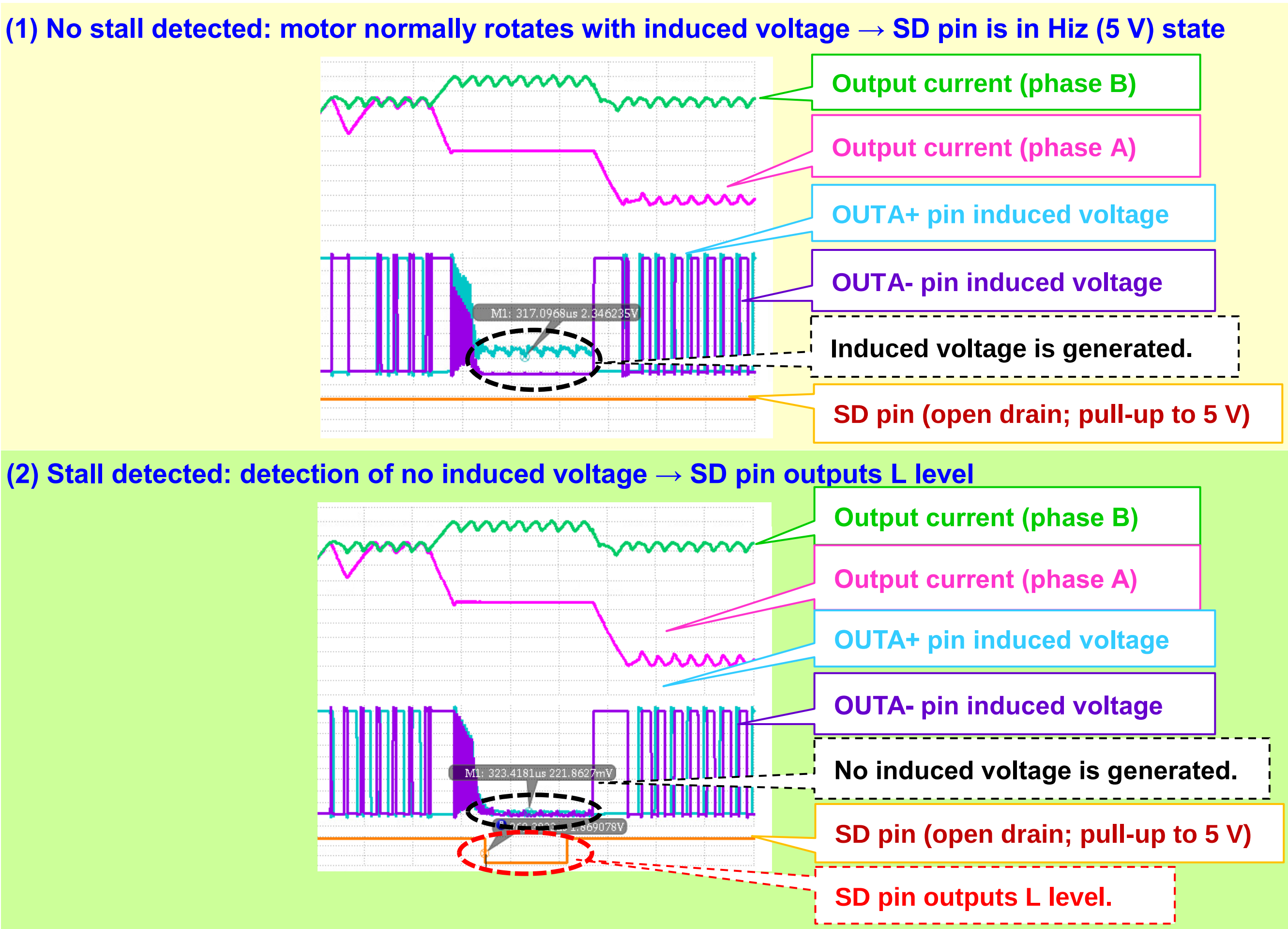


Figure 7. SD pin waveform example when a stall is detected

・Note the following stipulations arising from the operating principle. Refer to the datasheet for details.
  ・For motor rotation with 2-phase excitation, the stall-detection function does not work.
  ・When low-speed rotation, low current drive, excitation mode, or the type of motor causes insufficient induced current generation, the stall-detection function may not work correctly. Thoroughly check the motor characteristics, drive conditions, and other factors before setting a threshold.
  ・For example, when the motor starts from a stopped state, since insufficient induced current is generated due to low-speed rotation, the stall-detection function may not work correctly. To use the stall-detection function properly, exclude this period.

・Even if the system detects a stall, the output stays ON.
・When the motor resumes sufficient rotation, the SD pin no longer outputs L.
・Refer to "7.11 Stall detection (SD: Stall detection) function" in the datasheet.

9.2.2 Effect of stall-detection function

- Application example: Heads-up display
  - In a system that determines the mechanical origin position of the image-reflecting mirror inside a heads-up display shown in Figure 8, the stall-detection function may significantly reduce part and assembly costs.

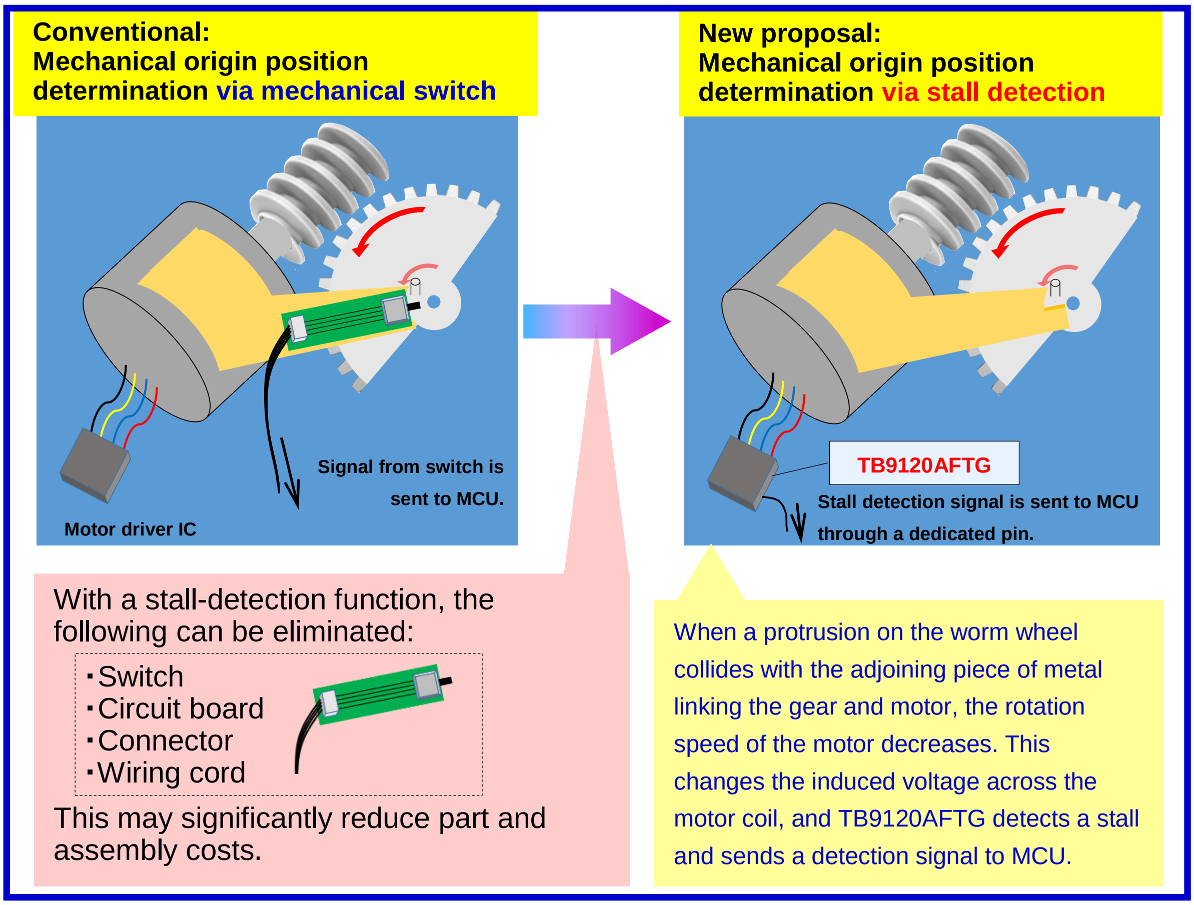


Figure 8. Application example and effect of a stall-detection function

9.2.3 Stall detection experimental result

- Purpose
  - Checks whether false detection occurs for the stall-detection function by varying main parameters.
  - Measures the threshold at which false detection occurs for the signal sent to the CLK pin. This occurs because false detection is likely when the rotation is slow (i.e., the CLK frequency is low), since the induced voltage is insufficient and makes detection difficult.
- Evaluation method
  - Three motor types:
    - Motor A: 125 mA
    - Motor B: 500 mA
    - Motor C: 850 mA

  For each type, the experiment measures the following parameters:

  (1) Vref pin voltage vs. frequency threshold at which false detection occurs for the signal sent to the CLK pin

(2) SDT threshold voltage vs. frequency threshold at which false detection occurs for the signal sent to the CLK pin
(3) VBAT pin voltage vs. frequency threshold at which false detection occurs for the signal sent to the CLK pin
(4) Excitation mode vs. frequency threshold at which false detection occurs for the signal sent to the CLK pin

・Criterion
 ・False detection is defined as a state where the SD pin outputs L even though no stall is actually occurring.

・Experimental result
 [A] Experimental result of motor A (125 mA)
 (1) VREF pin voltage (output current setting) vs. CLK frequency threshold [motor A]

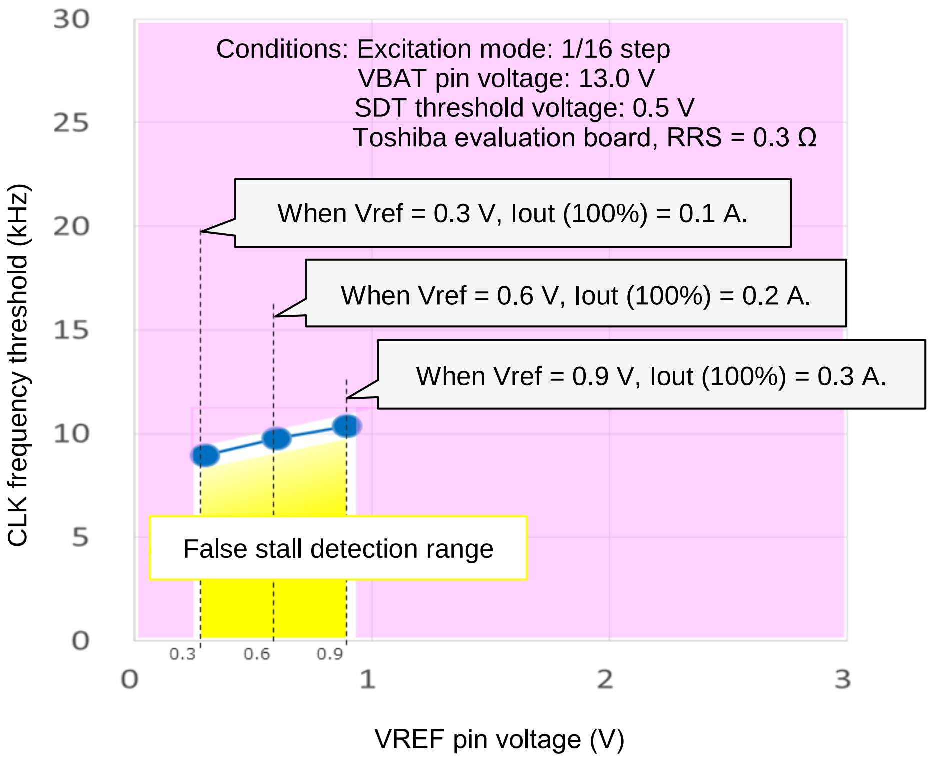


Figure 9. VREF pin voltage vs. CLK frequency threshold (for reference)

・As shown in Figure 9, the result is as follows:
 ・False stall detection occurs in the range denoted in yellow (■), in which the CLK frequency falls below the threshold denoted by blue dots (●).
 ・False stall detection shows a positive correlation between the set current and the CLK frequency threshold.

See notes 1, 2, and 3 on page 28.

(2) SDT threshold voltage vs. CLK frequency threshold [motor A]

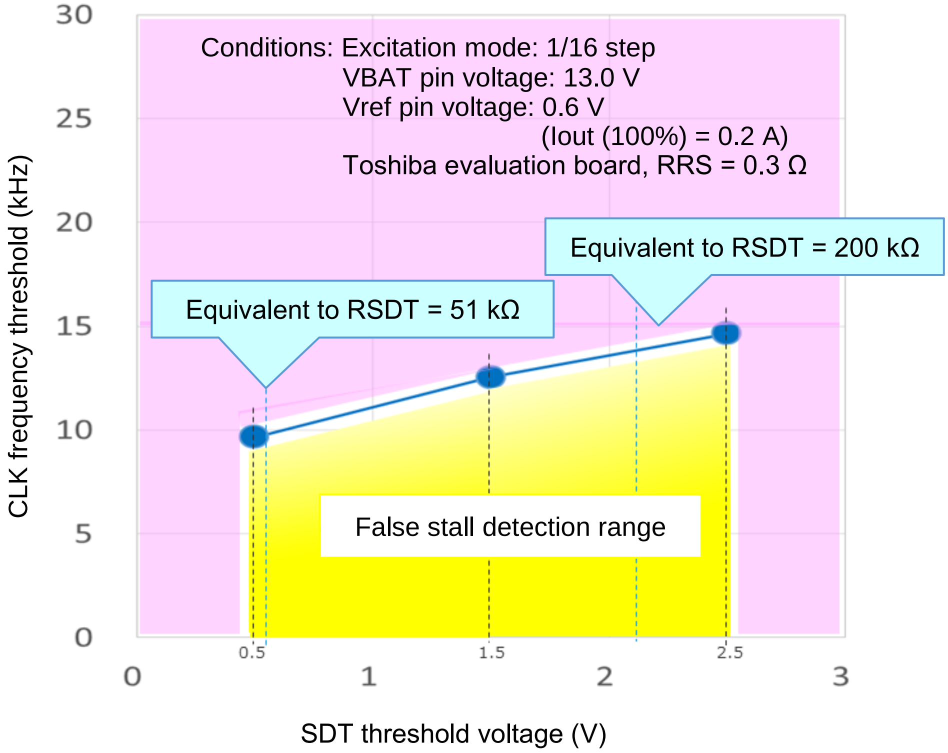


Figure 10. SDT threshold voltage vs. CLK frequency threshold (for reference)

- As shown in Figure 10, the result is as follows:
  - False stall detection occurs in the range denoted in yellow (■), in which the CLK frequency falls below the threshold denoted by blue dots (●).
  - False stall detection shows a positive correlation between the SDT threshold voltage and the CLK frequency threshold.

See Notes 1, 2, 4, and 5 on page 28.

(3) VBAT pin voltage vs. CLK frequency threshold [motor A]

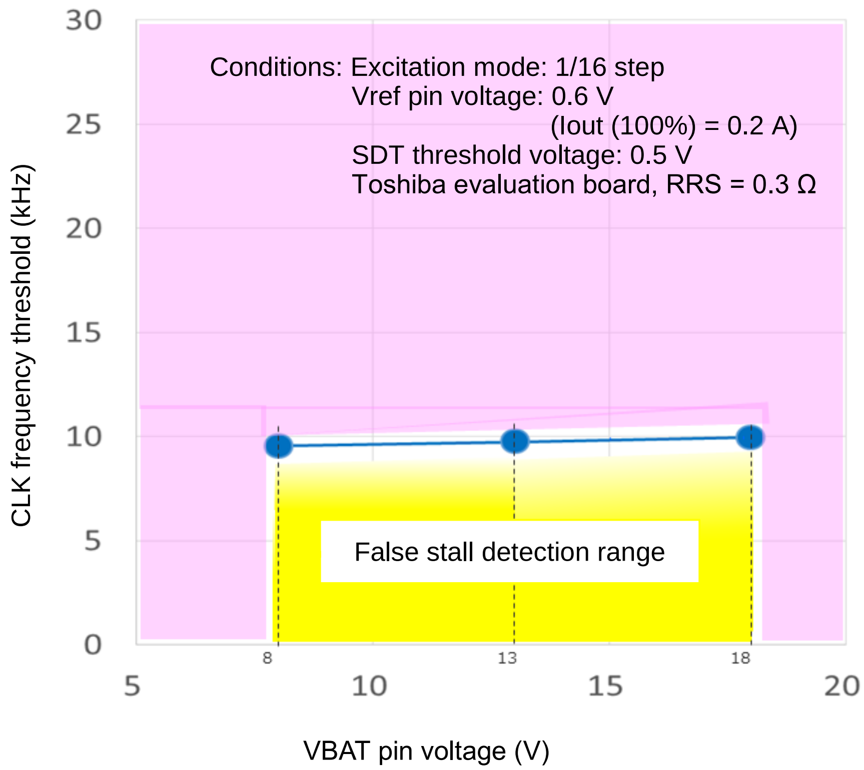


Figure 11. VBAT pin voltage vs. CLK frequency threshold (for reference)

- As shown in Figure 11, the result is as follows:
  - False stall detection occurs in the range denoted in yellow (■), in which the CLK frequency falls below the threshold denoted by blue dots (●).
  - False stall detection shows no dependency on VBAT voltage.

See Notes 1 and 2 on page 28.

(4) Excitation mode vs. CLK frequency threshold [motor A]

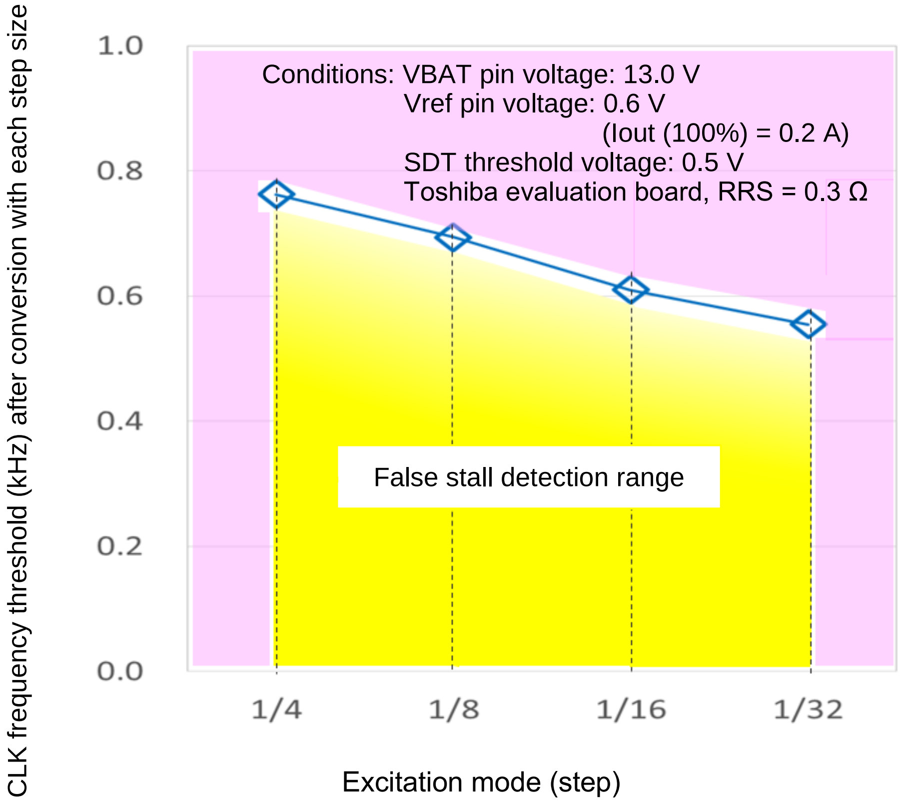


Figure 12. Excitation mode vs. CLK frequency threshold (for reference)

- As shown in Figure 12, the result is as follows:
  - False stall detection occurs in the range denoted in yellow (■), in which the CLK frequency falls below the threshold denoted by diamond-shaped marks (◇).
  - False stall detection shows a negative correlation where finer step resolution decreases the CLK frequency threshold after conversion with each step size.

See notes 1, 2, and 6 on page 28.

[B] Experimental result of motor B (500 mA)

(1) VREF pin voltage (output current setting) vs. CLK frequency threshold [motor B]

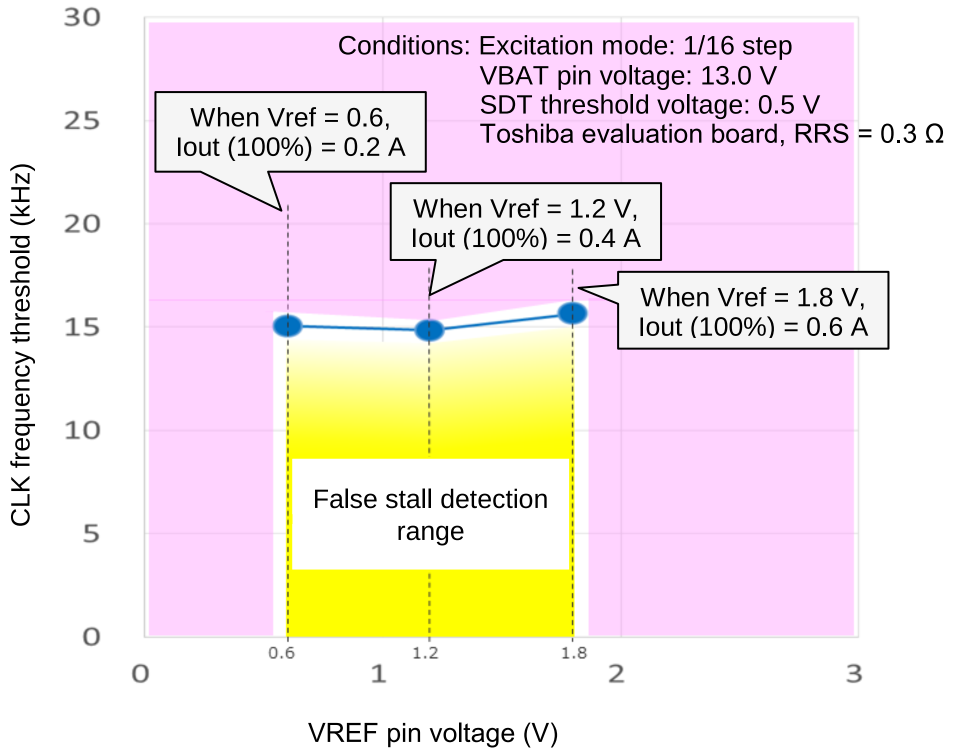


Figure 13. VREF pin voltage vs. CLK frequency threshold (for reference)

- As shown in Figure 13, the result is as follows:
  - False stall detection occurs in the range denoted in yellow (■), in which the CLK frequency falls below the threshold denoted by blue dots (●).
  - False stall detection has little dependency on set current.

See Notes 1, 2, and 3 on page 28.

(2) SDT threshold voltage vs. CLK frequency threshold [motor B]

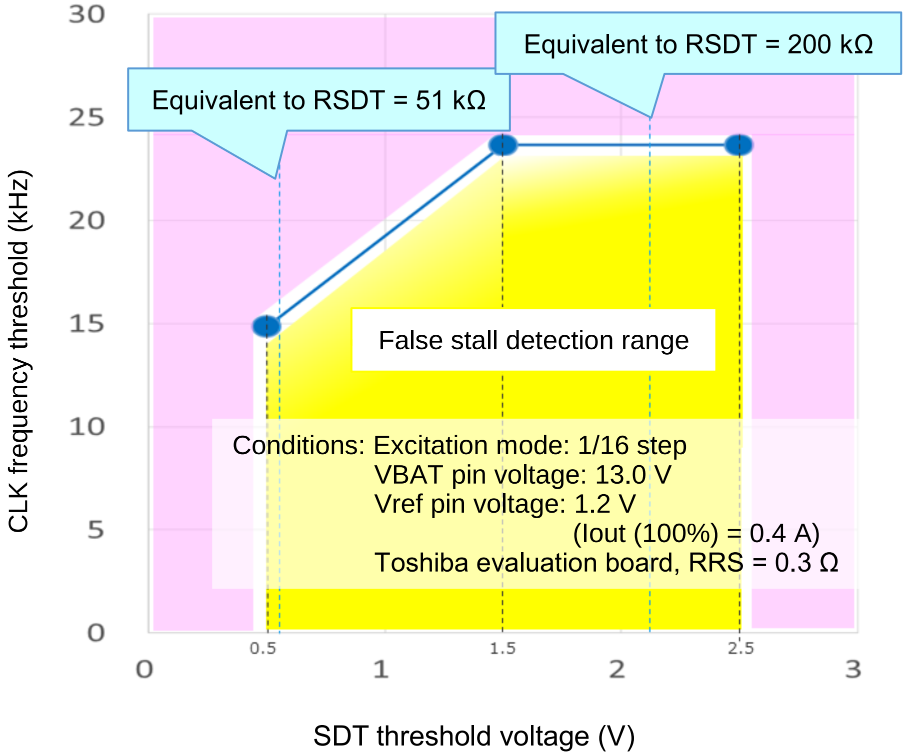


Figure 14. SDT threshold voltage vs. CLK frequency threshold (for reference)

- As shown in Figure 14, the result is as follows:
  - False stall detection occurs in the range denoted in yellow (■), in which the CLK frequency falls below the threshold denoted by blue dots (●).
  - False stall detection shows a partial positive correlation where, for a certain range, SDT threshold voltage increases with CLK frequency threshold.

See notes 1, 2, 4, and 5 on page 28.

(3) VBAT pin voltage vs. CLK frequency threshold [motor B]

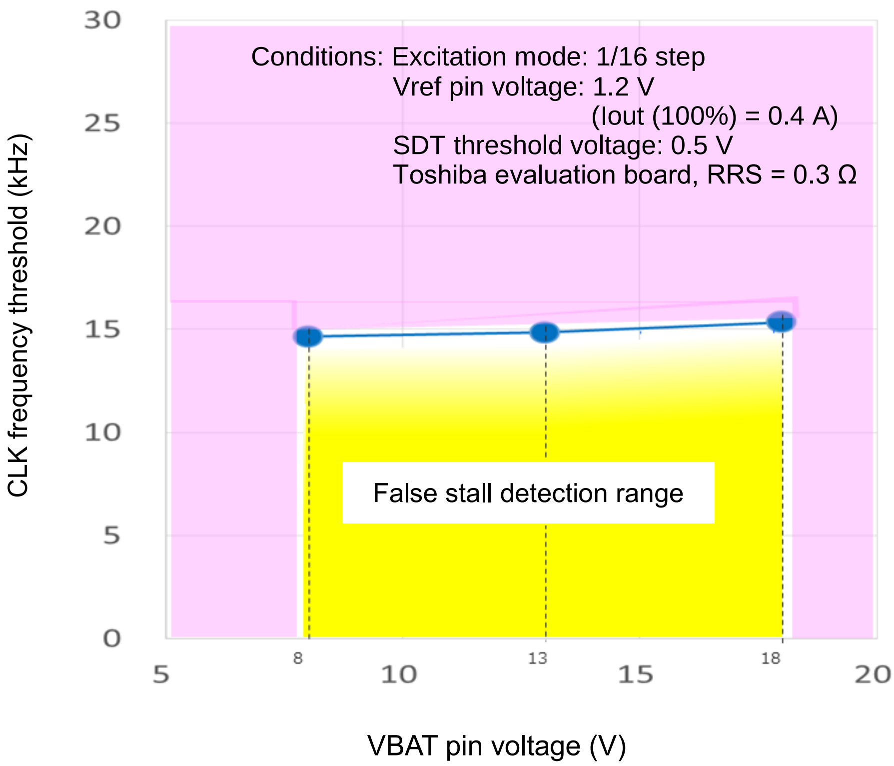


Figure 15. VBAT pin voltage vs. CLK frequency threshold (for reference)

- As shown in Figure 15, the result is as follows:
  - False stall detection occurs in the range denoted in yellow (■), in which the CLK frequency falls below the threshold denoted by blue dots (●).
  - False stall detection has little dependency on VBAT voltage.

See notes 1 and 2 on page 28.

(4) Excitation mode vs. CLK frequency threshold [motor B]

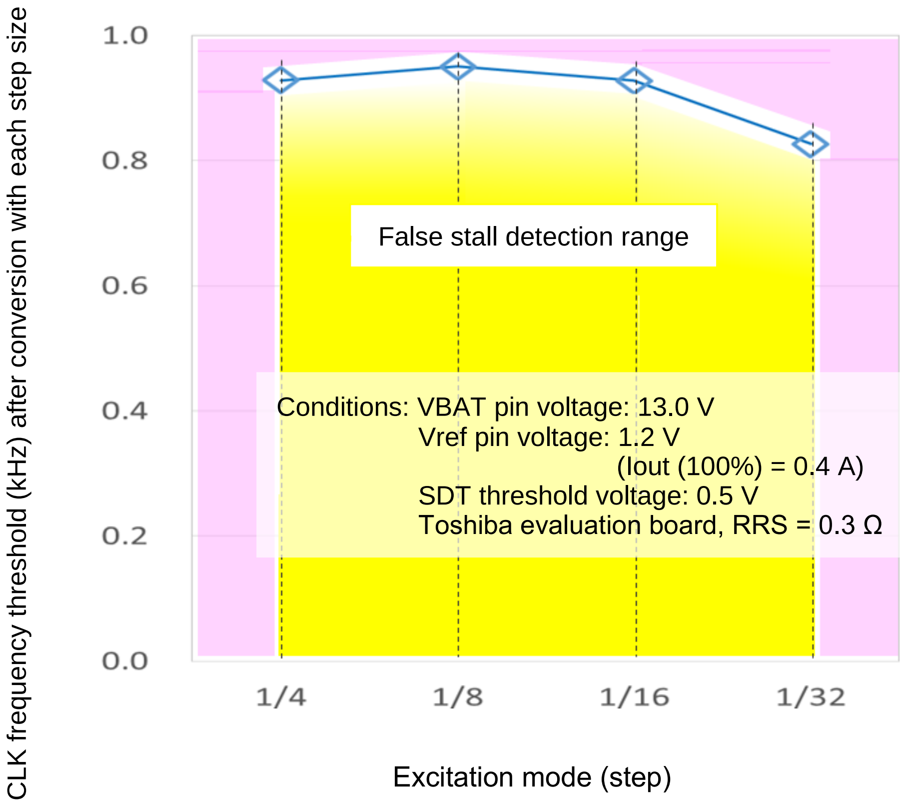


Figure 16. Excitation mode vs. CLK frequency threshold (for reference)

- As shown in Figure 16, the result is as follows:
  - False stall detection occurs in the range denoted in yellow (■), in which the CLK frequency falls below the threshold denoted by diamond-shaped marks (◇).
  - False stall detection shows a partial negative correlation where, for a certain range, finer step resolution decreases the CLK frequency threshold after conversion with each step size.

See notes 1, 2, and 6 on page 28.

[C] Experimental result of motor C (850 mA)

(1) VREF pin voltage (output current setting) vs. CLK frequency threshold [motor C]

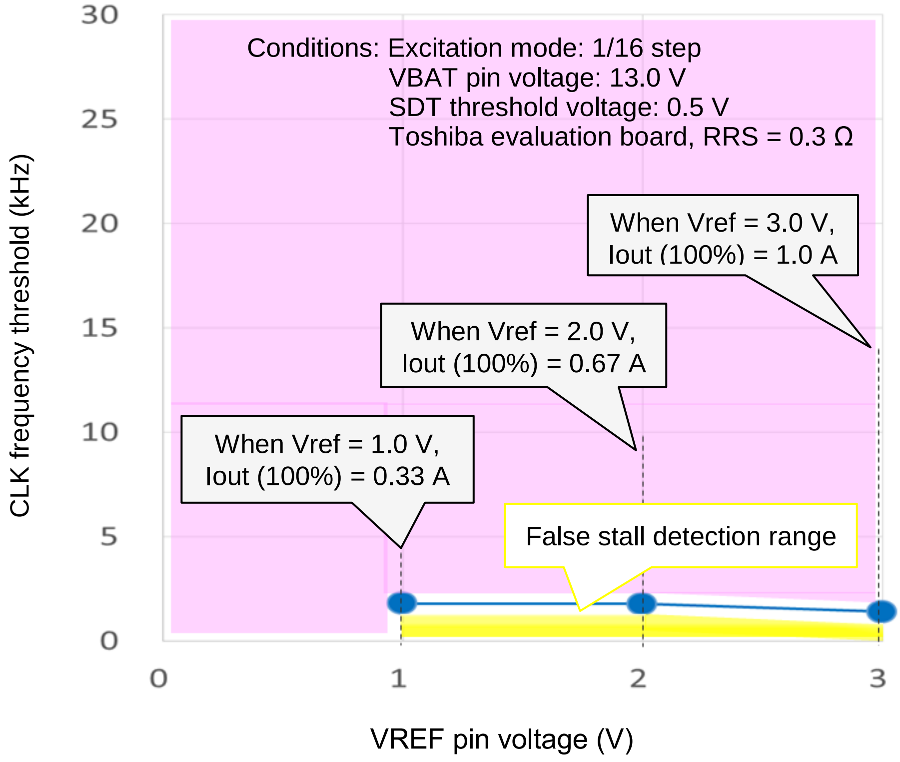


Figure 17. VREF pin voltage vs. CLK frequency threshold (for reference)

- As shown in Figure 17, the result is as follows:
  - False stall detection occurs in the range denoted in yellow (■), in which the CLK frequency falls below the threshold denoted by blue dots (●).
  - False stall detection has little dependency on set current.

See notes 1, 2, and 3 on page 28.

(2) SDT threshold voltage vs. CLK frequency threshold [motor C]

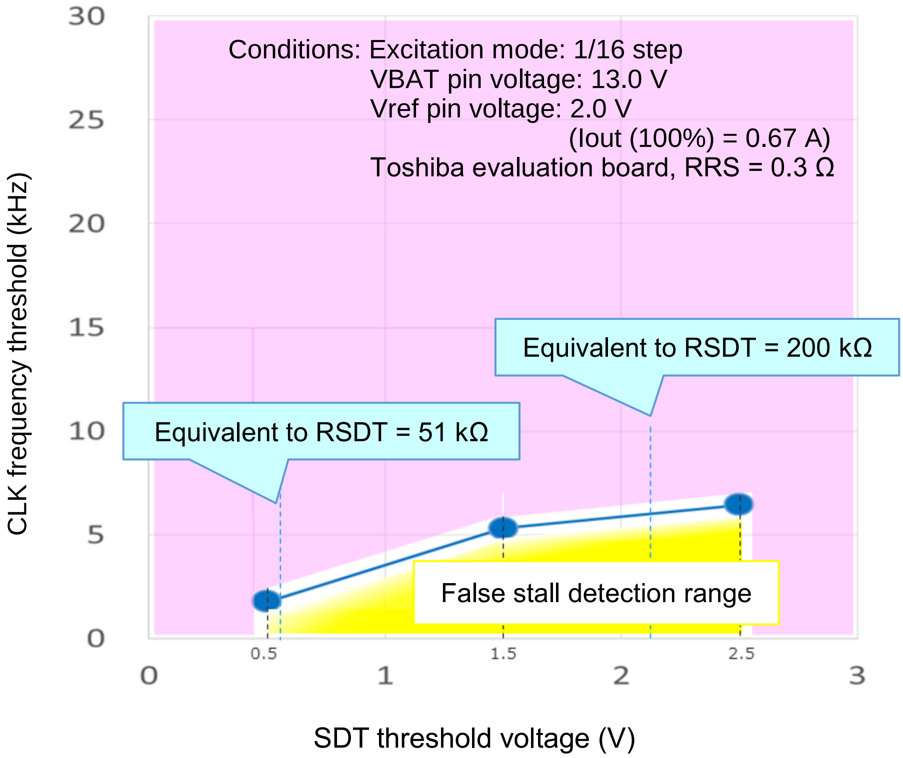


Figure 18. SDT threshold voltage vs. CLK frequency threshold (for reference)

- As shown in Figure 18, the result is as follows:
  - False stall detection occurs in the range denoted in yellow (■), in which the CLK frequency falls below the threshold denoted by blue dots (●).
  - False stall detection shows a positive correlation between the SDT threshold voltage and the CLK frequency threshold.

See notes 1, 2, 4, and 5 on page 28.

(3) VBAT pin voltage vs. CLK frequency threshold [motor C]

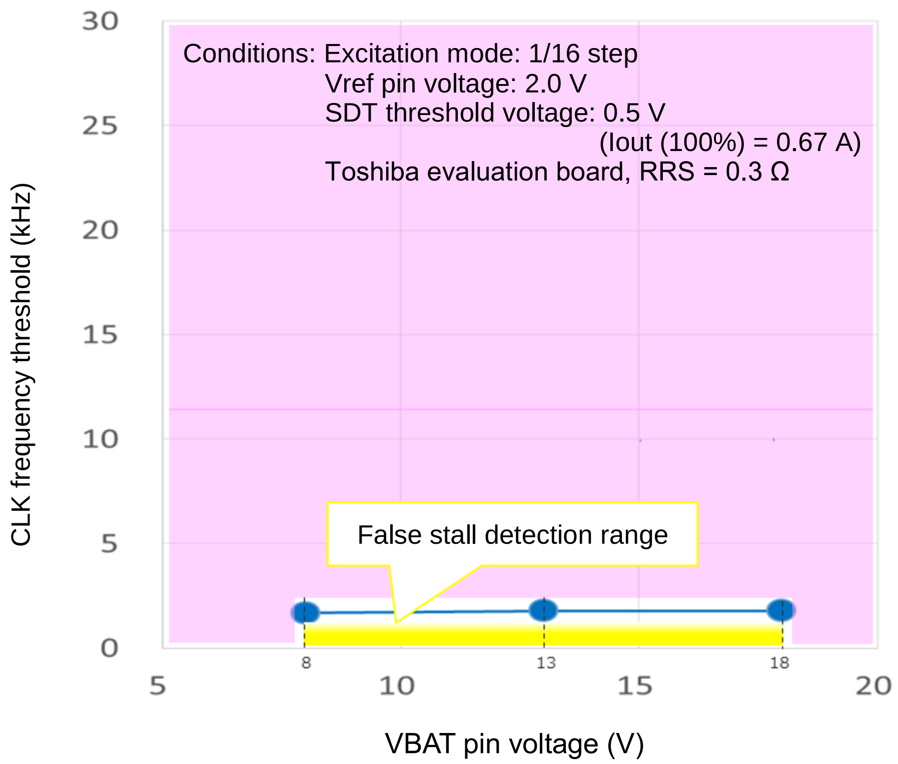


Figure 19. VBAT pin voltage vs. CLK frequency threshold (for reference)

- As shown in Figure 19, the result is as follows:
  - False stall detection occurs in the range denoted in yellow (■), in which the CLK frequency falls below the threshold denoted by blue dots (●).
  - False stall detection has no dependency on VBAT voltage.

See notes 1 and 2 on page 28.

(4) Excitation mode vs. CLK frequency threshold [motor C]

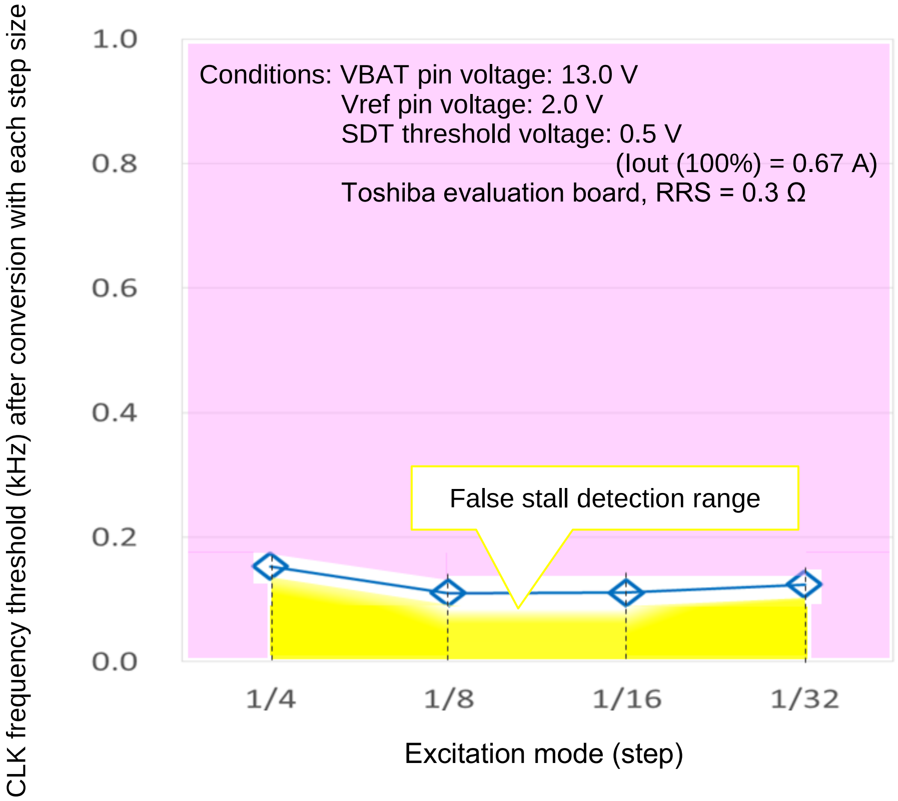


Figure 20. Excitation mode vs. CLK frequency threshold (for reference)

・As shown in Figure 20, the result is as follows:
- False stall detection occurs in the range denoted in yellow (■), in which the CLK frequency falls below the threshold denoted by diamond-shaped marks (◇).
- False stall detection has little dependency on step resolution.

See notes 1, 2, and 6 below.

Note 1: Plotted blue dots (●) and diamond-shaped marks (◇) show the false-detection threshold. In the range denoted in yellow (■) below these values, false detection is observed.
Note 2: Even in the range shown in pink (■) in the graph, IC and stall detection may not function.
Note 3: The VREF pin voltage setting (i.e., the output current setting) is determined based on the motor capability.
Note 4: Although the product specification requires a fixed resistor RSDT between the SDT pin and GND, in this experiment, threshold voltage was directly applied.
Note 5: For reference, some graphs show the points equivalent to RSDT resistance values of 50 kΩ and 200 kΩ when a resistor is connected.
Note 6: Full step conversion is defined as in the following example: If fCLK = 1600 Hz in 1/16 step mode, fCLK = 100 Hz after full step conversion (i.e., the frequency is divided by 16).

[D] Summary of experimental results

(1) Table 4 shows the effect on CLK frequency threshold.

Table 4. Effect on CLK frequency threshold

	Motor A Effect of parameters is relatively large.	**Motor B** CLK frequency threshold is relatively high in each set of conditions. False detection range is relatively large.	**Motor C** CLK frequency threshold is relatively low in every set of conditions. False detection range is relatively small.
VREF pin voltage	**Large** Shows positive correlation between set current and CLK frequency threshold.	**Medium** Little dependency on set current.	**Medium** Little dependency on set current.
SDT threshold voltage	**Large** Shows positive correlation between SDT threshold voltage and CLK frequency threshold.	**Large** Shows partial positive correlation between SDT threshold voltage and CLK frequency threshold.	**Large** Shows positive correlation between SDT threshold voltage and CLK frequency threshold.
VBAT pin voltage	**Small** No dependency on VBAT voltage.	**Medium** Little dependency on VBAT voltage.	**Small** No dependency on VBAT voltage.
Excitation mode	**Large** Shows negative correlation where finer step resolution decreases the CLK frequency threshold after conversion with each step size.	**Large** Shows partial negative correlation where finer step resolution decreases the CLK frequency threshold after conversion with each step size.	**Medium** Little dependency on step resolution.

(2) The common trends are as follows:

- CLK input signal frequency thresholds vary significantly depending on the motor.
- Since stall detection uses motor electromotive force, in a situation such as low motor speed which generates little electromotive force, false detection occurs.

9.2.4 Method of checking whether stall detection function can be useful in a system

・Purpose

・The purpose of this section is to explain the method of checking whether the stall detection function can be useful in a system.

・instructions

・First, waveforms should be displayed on an oscilloscope as shown in Figure 21.

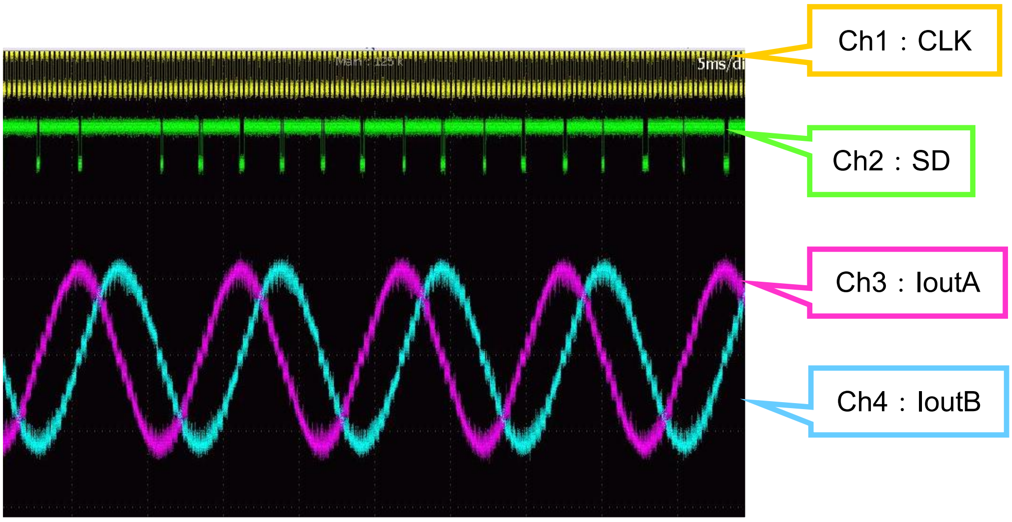


Figure 21. waveforms to check stall detection function (for reference)

・Ch1 : Signals observed at CLK pin
Signals inputted into CLK pin indicate how the speed is controlled.

・Ch2 : Signals observed at SD pin
Signals output from SD pin indicate whether stalls are detected.

・Ch3 : Current flowing through the motor coil on phase A measured by a current probe
Waveforms of Current flowing through a motor show how the motor is rotating.
The horizontal axis on an oscilloscope should be set so as to appear about 1 to 5 periods of waveforms on the screen.

・Ch4 : Current flowing through the motor coil on phase B measured by a current probe

・Figure 21 is captured using a trigger where SD pin switches H to L.

・Second, the dependence of signals output from SD pin upon the frequency of CLK should be observed.

・Signals output from SD pin should be paid attention to as the rotational speed of a motor is changing under average conditions in a system

・Each range of the frequency of a signal inputted into CLK pin (fCLK) should be found both when some signals output from SD pin as a stall is detected and when no signal outputs (SD=H).

・Judgement

・If f CLK used in an actual system is within the range where SD is always H, and if a stall is detected to output L from SD pin when an external force is applied to the rotational shaft of a motor, the stall detection function can be useful.

・Note

・Output signals from SD pin indicate whether stalls are detected. However, it is difficult to make sure whether the stall detection function is useful to a certain system or not only by the signals from SD pin.

10. Heat dissipation performance including circuit board

10.1 Transitional thermal resistance

・Figure 22 shows the transitional thermal resistance of the TB9120AFTG package.

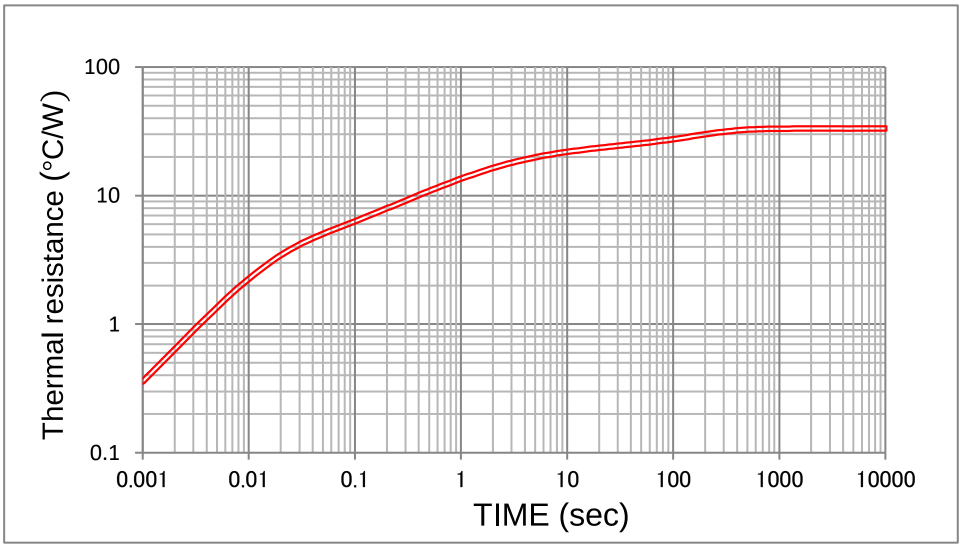


Figure 22. P-VQFN28-0606-0.65-002 transitional thermal resistance data (for reference)

Measurement conditions:

・Ta (ambient temperature) = 25°C
・Power consumption = 1 W
・No wind
・JEDEC 4-layer board (vias in IC mounting area: 9)

・Saturation thermal resistance (for reference)

Rth(j-a) = 31.3°C/W ··········· (1)

・The transitional thermal resistance data curve and saturation thermal resistance values vary depending on the heat -dissipation capability of the circuit board.

10.2 Power consumption

・The power consumption of the IC, represented by P, is calculated as follows:

$P = P_1 + P_2$ ··········· (2)

where
・P_1: Power consumption of motor output component (W)
・P_2: Power consumption of power-supply circuits (W)

・The power consumption of the motor output component, P_1, is calculated as follows:

・For 2-phase excitation: $P_{1(full)}$

$P_{1(full)}$ = Iout x Iout x Ron x number of phases ··········· (3)

・For 1-2-phase excitation to 8W1-2-phase excitation (other than 2-phase excitation): $P_{1(others)}$

$P_{1(others)}$ = Iout x 1/√2 x Iout x 1/√2 x Ron x number of phases

where
・Iout: Current flowing through motor coil (A)

- Ron: ON-resistance (sum of upper and lower resistance) (Ω)
- Number of phases: 2
- For 1-2-phase excitation to 8W1-2-phase excitation, average output power is multiplied by 1/√2.

- The power consumption of the VBAT circuits, P_2, is calculated as follows:

P_2 = VBAT x IBAT ………… (4)

where

- VBAT: Power-supply voltage to IC (V)
- IBAT: Current consumption of VBAT (A)

- Example 1: When 2-phase excitation is used, Iout = 0.5 A, Ron (sum of upper and lower resistances, 75°C) = 0.95 Ω, number of phases = 2, VBAT = 13.0 V, and IBAT = 3 mA, then equations (2)–(4) yield the following IC power consumption, P:

$P_{1(full)}$ = 0.475 W
P_2 = 0.039 W
P = 0.514 W ……… (5)

- Example 2: If the IC given in Example 1 is in standby mode, where one assumes that Iout = 0.00 A and IBAT = 1 μA, then the IC power consumption, P, is calculated as follows:

$P_{1(full)}$ = 0.00 W
P_2 = 0.013 mW
P = 0.013 mW

10.3 Junction temperature

- Junction temperature, Tj, is calculated as follows:

Tj = Ta + P x Rth(j-a) ………… (6)

Where

- Tj: Junction temperature (°C)
- Ta: Ambient temperature (°C)
- P: IC power consumption (W)
- Rth(j-a): Thermal resistance (°C/W)

- Example 3: For a JEDEC 4-layer board, the motor driving conditions given in Example 1, and Ta = 75°C, equations (1), (5), and (6) yield the following junction temperature, Tj:

Tj = 91.1°C

- Since this junction temperature is much less than the absolute maximum rating of 150°C, thermal problems that would make the IC unusable are unlikely, such as an over-temperature event.
- Rth(j-a) varies depending on the circuit board. It is recommended to test it under actual use conditions.
- The calculated value contains some error compared actual motor operation. This is due to, for example, ripple current caused by constant-current PWM control resulting in an average output current that is lower than the calculated value.
- Design the circuit board and other parts while considering thermal effects such as temperature derating so that the junction temperature (Tj) never exceeds 150°C. Always evaluate the design thoroughly.

10.4 Allowable power dissipation

・Figure 23 shows a PD-Ta curve for the TB9120AFTG package.

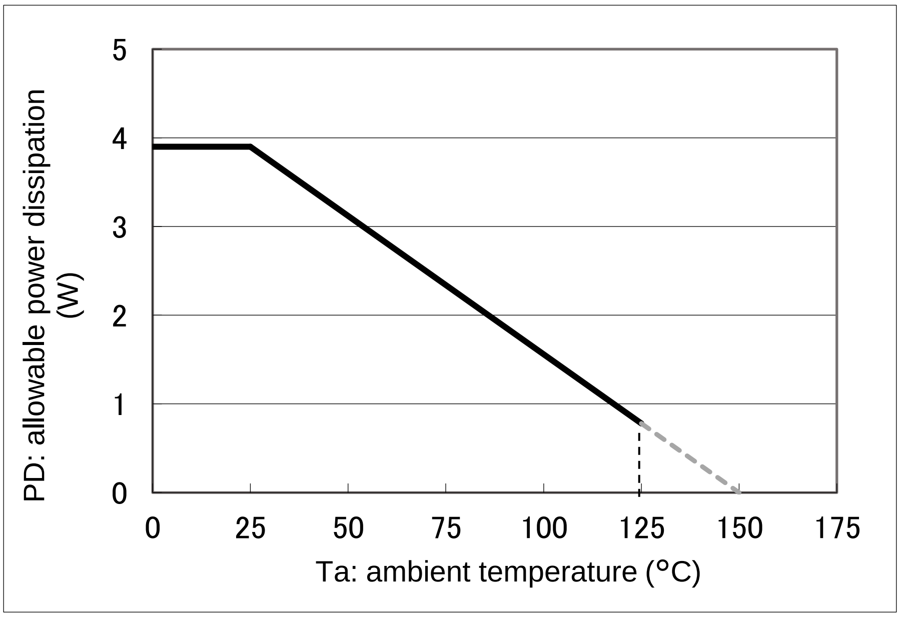


Figure 23. P-VQFN28-0606-0.65-002 PD-Ta curve (for reference)

Measurement conditions

- Ta (ambient temperature) = 25°C
- Power consumption = 1 W
- No wind
- JEDEC 4-layer board (vias in IC mounting area: 9)

・Allowable power dissipation, PD, is as follows:

PD = (Tjmax - Ta) / Rth(j-a) ………… (7)

where

- Tjmax: Absolute maximum junction temperature (°C)

  Tjmax = 150(°C) ………… (8)

- Ta: Ambient temperature (°C)
- Rth(j-a): Thermal resistance (°C/W)

・Example 4: Given the conditions in Figure 23 and Ta = 75°C, equations (1), (7), and (8) yield the following allowable power dissipation, PD:

PD = 2.39 W

・When Ta = 75°C, IC power consumption must be at most 2.39 W. For actual motor operation, it is recommended to use conditions that provide a margin of at least 20%.

11. Pin FMEA

11.1 Pin short-circuit FMEA

Table 5-1 shows pin short-circuit FMEA for pin numbers 1 to 7.

Table 5-1. Pin short-circuit FMEA 1/4

Pin number	Pin name	Description	Voltage, signal	Short circuit in 5 V circuit	VBAT short circuit	GND short circuit	Left adjacent pin short circuit	Right adjacent pin short circuit
1	VccOUT	5 V OUT	5 V output	No issue.	Exceeds withstand voltage, causing breakdown.	Generates over-current, reduces 5 V output voltage, and activates POR.	End of pin array. No issue.	No issue.
2	VDD	5 V IN	5 V input	No issue.	Exceeds withstand voltage, causing breakdown.	Generates over-current, reduces 5 V output voltage, and activates POR. (Note 1)	No issue.	No issue, but, motor output is no longer normal.
3	OSCM	PWM frequency; 5 V circuit	Oscillation signal output	No issue, but motor output is no longer normal.	Exceeds withstand voltage, causing breakdown.	No issue, but motor output is no longer normal.	No issue, but motor output is no longer normal.	No issue, but motor output is no longer normal.
4	VREF	5 V power supply input	5 V circuit input	No issue.	Exceeds withstand voltage, causing breakdown.	No issue.	No issue, but motor output is no longer normal.	No issue. Since VREF = 0 V, output current no longer flows.
5	GND	GND	GND	No issue, but large current flows through the external 5 V power supply.	No issue, but results in large current.	No issue.	No issue. Since VREF = 0 V, output current no longer flows.	No issue.
6	TEST2	Test (Note 2)	No signal	No issue, but current flows through external 5 V power supply.	Exceeds withstand voltage, causing breakdown.	No issue.	No issue.	No issue, but current keeps flowing. Stall may not be detected correctly.
7	SDT	Stall set resistance	Current output	No issue.	Exceeds withstand voltage, causing breakdown.	No issue, but current keeps flowing. Stall is not detected.	No issue, but current keeps flowing. Stall may not be detected correctly.	End of pin array. No issue.

Note 1: To use this IC, always connect the VccOUT and VDD pins outside the IC. Then, operation proceeds as described. If the VDD pin is used alone, the result for a GND short-circuit will be "No issue."

Note 2: To use the TEST2 pin, keep it open (unconnected).

・Table 5-2 shows pin short-circuit FMEA for pin numbers 8 to 14.

Table 5-2. Pin short-circuit FMEA 2/4

Pin number	Pin name	Description	Voltage, signal	Short circuit in 5 V circuit	VBAT short circuit	GND short circuit	Left adjacent pin short circuit	Right adjacent pin short circuit
8	RSA	RS resistance	GND	No issue, but large current flows through the external 5 V power supply.	Invalidates set current, resulting in large current.	No issue. Invalidates set current.	End of pin array; No issue.	H: System detects a short circuit to ground and turns output off. L: Same potential. No issue.
9	OUTA-	Motor output	VBAT/ GND	No issue, but results in large current. May trigger over-current detection.	H: No issue. L: Triggers over-current detection and turns output off.	H: Triggers over-current detection and turns output off. L: No issue.	H: System detects a short circuit to ground and turns output off. L: Same potential. No issue.	Triggers over-current detection. No issue.
10	OUTA+	Motor output	VBAT/ GND	No issue, but results in large current. May trigger over-current detection.	H: No issue. L: Triggers over-current detection and turns output off.	H: Triggers over-current detection and turns output off. L: No issue.	Triggers over-current detection. No issue.	H: Same potential. No issue. L: System detects a short circuit to ground and turns output off.
11	VBAT	VBAT input	VBAT	No issue, but large current flows through the external 5 V power supply.	No issue.	Results in large current flows, but since it flows externally, there is no issue.	H: Same potential. No issue. L: System detects a short circuit to ground and turns output off.	H: Same potential. No issue. L: System detects a short circuit to ground and turns output off.
12	OUTB-	Motor output	VBAT/ GND	No issue, but results in large current. May trigger over-current detection.	H: No issue. L: Triggers over-current detection and turns output off.	H: Triggers over-current detection and turns output off. L: No issue.	H: Same potential. No issue. L: System detects a short circuit to ground and turns output off.	Triggers over-current detection. No issue.
13	OUTB+	Motor output	VBAT/ GND	No issue, but results in large current. May trigger over-current detection.	H: No issue. L: Triggers over-current detection and turns output off.	H: Triggers over-current detection and turns output off. L: No issue.	Triggers over-current detection. No issue.	H: System detects a short circuit to ground and turns output off. L: Same potential. No issue.
14	RSB	RS resistance	GND	No issue, but large current flows through the external 5 V power supply.	Invalidates set current, resulting in large current.	No issue. Invalidates set current.	H: System detects a short circuit to ground and turns output off. L: Same potential. No issue.	End of pin array. No issue.

・Table 5-3 shows pin short-circuit FMEA for pin numbers 15 to 21.

Table 5-3. Pin short-circuit FMEA 3/4

Pin number	Pin name	Description	Voltage, signal	Short circuit in 5 V circuit	VBAT short circuit	GND short circuit	Left adjacent pin short circuit	Right adjacent pin short circuit
15	CLK	5 V circuit input	5 V/ GND	No issue. Motor does not rotate.	Exceeds withstand voltage, causing breakdown.	No issue. Motor does not rotate.	End of pin array. No issue.	No issue. Motor does not rotate. Set current may be changed.
16	TORQUE0	5 V circuit input	5 V/ GND	No issue. Set current becomes either 30% or 70%.	Exceeds withstand voltage, causing breakdown.	No issue. Set current becomes either 50% or 100%.	No issue. Motor does not rotate. Set current may be changed.	No issue. Set current may be changed.
17	TORQUE1	5 V circuit input	5 V/ GND	No issue. Set current becomes either 30% or 50%.	Exceeds withstand voltage, causing breakdown.	No issue. Set current becomes either 70% or 100%.	No issue. Set current may be changed.	No issue. Set current and/or excitation mode may be changed.
18	DMODE0	5 V circuit input	5 V/ GND	No issue. Fixed to a particular setting mode.	Exceeds withstand voltage, causing breakdown.	No issue. Fixed to a particular setting mode.	No issue. Set current and/or excitation mode may be changed.	No issue. Excitation mode may be changed.
19	DMODE1	5 V circuit input	5 V/ GND	No issue. Fixed to a particular setting mode.	Exceeds withstand voltage, causing breakdown.	No issue. Fixed to a particular setting mode.	No issue. Excitation mode may be changed.	No issue. Excitation mode may be changed.
20	DMODE2	5 V circuit input	5 V/ GND	No issue. Fixed to a particular setting mode.	Exceeds withstand voltage, causing breakdown.	No issue. Fixed to a particular setting mode.	No issue. Excitation mode may be changed.	No issue. Excitation mode may be changed and fixed to initial state.
21	START	5 V circuit input	5 V/ GND	The setting is continuously initialized.	Exceeds withstand voltage, causing breakdown.	No issue. Cannot be initialized.	No issue. Excitation mode may be changed and fixed to initial state.	End of pin array; No issue.

・Table 5-4 shows pin short-circuit FMEA for pin numbers 22 to 28.

Table 5-4. Pin short-circuit FMEA 4/4

Pin number	Pin name	Description	Voltage, signal	Short circuit in 5 V circuit	VBAT short circuit	GND short circuit	Left adjacent pin short circuit	Right adjacent pin short circuit
22	BSTBY	5 V circuit input	5 V/ GND	No issue. Cannot enter standby mode.	Exceeds withstand voltage, causing breakdown.	No issue. Fixed to standby mode.	End of pin array. No issue.	No issue. May be fixed to standby mode.
23	CW/CCW	5 V circuit input	5 V/ GND	No issue. Fixed to clockwise.	Exceeds withstand voltage, causing breakdown.	No issue. Fixed to counterclockwise.	No issue. May be fixed to standby mode.	No issue. May enter DISABLE state.
24	ENABLE	5 V circuit input	5 V/ GND	No issue. Cannot be disabled.	Exceeds withstand voltage, causing breakdown.	No issue. Enters DISABLE state.	No issue. May enter DISABLE state.	No issue. Enters DISABLE state.
25	TEST1	Test (Note 3)	GND	No issue, but large current flows through the external 5 V power supply.	No issue, but results in large current.	No issue.	No issue. Enters DISABLE state.	No issue, but current keeps flowing externally through the pull-up resistor. However, the microcontroller recognizes it as L.
26	MO	Open-drain output	5 V/ GND	No issue.	Exceeds withstand voltage, causing breakdown.	No issue, but current keeps flowing externally through the pull-up resistor. However, the microcontroller recognizes it as L.	No issue, but current keeps flowing externally through the pull-up resistor. However, the microcontroller recognizes it as L.	No issue.
27	DIAG	Open-drain output	5 V/ GND	No issue.	Exceeds withstand voltage, causing breakdown.	No issue, but current keeps flowing externally through the pull-up resistor. However, the microcontroller recognizes it as L.	No issue.	No issue.
28	SD	Open-drain output	5 V/ GND	No issue.	Exceeds withstand voltage, causing breakdown.	No issue, but current keeps flowing externally through the pull-up resistor. However, the microcontroller recognizes it as L.	No issue.	End of pin array. No issue.

Note 3: To use the TEST1 pin, connect it to GND.

11.2 Pin open FMEA

・Table 6 shows pin open FMEA.

Table 6. Pin open FMEA

Pin number	Pin name	Description	Voltage, signal	Pin open
1	VccOUT (Note)	5 V OUT	5 V output	No issue. IC does not work. No voltage is supplied to VDD. 5 V circuit does not work.
2	VDD	5 V IN	5 V input	No issue. IC does not work. No voltage is supplied to VDD. 5 V circuit does not work.
3	OSCM	PWM frequency; 5 V circuit	Oscillation signal output	No issue, but motor output is no longer normal.
4	VREF	5 V power supply input	5 V circuit input	No issue. Motor current decreases and set current is not output correctly.
5	GND	GND	GND	No issue. IC does not work normally.
6	TEST2	Test	No signal	No issue.
7	SDT	Stall set resistance	Current output	No issue. Stall detection does not work correctly.
8	RSA	RS resistance	GND	No issue. PWM constant-current control does not work and output turns off (output is in a high-impedance state).
9	OUTA-	Motor output	VBAT/GND	No issue. System detects load open and turns output off (output is in a high-impedance state).
10	OUTA+	Motor output	VBAT/GND	No issue. System detects load open and turns output off (output is in a high-impedance state).
11	VBAT	VBAT input	VBAT	No issue. System detects VBAT low voltage and turns output off (output is in a high-impedance state).
12	OUTB-	Motor output	VBAT/GND	No issue. System detects load open and turns output off (output is in a high-impedance state).
13	OUTB+	Motor output	VBAT/GND	No issue. System detects load open and turns output off (output is in a high-impedance state).
14	RSB	RS resistance	GND	No issue. PWM constant-current control does not work and output turns off (output is in a high-impedance state).
15	CLK	5 V circuit input	5 V/GND	No issue. Motor does not rotate.
16	TORQUE0	5 V circuit input	5 V/GND	No issue. Fixed to TORQUE0 = L. Output current setting may change.
17	TORQUE1	5 V circuit input	5 V/GND	No issue. Fixed to TORQUE1 = L. Output current setting may change.
18	DMODE0	5 V circuit input	5 V/GND	No issue. Fixed to DMODE0 = L. Excitation mode may change.
19	DMODE1	5 V circuit input	5 V/GND	No issue. Fixed to DMODE1 = L. Excitation mode may change.
20	DMODE2	5 V circuit input	5 V/GND	No issue. Fixed to DMODE2 = L. Excitation mode may change.
21	START	5 V circuit input	5 V/GND	No issue. Fixed to START = L. Enters normal operation (clockwise or counterclockwise) mode.
22	BSTBY	5 V circuit input	5 V/GND	No issue. Fixed to BSTBY = L. Enters standby mode.
23	CW/CCW	5 V circuit input	5 V/GND	No issue. Fixed to CW/CCW = L. Operates CCW (counterclockwise).
24	ENABLE	5 V circuit input	5 V/GND	No issue. Fixed to ENABLE = L. Output turns off (output is in a high-impedance state).
25	TEST1	Test	GND	No issue.
26	MO	Open-drain output	5 V/GND	No issue. System cannot monitor MO detection signal.
27	DIAG	Open-drain output	5 V/GND	No issue. System cannot monitor DIAG detection signal.
28	SD	Open-drain output	5 V/GND	No issue. System cannot monitor SD detection signal.

Note: To use this IC, always connect the VccOUT and VDD pins outside the IC.

12. Differences compared to TB9120FTG

12.1 Product overview

・In TB9120AFTG, disabling the OSCM pin anomaly-detection function, which is implemented in TB9120FTG, improves the noise tolerance.

12.2 Differences compared to TB9120FTG

・Table 7 shows the differences between TB9120FTG and TB9120AFTG.

Table 7. Differences between TB9120FTG and TB9120AFTG

Item \ Product	TB9120FTG	TB9120AFTG
C_{OSCM} (Note)	Necessary	Unnecessary
fPWM range	50 kHz ≤ fPWM ≤ 80 kHz	20 kHz ≤ fPWM ≤ 80 kHz
Flag signal from DIAG pin	OSCM pin anomaly, ISD, TSD, and load open	ISD, TSD, and load open
Laser marking	"TB9120FTG"	"9120AFTG"

Note: C_{OSCM} is an external capacitor between OSCM pin and GND.

13. Example application circuit

13.1 Circuit diagram

・Figure 24 shows the circuit diagram for an example application circuit.

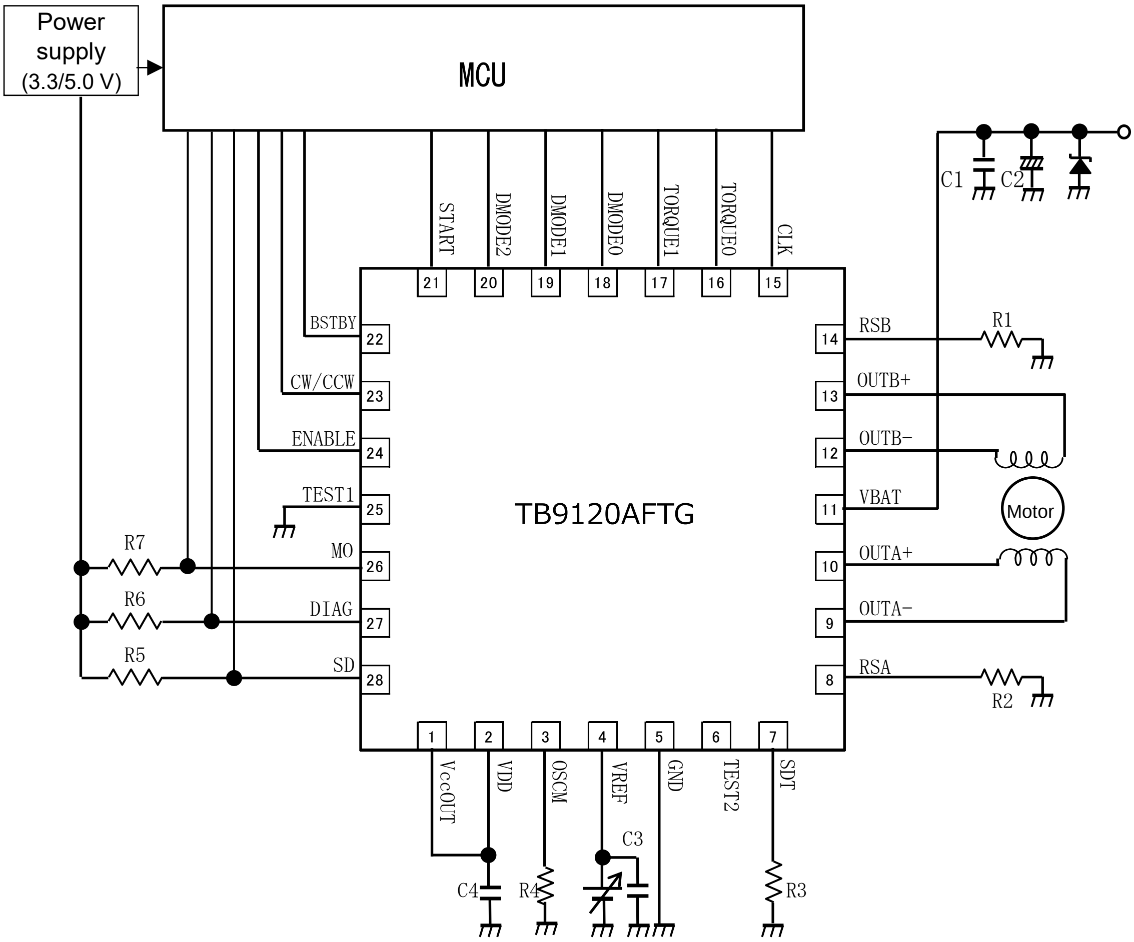


Figure 24. Circuit diagram of example application circuit

13.2 Reference values for part constants

・Table 8 shows reference values for part constants in the example application circuit.

Table 8. Reference values for part constants

Part symbol	Reference value	Remarks
R1	Resistance specified in "5. Output current" and "5.1 Output current value setting by VREF"	
R2	Resistance specified in "5. Output current" and "5.1 Output current value setting by VREF"	
R3	0 to 230 kΩ	
R4	60 kΩ to 300 kΩ	Recommended tolerance: +/-5%
R5	51 kΩ	
R6	51 kΩ	
R7	51 kΩ	
C1	0.1 μF	Laminated ceramic capacitor
C2	10 μF to 100 μF	Electrolytic capacitor
C3	0.1 μF	Laminated ceramic capacitor
C4	1000 pF to 0.1 μF	Laminated ceramic capacitor

The above are recommended values for your reference. Thoroughly test values on an actual circuit board before approving a design for mass production.

13.3 Notes

・The circuit diagram in the previous page is an example application circuit. It does not guarantee suitability for mass production.

・The VccOUT pin outputs 5 V. However, do not use it for any of the following purposes:
- Pull-up power supply for an input signal pin to this IC (CLK, TORQUE0, TORQUE1, CW/CCW, DMODE0, DMODE1, DMODE2, START, ENABLE, or BSTBY)
- VREF voltage supply
- Pull-up power supply for a detection flag output signal pin (MO, DIAG, or SD)
- Power supply to any component outside of the IC

・An external resistor ROSCM, which determines the PWM frequency (fPWM), is connected between the OSCM pin and GND.

・Current-detection resistors are connected between RSA and GND as well as between RSB and GND. Do not attach any parts other than the current-detection resistors here. Resistors with pure and fixed resistance having as small capacitive or inductive components as possible are essential for accurate current detection.

・Use a microcontroller or external power supply to pull up the BSTBY and DMODE2 pins. As shown in the circuit diagram of the example application circuit on the previous page, the VccOUT pin is connected to VDD and then to GND via a capacitor, but do not connect any other signals to the VccOUT pin.

・This IC is not designed to keep GND for small signals and GND for high-power signals separate. In your board wiring design, use a ground plane for both small-signal GND and GND from current detection resistors to keep the difference in potential as small as possible. Connect metal-exposed pads on the reverse side of the IC to the ground plane.

・To reduce noise, additional capacitors between GND and the following pins are effective: OUTA+, OUTA-, OUTB+, and OUTB-. Suitable capacitance values may vary depending on motor-specific constants and driving conditions such as voltage. For each system, find the value at which the motor-coil current waveform is distorted for various capacitance values.

Multiply the value by 10 to provide a safety margin. This yields a suitable capacitance value with which the system operates properly.

・Refer to "11. Example of Application Circuit" in the datasheet.

14. Evaluation board

14.1 Wiring

・Figure 25 shows the wiring diagram of the evaluation board.

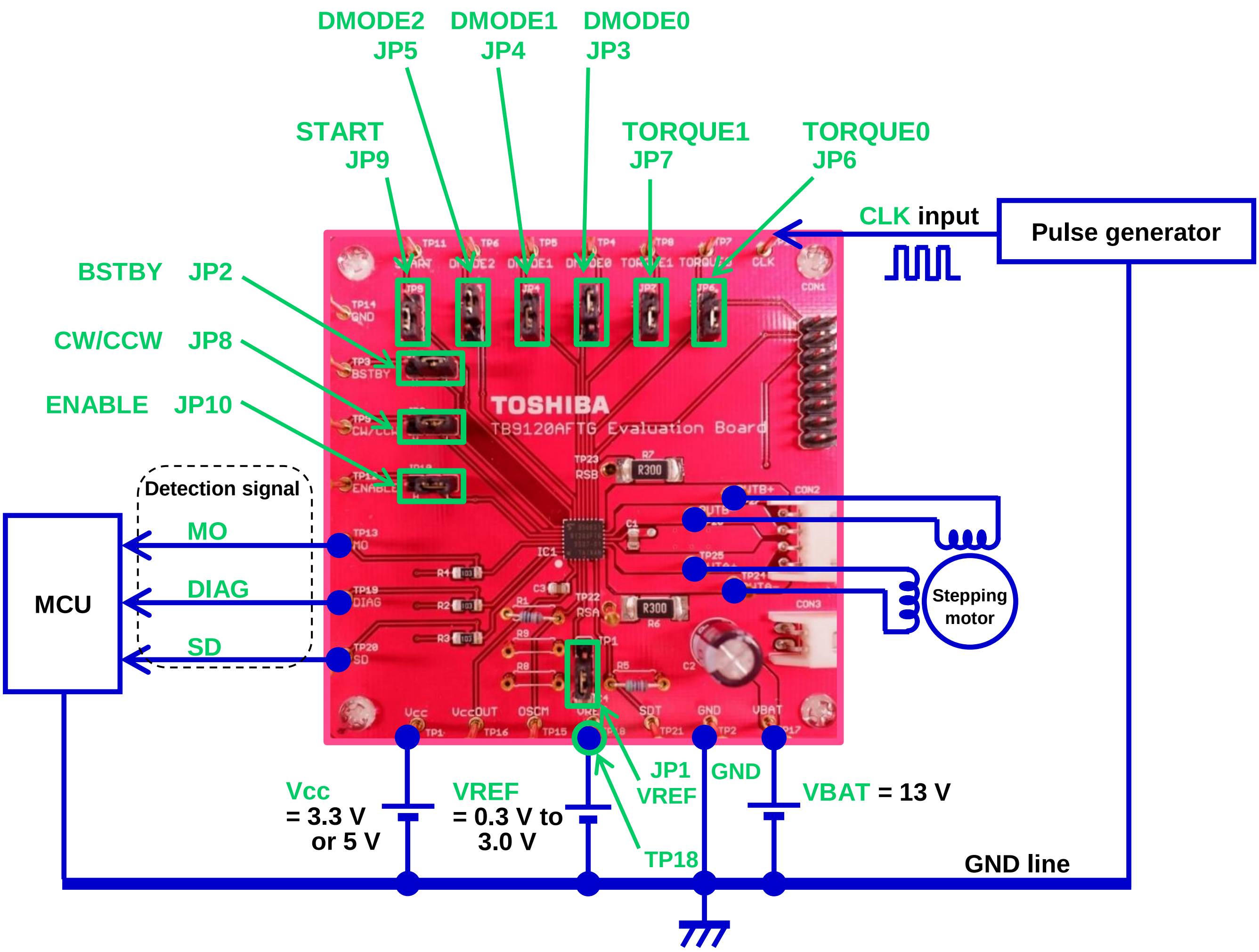
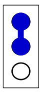
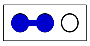
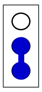
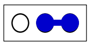


Figure 25. Wiring diagram of evaluation board

14.2 JP setting

・Set jumper wires as shown in Table 9.

Table 9. Jumper wire setting

<table>
<tr><th></th><th> and  : H short-circuited</th><th> and  : L short-circuited</th></tr>
<tr><td>JP1 VREF</td><td>VREF is determined by R8 and R9.</td><td>VREF voltage is applied to TP18.</td></tr>
<tr><td>JP2 BSTBY</td><td>H: Standby mode OFF</td><td>L: Standby mode ON</td></tr>
<tr><td>JP3 DMODE0</td><td colspan="2" rowspan="3">See the following table:
<table>
<tr><th>DMODE0</th><th>DMODE1</th><th>DMODE2</th><th>Function</th></tr>
<tr><td>L</td><td>L</td><td>L</td><td>Phase A 71%, phase B 71%</td></tr>
<tr><td>L</td><td>L</td><td>H</td><td>Sets 2-phase excitation</td></tr>
<tr><td>L</td><td>H</td><td>L</td><td>Sets 1-2-phase excitation (a)</td></tr>
<tr><td>L</td><td>H</td><td>H</td><td>Sets W1-2-phase excitation</td></tr>
<tr><td>H</td><td>L</td><td>L</td><td>Sets 1-2-phase excitation (b)</td></tr>
<tr><td>H</td><td>L</td><td>H</td><td>Sets 2W1-2-phase excitation</td></tr>
<tr><td>H</td><td>H</td><td>L</td><td>Sets 4W1-2-phase excitation</td></tr>
<tr><td>H</td><td>H</td><td>H</td><td>Sets 8W1-2-phase excitation</td></tr>
</table></td></tr>
<tr><td>JP4 DMODE1</td></tr>
<tr><td>JP5 DMODE2</td></tr>
<tr><td>JP6 TORQUE0</td><td colspan="2" rowspan="2">See the following table:
<table>
<tr><th>TORQUE0</th><th>TORQUE1</th><th>Function</th></tr>
<tr><td>L</td><td>L</td><td>Current set value x 100%</td></tr>
<tr><td>H</td><td>L</td><td>Current set value x 70%</td></tr>
<tr><td>L</td><td>H</td><td>Current set value x 50%</td></tr>
<tr><td>H</td><td>H</td><td>Current set value x 30%</td></tr>
</table></td></tr>
<tr><td>JP7 TORQUE1</td></tr>
<tr><td>JP8 CW/CCW</td><td>H: Clockwise</td><td>L: Counterclockwise</td></tr>
<tr><td>JP9 START</td><td>H: Initialization of electrical angle</td><td>L: Normal operation</td></tr>
<tr><td>JP10 ENABLE</td><td>H: Output MOSFET operation ON</td><td>L: Output MOSFET operation OFF</td></tr>
</table>

14.3 Procedure

・Wiring

(1) Connect a stepping motor to OUTA+, OUTA-, OUTB+, and OUTB-.
(2) Connect the power supply to VBAT.
(3) Connect the power supply to Vcc.
(4) Connect the power supply to VREF.
(5) Connect a pulse generator to CLK.

・Switching power supply on

(1) Check that BSTBY = L and ENABLE = L.
(2) Apply 7 to 18 V to VBAT.
(3) Apply 3.3 to 5 V to Vcc.
(4) Apply 0.3 to 3.0 V to VREF.
(5) Calculate the current with the following formula:

$$\text{Iout (100\%)} = 1/10 \times \frac{\text{Vref (V)}}{\text{RRS }(\Omega)}$$

Current-detection resistance on the board: Initial setting for RRS = 0.3 Ω

・Input signal setting

(1) Set an excitation mode using DMODE0, DMODE1, and DMODE2.
 Note: If DMODE0 = DMODE1 = DMODE2 = L, the motor does not rotate.

(2) Set TORQUE0 and TORQUE1 current.

(3) Set BSTBY to H.

(4) Input a clock signal to CLK.

(5) Set START to L.

(6) Set ENABLE to H.

14.4 Circuit diagram

・Figure 26 shows the circuit diagram of the evaluation board.

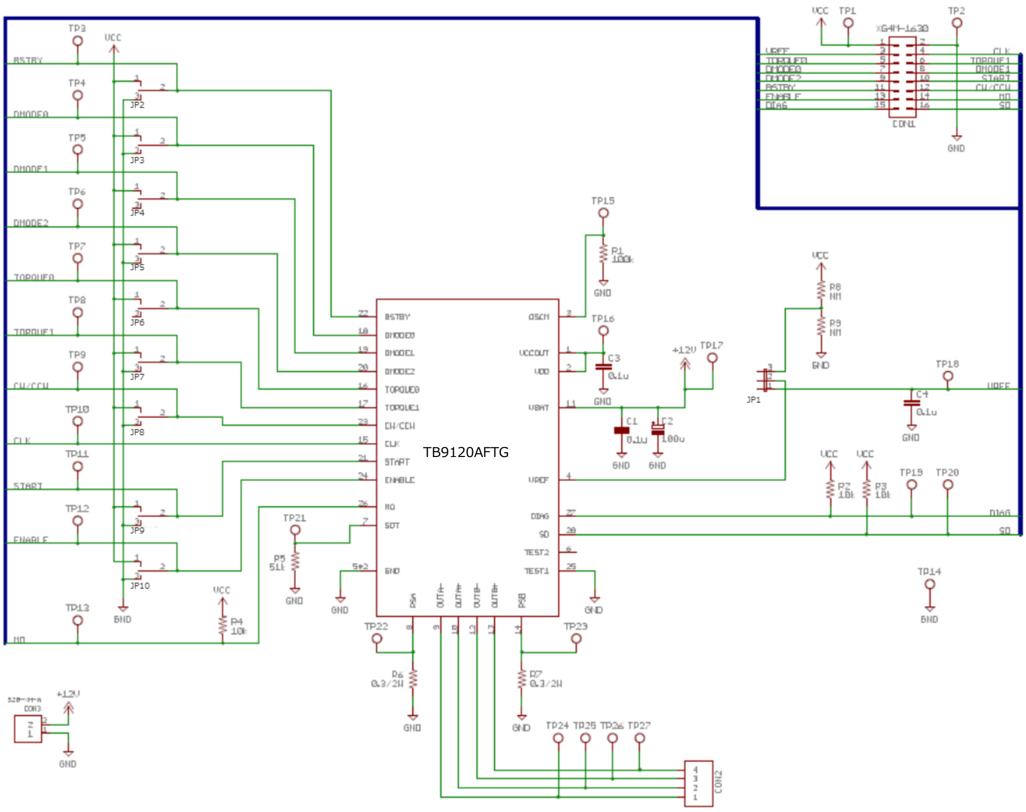


Figure 26. Circuit diagram of evaluation board

15. Recommended land pattern

15.1 Pattern diagram

・Figure 27 shows a recommended land pattern.

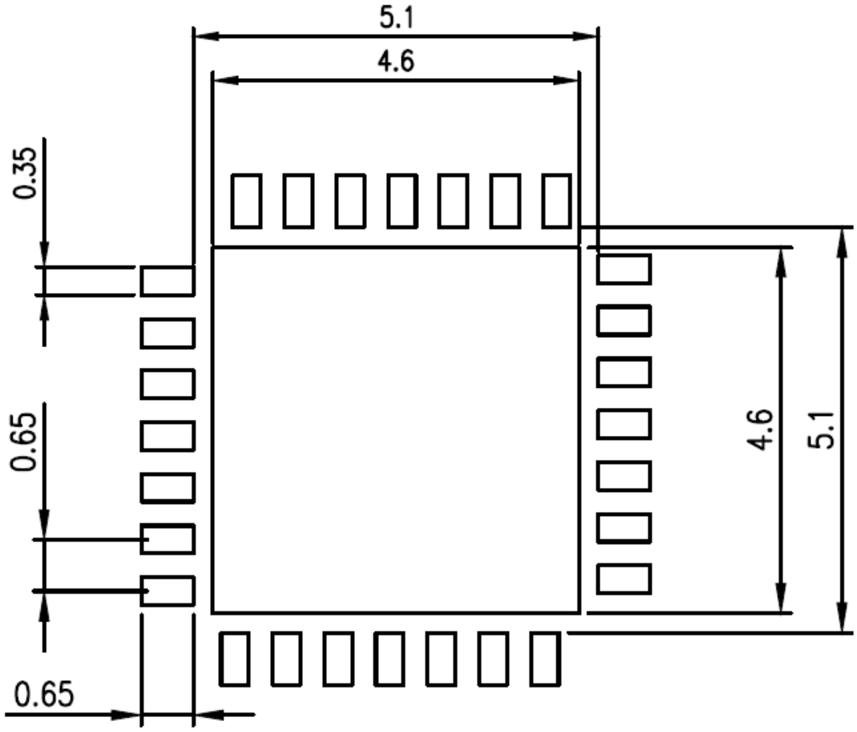


Figure 27. Recommended land pattern

15.2 Notes

・The diagram is shown in millimeters.

・This figure is a reference diagram complying with JEITA ET-7501 Level 3. We assume no liability for correctness and completeness of the figure and information.

・It is the user's responsibility to thoroughly evaluate various conditions (such as soldering conditions) and adjust them.

・Figures in this material are not intended to show actual shapes and dimensions accurately. Do not estimate the dimensions of the actual product to use for your design by measuring the figures.

・When designing for or using this product, always check and comply with the latest product information as well as other relevant documents, such as instruction manuals of equipment using this product.

15.3 Design around E-Pad

・For circuit board design around the E-Pad, be sure to refer to "3.2. Design around E-Pad" on page 5/14 of "Package Mounting Guide QFN", which is introduced on the next page.

16. Package mounting guide

- Please see the reference document "Package Mounting Guide QFN".

- To download this document, go to our website:

  https://toshiba.semicon-storage.com/ap-en/semiconductor/design-development/package.html

  Scroll down the page and click on "Package Mounting Guide QFN" in "Package Mounting Guide".

- It describes circuit board design techniques and mounting methods. Efficient thermal dissipation using thermal vias on the mount board is mandatory to achieve full performance for the power IC.

17. 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.

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.

18. 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 ratings 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 detection functions. If the power supply is unstable, the detection function may not operate, causing IC breakdown. IC breakdown may cause injury, smoke or ignition.

[5] Carefully select external parts (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.

[6] Anomaly detection functions, such as ISD and TSD, are functions which detects or avoids abnormal conditions temporarily, and don’t guarantee that IC does not break down. In addition, not only may the detection functions not work properly but also IC may break down when IC is used out of the range described specifications.

19. Points to remember on handling of ICs

Over current detection circuit

Over current detection circuit do not necessarily protect ICs under all circumstances. If a short circuit continues for a long time, IC may break down due to severe stress. Therefore, a system should be designed to release a status of over current immediately.

Depending on the method of use and/or usage conditions, such as exceeding absolute maximum ratings can cause 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.

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.

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 (Tj) at any time and condition. These ICs generate heat even during normal use. An inadequate IC heat radiation design can lead to decrease in IC life, deterioration of IC characteristics or IC breakdown. In addition, please design the device taking into considerate the effect of IC heat radiation with peripheral components.

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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