Toshiba BiCD Process Integrated Circuit Silicon Monolithic

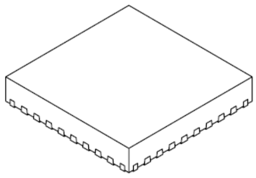
TB67S539SFTG

BiCD Constant-Current Two-Phase Bipolar Stepping Motor Driver IC

1. Description

The TB67S539SFTG is a two-phase bipolar stepping motor driver using a PWM chopper.
Fabricated with the BiCD process, the TB67S539SFTG is rated at 40 V/2.0 A (Absolute maximum ratings).
A stepping motor can be operated with a single VM power supply by built-in regulator.

TB67S539SFTG



P-VQFN32-0505-0.50-004

Weight: 0.066 g (typ.)

2. Features

- BiCD process monolithic IC.
- Capable of controlling bipolar stepping motor.
- Advanced Current Detect System (ACDS) realizes a PWM constant-current control without external current detection resistors.
- Advanced Dynamic Mixed Decay (ADMD) realizes a high efficiency PWM constant-current control.
- Clock input control.
- Operational in full, half, quarter, 1/8, 1/16, and 1/32 step resolutions.
- BiCD process: Use DMOSFET for the output power transistor.
- High withstand voltage and large current drive: 40 V / 2.0 A (Absolute maximum ratings).
- Built-in thermal shutdown (TSD), over-current detection (ISD), and under voltage lockout (UVLO).
- External components for a charge pump are reduced.
- Package: QFN32 (5 mm × 5 mm).

3. Block Diagram

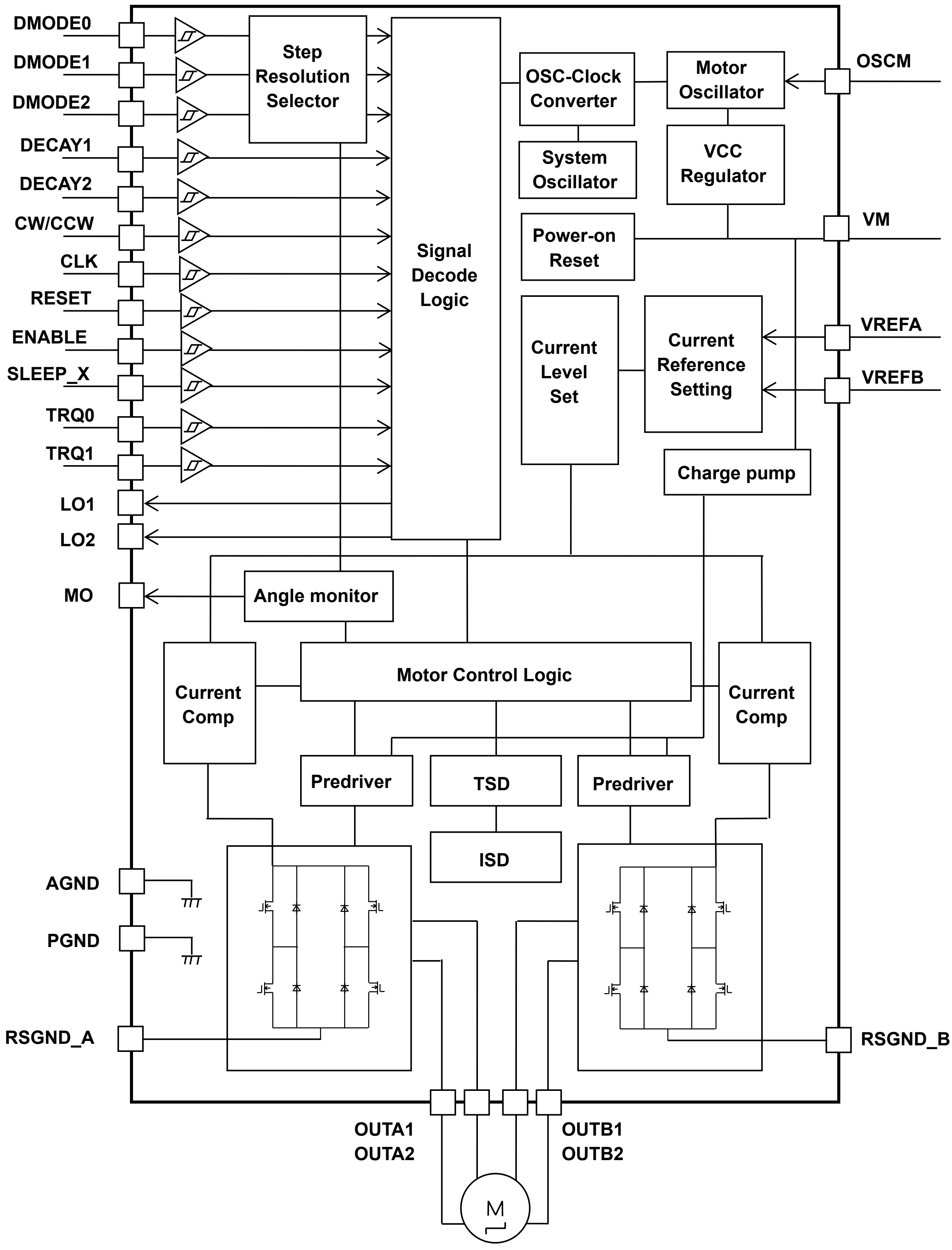


Figure 3.1 Block Diagram

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

Note: All the grounding wires of the TB67S539SFTG should run on the solder mask on the PCB and be externally terminated at only one point. Also, a grounding method should be considered for efficient heat dissipation. Careful attention should be paid to the layout of the output, VM and GND traces, to avoid short circuits across output pins or to the power supply or ground. If such a short circuit occurs, the device may be permanently damaged. Also, the utmost care should be taken for pattern designing and implementation of the device since it has power supply pins (VM, OUTA1, OUTA2, OUTB1, OUTB2, AGND, PGND, RSGND_A, and RSGND_B) through which a particularly large current may run. If these pins are wired incorrectly, an operation error may occur or the device may be destroyed. The logic input pins must also be wired correctly. Otherwise, the device may be damaged owing to a current running through the IC that is larger than the specified current. Careful attention should be paid to design patterns and mountings.

4. Pin Assignments

(Top View)

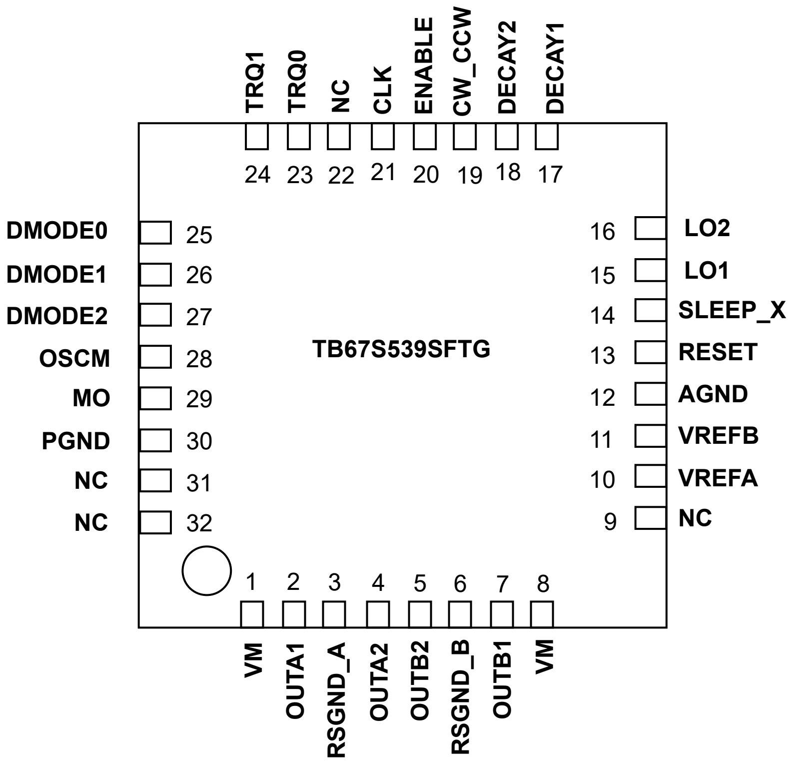


Figure 4.1 Pin Assignments

5. Pin Description

5.1. Pin Function Description TB67S539SFTG

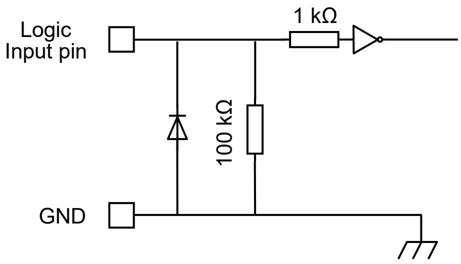
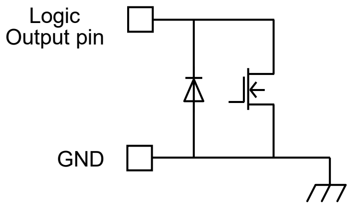
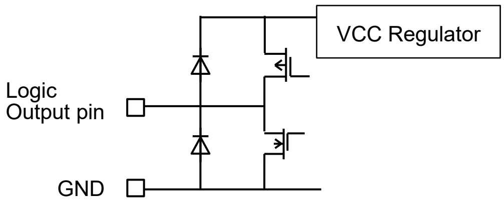
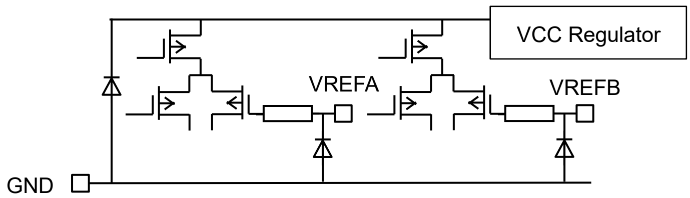
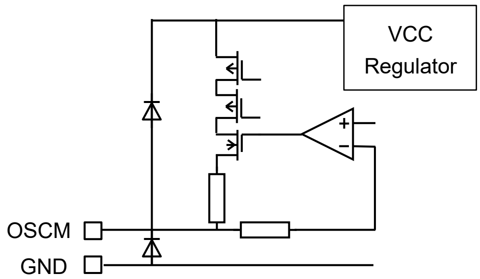
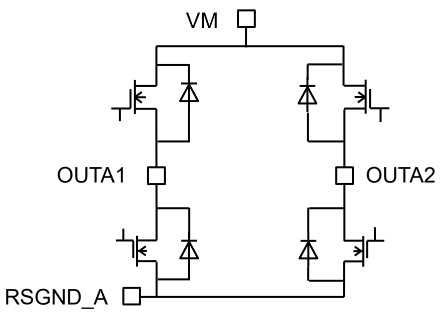
Table 5.1 Pin Function Description

Pin number	Pin name	Function
1	VM	VM voltage input pin
2	OUTA1	Motor A ch output pin
3	RSGND_A	Motor A ch GND pin
4	OUTA2	Motor A ch output pin
5	OUTB2	Motor B ch output pin
6	RSGND_B	Motor B ch GND pin
7	OUTB1	Motor B ch output pin
8	VM	VM voltage input pin
9	NC	Non connection
10	VREFA	A ch output current threshold reference pin
11	VREFB	B ch output current threshold reference pin
12	AGND	GND pin
13	RESET	RESET signal input pin. The electrical angle is initialized.
14	SLEEP_X	SLEEP signal input pin
15	LO1	Reset signal output pin at error detection
16	LO2	Reset signal output pin at error detection
17	DECAY1	Constant-current chopping control change pin
18	DECAY2	Constant-current chopping control change pin
19	CW_CCW	Rotation direction change pin
20	ENABLE	ENABLE signal input pin. A ch and B ch motor output ON/OFF control pin
21	CLK	Clock signal input pin. The electrical angle leads at a rising edge.
22	NC	Non connection
23	TRQ0	Torque change pin
24	TRQ1	Torque change pin
25	DMODE0	Step resolution setting pin
26	DMODE1	Step resolution setting pin
27	DMODE2	Step resolution setting pin
28	OSCM	Resistor connection pin for OSCM setting
29	MO	Electrical angle monitor pin
30	PGND	Motor output GND pin
31	NC	Non connection
32	NC	Non connection

Note: NC pins should be set open.

5.2. Input and Output Equivalent Circuit

Table 5.2 Input and Output Equivalent Circuit

端子名称	等価回路
CLK, ENABLE RESET, CW/CCW DMODE0, DMODE1 DMODE2, TRQ0 TRQ1, SLEEP_X DECAY1, DECAY2	
MO LO1	
LO2	
VREFA VREFB	
OSCM	
VM OUTA1 OUTA2 OUTB1 OUTB2 RSGND_A RSGND_B	 Note: Same as OUTB1 and OUTB2

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

6. Functional Description: TB67S539SFTG

6.1. SLEEP_X function

The operation can resume from the output forced off state, which is configured by the thermal shutdown detection (TSD) and the over-current detection (ISD), by setting SLEEP mode once and then setting the normal operation mode again. The SLEEP_X pin is set to Low, and SLEEP mode is set after 100 μs. The SLEEP_X pin is set to High, and normal mode resumes after 10 ms(Max).

Table 6.1 SLEEP_X function

SLEEP_X	Function
L	SLEEP mode (Charge pump stop, and VCC Reg stop)
H	Normal operation

6.2. CLK function

Each up-edge of the CLK signal shifts the current step and electrical angle of the motor.

Table 6.2 CLK function

CLK	Function
↑	Shifts the electrical angle and current step per each up-edge.
↓	- (Holds the former state)

6.3. ENABLE function

The ENABLE pin controls the ON and OFF of the stepping motor outputs. The normal constant-current control is started by switching ON. In the setting of switching OFF, the MOSFET is OFF and the output becomes high impedence state.

Table 6.3 ENABLE function

ENABLE	Function
H	Output MOSFET operation: ON (Normal operation)
L	Output MOSFET operation: OFF (opertion stop and high impedence state)

6.4. CW/CCW function

The CW/CCW pin controls the rotation direction of the stepping motor.

Table 6.4 CW/CCW function

CW/CCW	Function
H	Forward rotation (CW)
L	Reverse rotation (CCW)

6.5. DMODE0, DMODE1, and DMODE2 functions

The DMODE pins are used to set the step resolution for stepping motor operation.

Table 6.5 DMODE0, DMODE1, and DMODE2 functions

DMODE0	DMODE1	DMODE2	Function
L	L	L	Full step resolution setting
L	L	H	Half step resolution (a) setting
L	H	L	Half step resolution (b) setting
L	H	H	Quarter step resolution setting
H	L	L	1/8 step resolution setting
H	L	H	1/16 step resolution setting
H	H	L	1/32 step resolution setting
H	H	H	1/32 step resolution setting

6.6. Sequence in each drive mode: Clock input control mode

6.6.1. Full step resolution setting

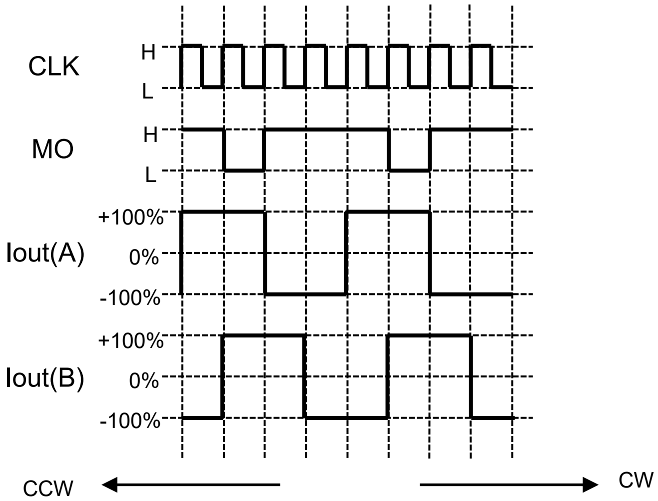


Figure 6.1 Full step resolution setting

6.6.2. Half step resolution (a) setting

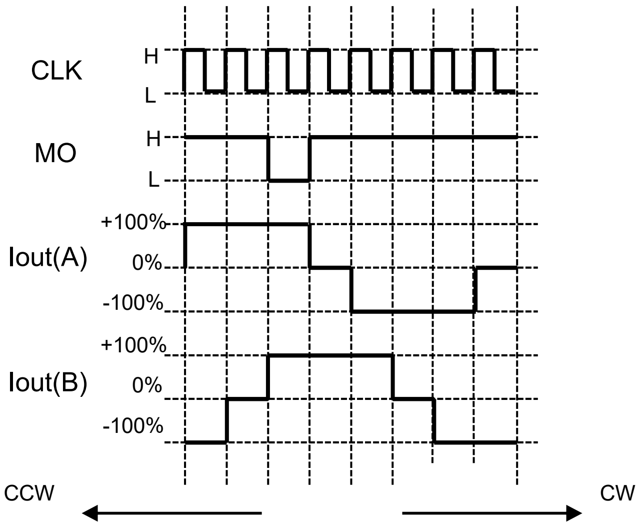


Figure 6.2 Half step resolution (a) setting

Waveform of MO output: State of pull-up.

Note: Timing charts may be simplified for explanatory purpose.

6.6.3. Half step resolution (b) setting

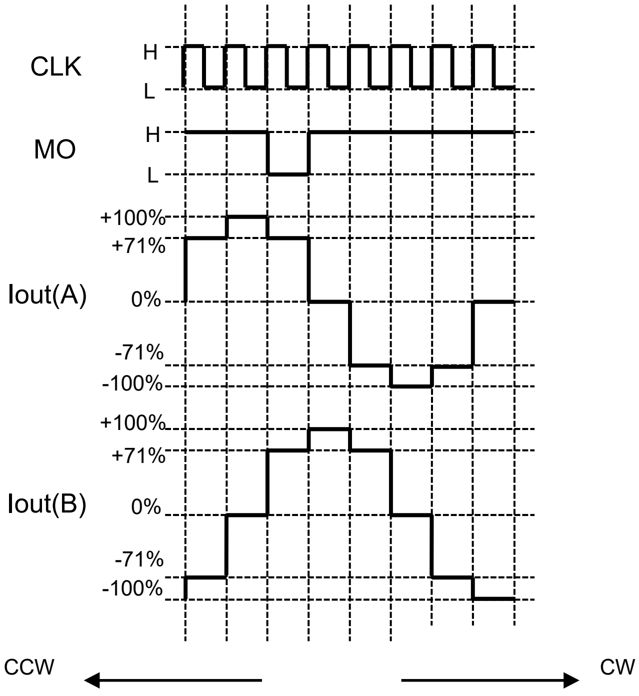


Figure 6.3 Half step resolution (b) setting

6.6.4. Quarter step resolution setting

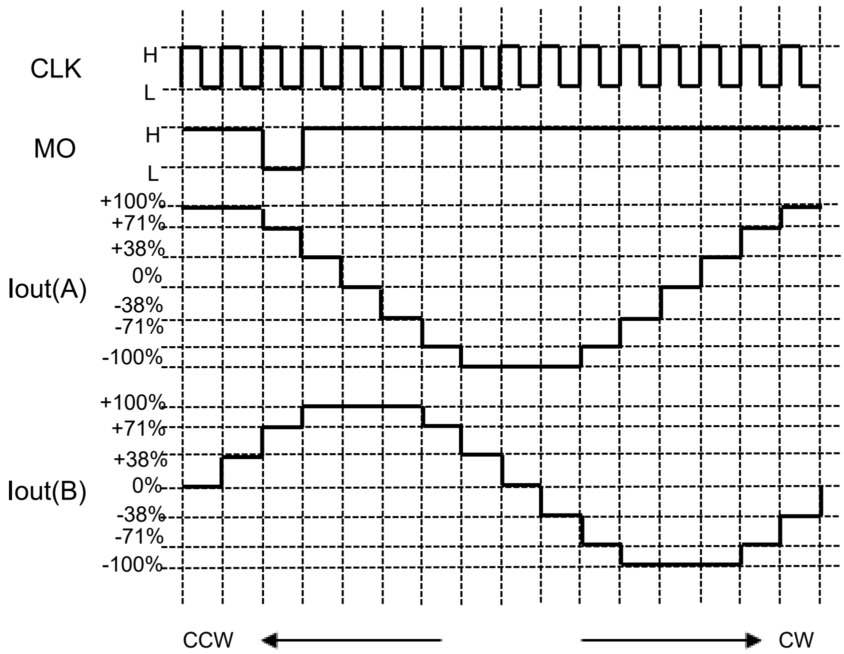


Figure 6.4 Quarter step resolution setting

Waveform of MO output: State of pull-up.

Note: Timing charts may be simplified for explanatory purpose.

6.6.5. 1/8 step resolution setting

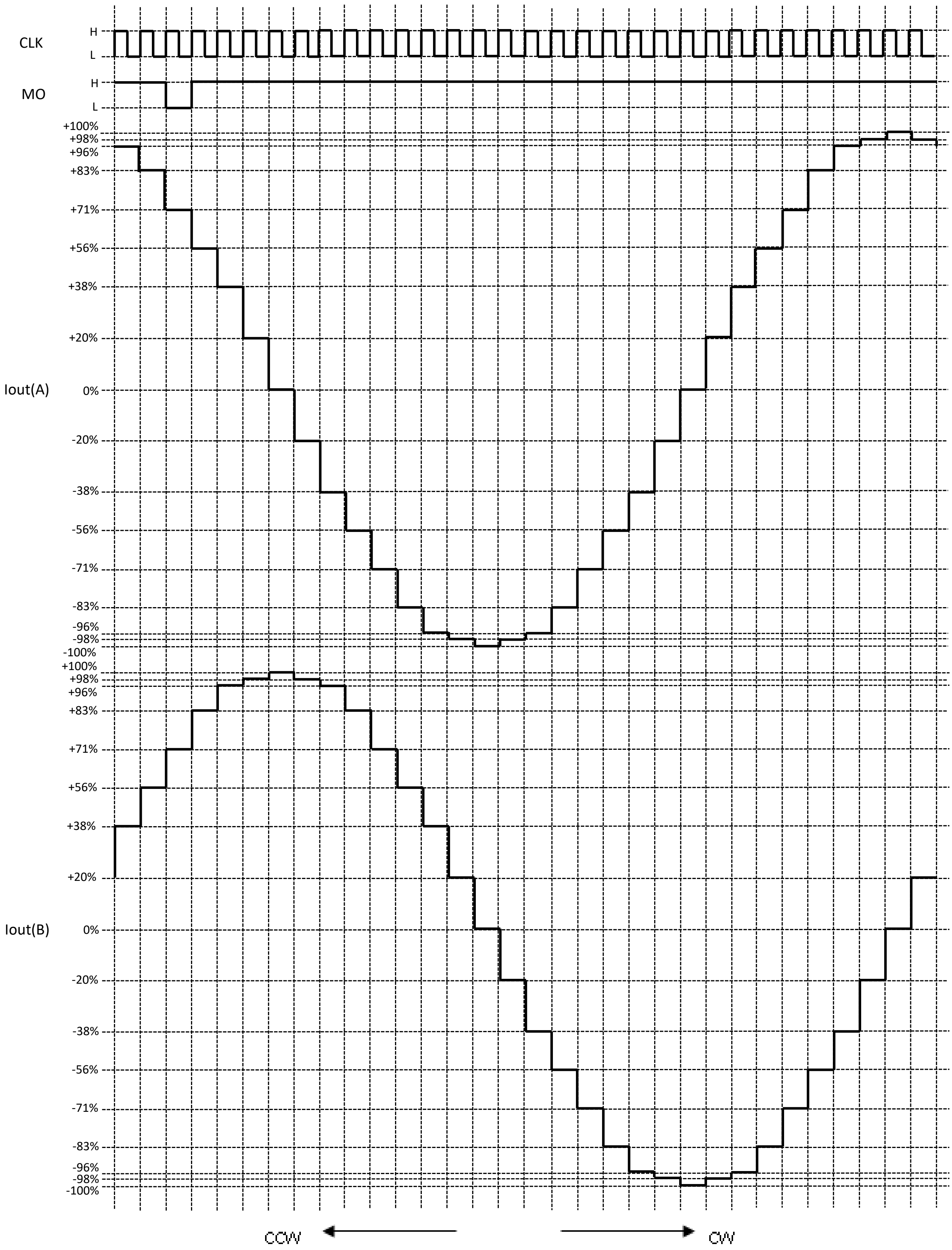


Figure 6.5 1/8 step resolution setting

Waveform of MO output: State of pull-up.
Note: Timing charts may be simplified for explanatory purpose.

6.6.6. 1/16 step resolution setting

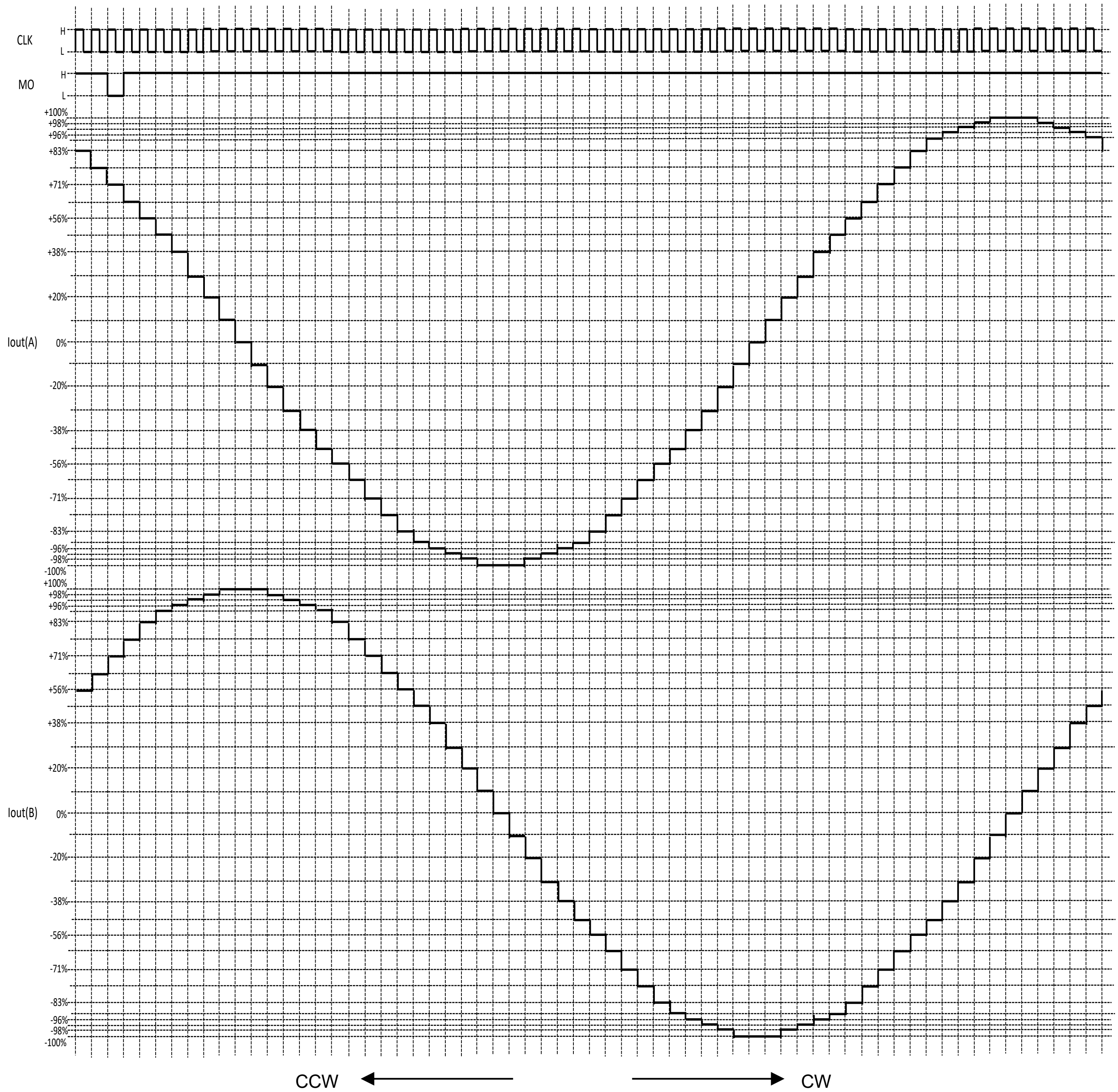


Figure 6.6 1/16 step resolution setting

Waveform of MO output: State of pull-up.

Note: Timing charts may be simplified for explanatory purpose.

6.6.7. 1/32 step resolution setting

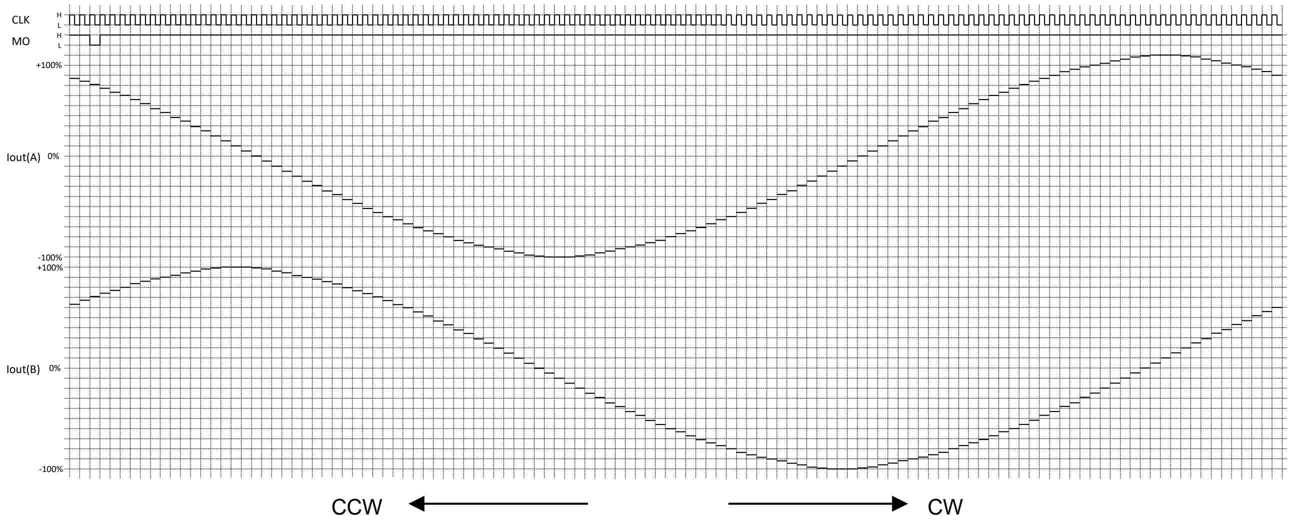


Figure 6.7 1/32 step resolution setting

Waveform of MO output: State of pull-up.

Note: Timing charts may be simplified for explanatory purpose.

6.7. Step resolution and set current

For step current of each resolution, refer to the following tables. The values in the case of CW_CCW=High setting are shown.

Table 6.6 step current of each resolution

STEP	1/32		1/16		1/8		1/4		1/2(b)		1/2(a)		Full	
—	Ach (%)	Bch (%)	Ach (%)	Bch (%)	Ach (%)	Bch (%)	Ach (%)	Bch (%)	Ach (%)	Bch (%)	Ach (%)	Bch (%)	Ach (%)	Bch (%)
θ0	100	0	100	0	100	0	100	0	100	0	100	0		
θ1	100	5												
θ2	100	10	100	10										
θ3	99	15												
θ4	98	20	98	20	98	20								
θ5	97	24												
θ6	96	29	96	29										
θ7	94	34												
θ8	92	38	92	38	92	38	92	38						
θ9	90	43												
θ10	88	47	88	47										
θ11	86	51												
θ12	83	56	83	56	83	56								
θ13	80	60												
θ14	77	63	77	63										
θ15	74	67												
θ16	71	71	71	71	71	71	71	71	71	71	100	100	100	100
θ17	67	74												
θ18	63	77	63	77										
θ19	60	80												
θ20	56	83	56	83	56	83								
θ21	51	86												
θ22	47	88	47	88										
θ23	43	90												
θ24	38	92	38	92	38	92	38	92						
θ25	34	94												
θ26	29	96	29	96										
θ27	24	97												
θ28	20	98	20	98	20	98								
θ29	15	99												
θ30	10	100	10	100										
θ31	5	100												
θ32	0	100	0	100	0	100	0	100	0	100	0	100		
θ33	-5	100												
θ34	-10	100	-10	100										
θ35	-15	99												
θ36	-20	98	-20	98	-20	98								
θ37	-24	97												
θ38	-29	96	-29	96										

STEP	1/32		1/16		1/8		1/4		1/2(b)		1/2(a)		Full	
—	Ach (%)	Bch (%)	Ach (%)	Bch (%)	Ach (%)	Bch (%)	Ach (%)	Bch (%)	Ach (%)	Bch (%)	Ach (%)	Bch (%)	Ach (%)	Bch (%)
θ39	-34	94												
θ40	-38	92	-38	92	-38	92	-38	92						
θ41	-43	90												
θ42	-47	88	-47	88										
θ43	-51	86												
θ44	-56	83	-56	83	-56	83								
θ45	-60	80												
θ46	-63	77	-63	77										
θ47	-67	74												
θ48	-71	71	-71	71	-71	71	-71	71	-71	71	-100	100	-100	100
θ49	-74	67												
θ50	-77	63	-77	63										
θ51	-80	60												
θ52	-83	56	-83	56	-83	56								
θ53	-86	51												
θ54	-88	47	-88	47										
θ55	-90	43												
θ56	-92	38	-92	38	-92	38	-92	38						
θ57	-94	34												
θ58	-96	29	-96	29										
θ59	-97	24												
θ60	-98	20	-98	20	-98	20								
θ61	-99	15												
θ62	-100	10	-100	10										
θ63	-100	5												
θ64	-100	0	-100	0	-100	0	-100	0	-100	0	-100	0		
θ65	-100	-5												
θ66	-100	-10	-100	-10										
θ67	-99	-15												
θ68	-98	-20	-98	-20	-98	-20								
θ69	-97	-24												
θ70	-96	-29	-96	-29										
θ71	-94	-34												
θ72	-92	-38	-92	-38	-92	-38	-92	-38						
θ73	-90	-43												
θ74	-88	-47	-88	-47										
θ75	-86	-51												
θ76	-83	-56	-83	-56	-83	-56								
θ77	-80	-60												
θ78	-77	-63	-77	-63										
θ79	-74	-67												
θ80	-71	-71	-71	-71	-71	-71	-71	-71	-71	-71	-100	-100	-100	-100
θ81	-67	-74												

STEP	1/32		1/16		1/8		1/4		1/2(b)		1/2(a)		Full	
—	Ach (%)	Bch (%)	Ach (%)	Bch (%)	Ach (%)	Bch (%)	Ach (%)	Bch (%)	Ach (%)	Bch (%)	Ach (%)	Bch (%)	Ach (%)	Bch (%)
θ82	-63	-77	-63	-77										
θ83	-60	-80												
θ84	-56	-83	-56	-83	-56	-83								
θ85	-51	-86												
θ86	-47	-88	-47	-88										
θ87	-43	-90												
θ88	-38	-92	-38	-92	-38	-92	-38	-92						
θ89	-34	-94												
θ90	-29	-96	-29	-96										
θ91	-24	-97												
θ92	-20	-98	-20	-98	-20	-98								
θ93	-15	-99												
θ94	-10	-100	-10	-100										
θ95	-5	-100												
θ96	0	-100	0	-100	0	-100	0	-100	0	-100	0	-100		
θ97	5	-100												
θ98	10	-100	10	-100										
θ99	15	-99												
θ100	20	-98	20	-98	20	-98								
θ101	24	-97												
θ102	29	-96	29	-96										
θ103	34	-94												
θ104	38	-92	38	-92	38	-92	38	-92						
θ105	43	-90												
θ106	47	-88	47	-88										
θ107	51	-86												
θ108	56	-83	56	-83	56	-83								
θ109	60	-80												
θ110	63	-77	63	-77										
θ111	67	-74												
θ112	71	-71	71	-71	71	-71	71	-71	71	-71	100	-100	100	-100
θ113	74	-67												
θ114	77	-63	77	-63										
θ115	80	-60												
θ116	83	-56	83	-56	83	-56								
θ117	86	-51												
θ118	88	-47	88	-47										
θ119	90	-43												
θ120	92	-38	92	-38	92	-38	92	-38						
θ121	94	-34												
θ122	96	-29	96	-29										
θ123	97	-24												
θ124	98	-20	98	-20	98	-20								

STEP	1/32		1/16		1/8		1/4		1/2(b)		1/2(a)		Full	
—	Ach (%)	Bch (%)	Ach (%)	Bch (%)	Ach (%)	Bch (%)	Ach (%)	Bch (%)	Ach (%)	Bch (%)	Ach (%)	Bch (%)	Ach (%)	Bch (%)
θ125	99	-15												
θ126	100	-10	100	-10										
θ127	100	-5												
θ128	100	0	100	0	100	0	100	0	100	0	100	0		

6.8. Selectable Mixed Decay Function

Selectable Mixed Decay function can adjust the regeneration amount of the current during Decay period using the DECAY pins.
Mixed Decay control is realized by changing three controls: Charge, Slow Decay, and Fast Decay.
The constant-current control can be selected from the following four settings by DECAY pins. When this setting is changed during the constant-current operation, the changed setting is applied from next chopping cycle.

Table 6.7 Selectable Mixed Decay Function

DECAY2 pin	DECAY1 pin	Function
L	L	Mixed Decay
L	H	Slow Decay only
H	L	Fast Decay only
H	H	ADMD

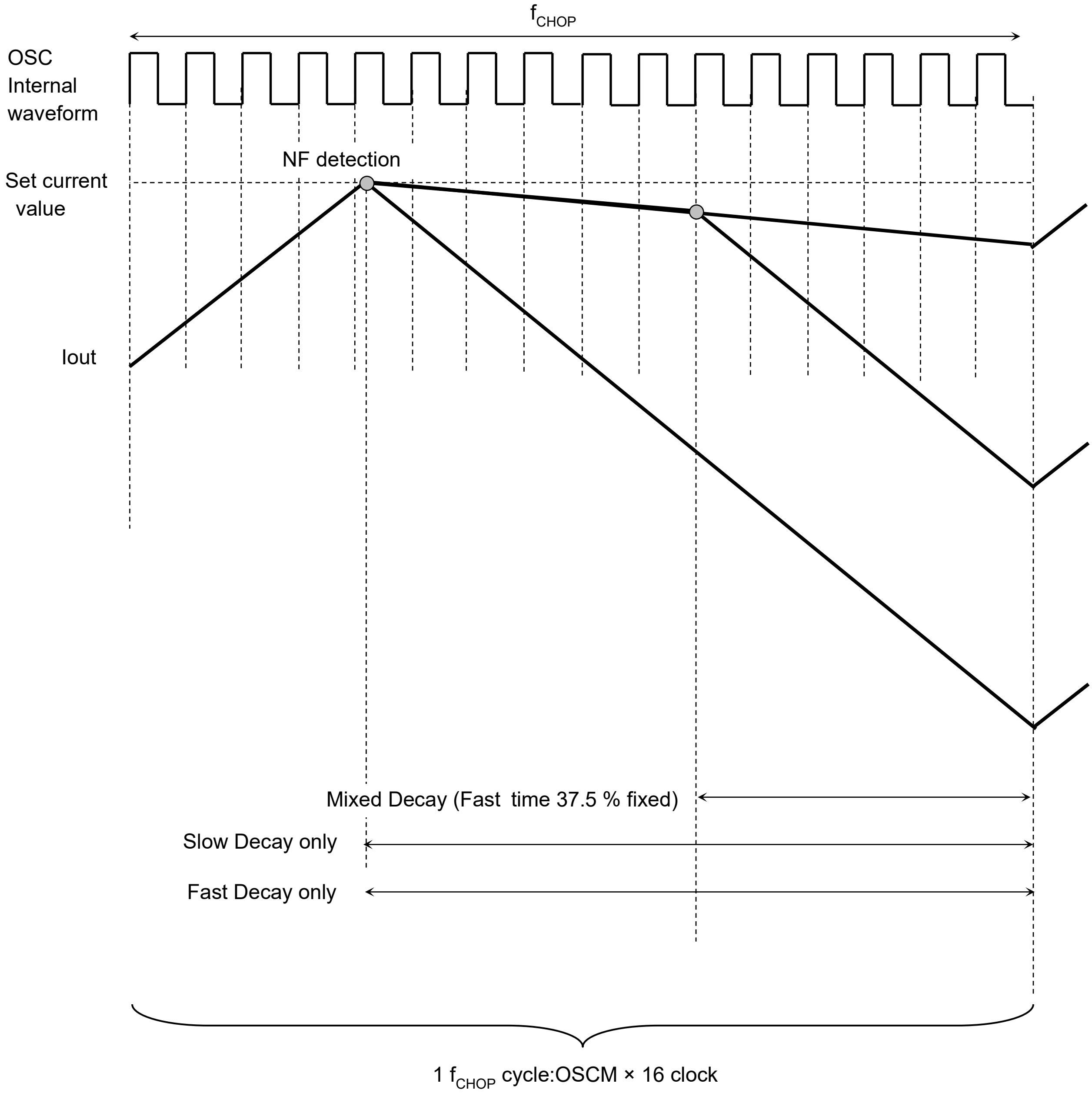


Figure 6.8 Selectable Mixed Decay Function

Note: Timing charts may be simplified for explanatory purpose

6.8.1. Mixed Decay Waveform (Current Waveform)

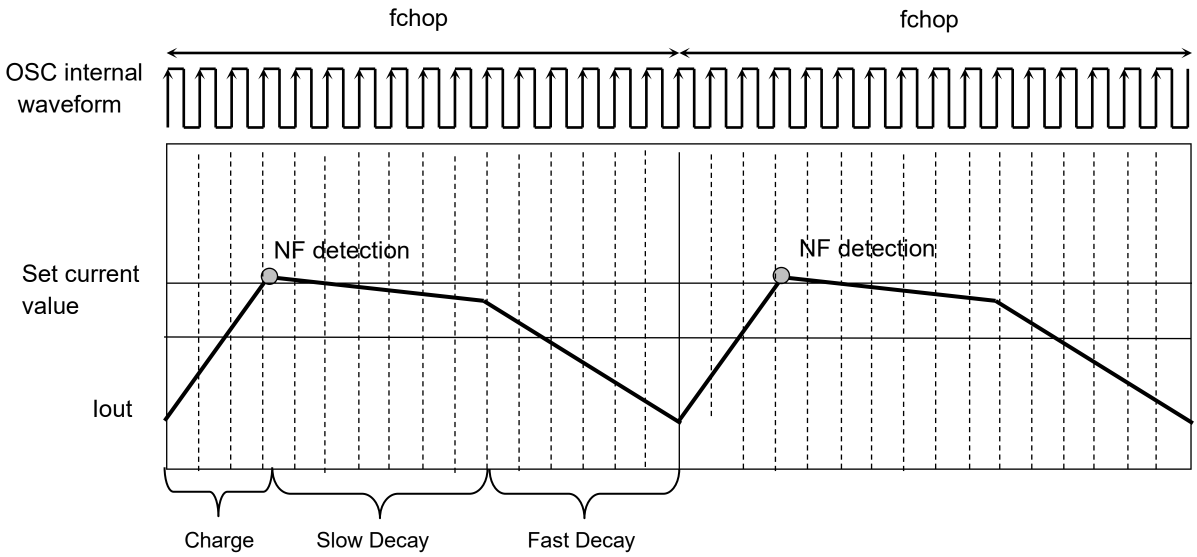


Figure 6.9 Mixed Decay Waveform

Note: Timing charts may be simplified for explanatory purpose.

6.8.2. Each Time of Constant Current PWM Operation

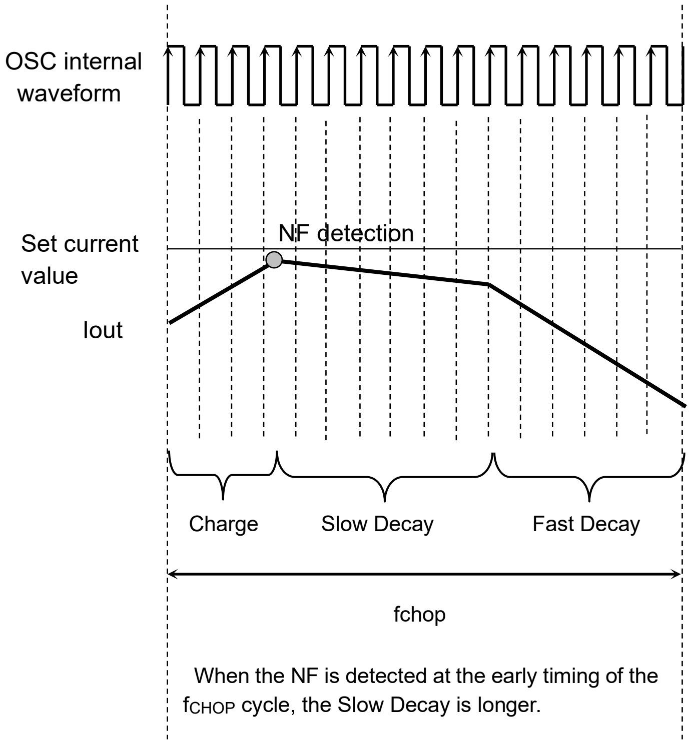


Figure 6.10

Each Time of Constant Current (1)

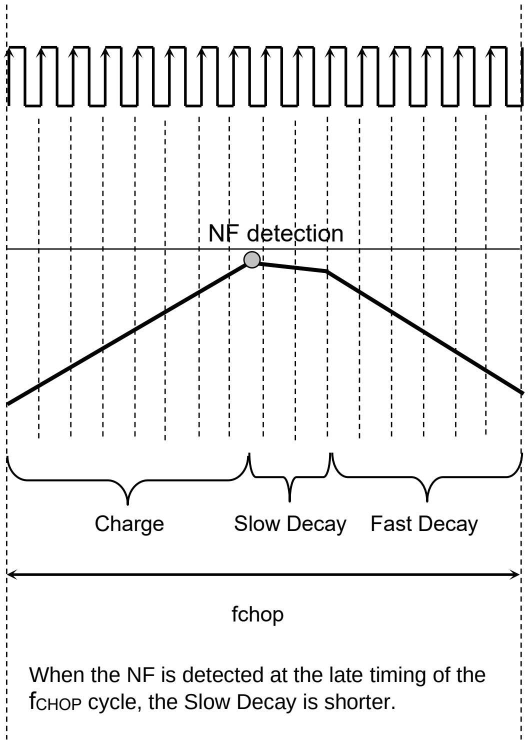


Figure 6.11

Each Time of Constant Current (2)

The Charge period (the time until the motor current reaches the set current value) is determined by the operating status.
Therefore, the NF detection (the motor current reaches the set current value) timing with in the chopping cycle will change. When the NF is detected at the early timing of the f_{CHOP} cycle, the Slow Decay is longer. When the NF is detected at the late timing of the f_{CHOP} cycle, the Slow Decay is shorter, as shown above.

Note: The chopping cycle is determined as: f_{CHOP} - (Charge + Fast Decay) = Slow Decay
(Fast Decay time is 37.5 % fixed (OSCM: 6 clocks)

Note: Timing charts may be simplified for explanatory purpose.

6.8.3. Mixed Decay Current Waveform

6.8.3.1. When the set current value is increased

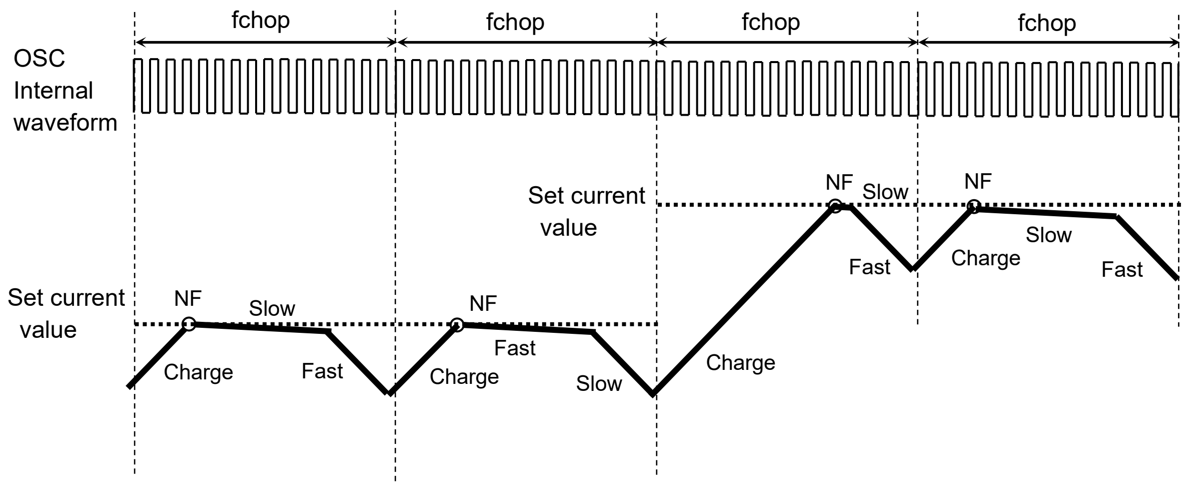


Figure 6.12 When the set current value is increased

6.8.3.2. When the Charge period is more than 1 f_{CHOP} cycle

When the Charge period (the motor current reaches next step of the set current value) is longer than 1 f_{CHOP} cycle, the Charge period extends until the motor current reaches the NF threshold. Once the current reaches the next current step, then the sequence goes on to Mixed Decay control.

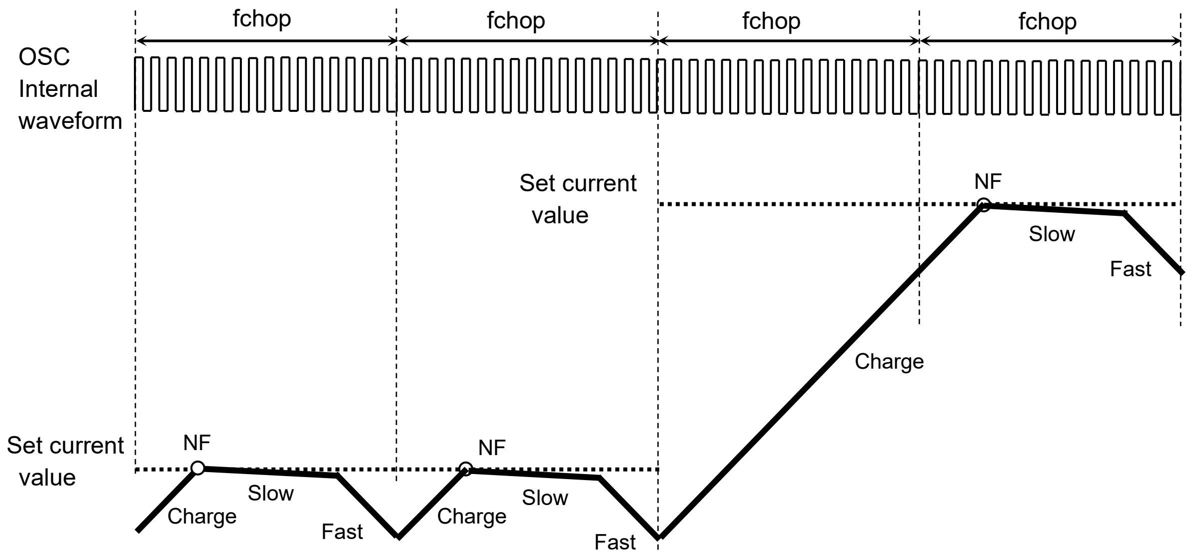


Figure 6.13 When the Charge period is more than 1 f_{CHOP} cycle

6.8.3.3. When the set current value is decreased

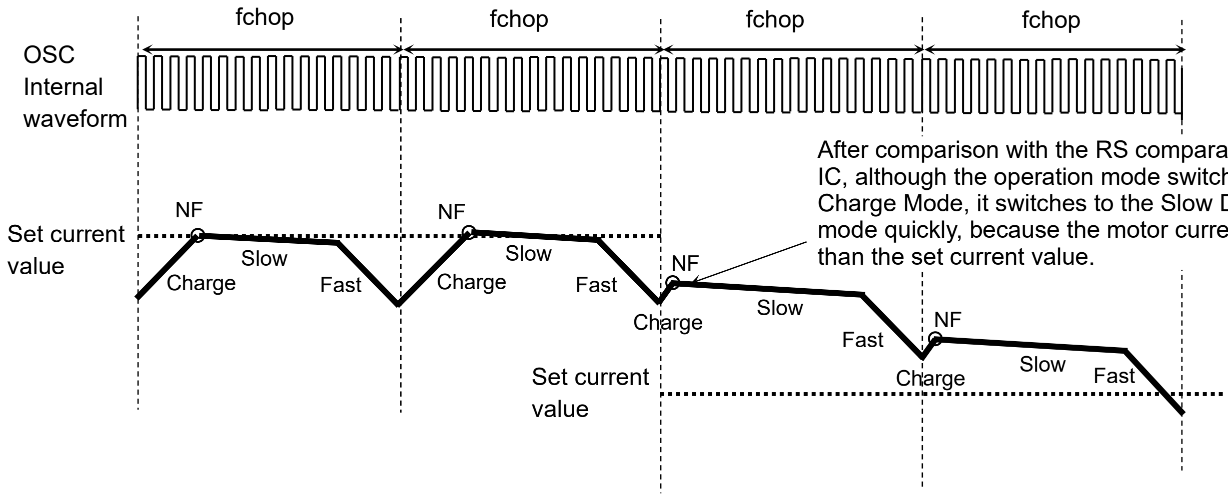


Figure 6.14 When the set current value is decreased

Note: Timing charts may be simplified for explanatory purpose.

6.9. ADMD (Advanced Dynamic Mixed Decay) Constant Current Control

The ADMD monitors both the current which flows from the power supply to the motor, and the current which regenerates from the motor to the power supply. The ADMD also controls constant current PWM.
The basic sequence of the ADMD is as follows.

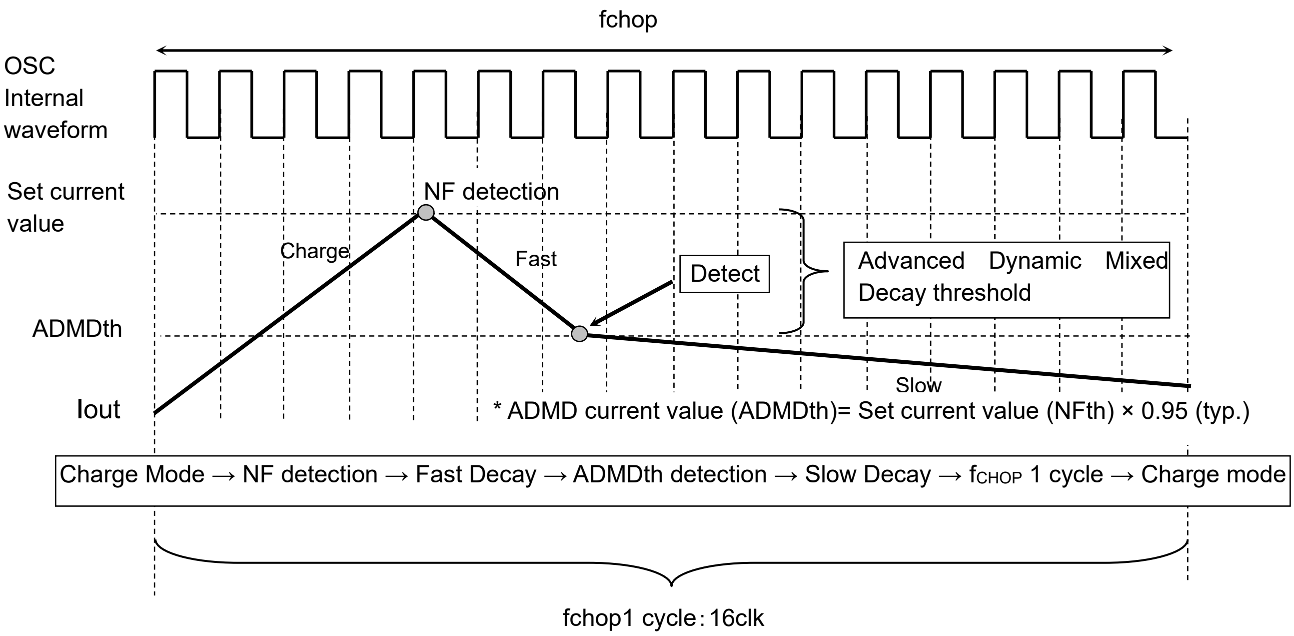


Figure 6.15 ADMD (Advanced Dynamic Mixed Decay) Constant Current Control

Note: Timing charts may be simplified for explanatory purpose. The values in the timing chart are reference values.

Each filter is attached in order to avoid current-detection error caused by the external noise, etc. (Shown in below figure.)
L value of the motor to be used is small, and when the current value reaches ADMDth (ADMD current value) within the ADMDtblank period, it changes to Slow operation after the ADMDtblank period elapsed. In this case, the ADMD current value (ADMDth) becomes smaller than ''the set current value (NFth) x 0.95 (typ.)''.

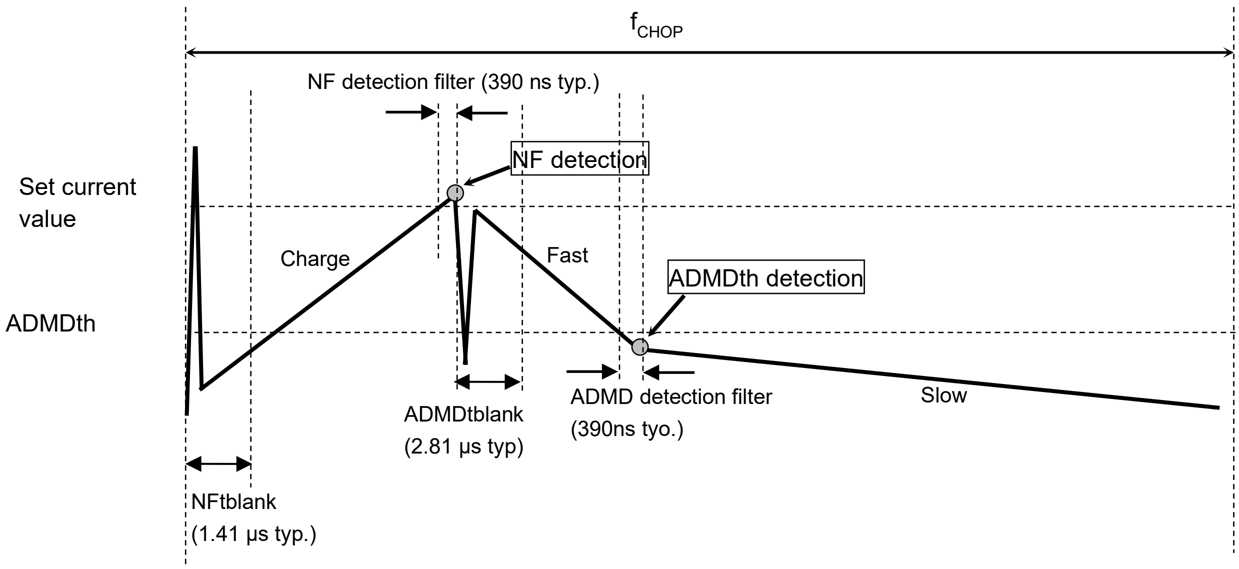


Figure 6.16 Each filter settings

Note : Timing charts may be simplified for explanatory purpose. The values in the timing chart are reference values.

6.9.1. Auto Decay Mode Current Waveform

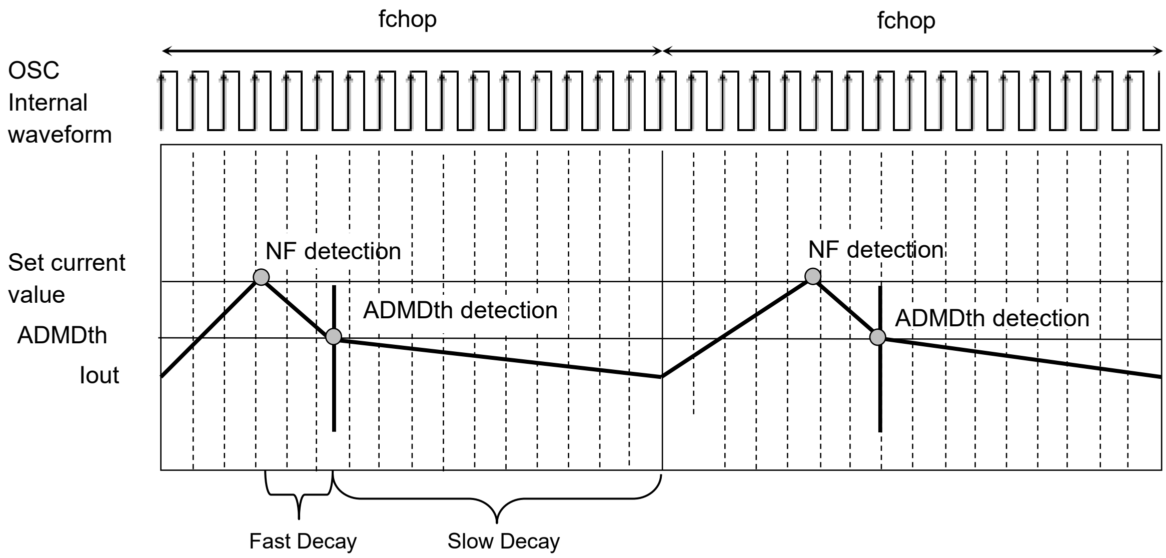


Figure 6.17 Auto Decay Mode Current Waveform

Note: Timing charts may be simplified for explanatory purpose.

6.9.1.1. When the next current value is increased

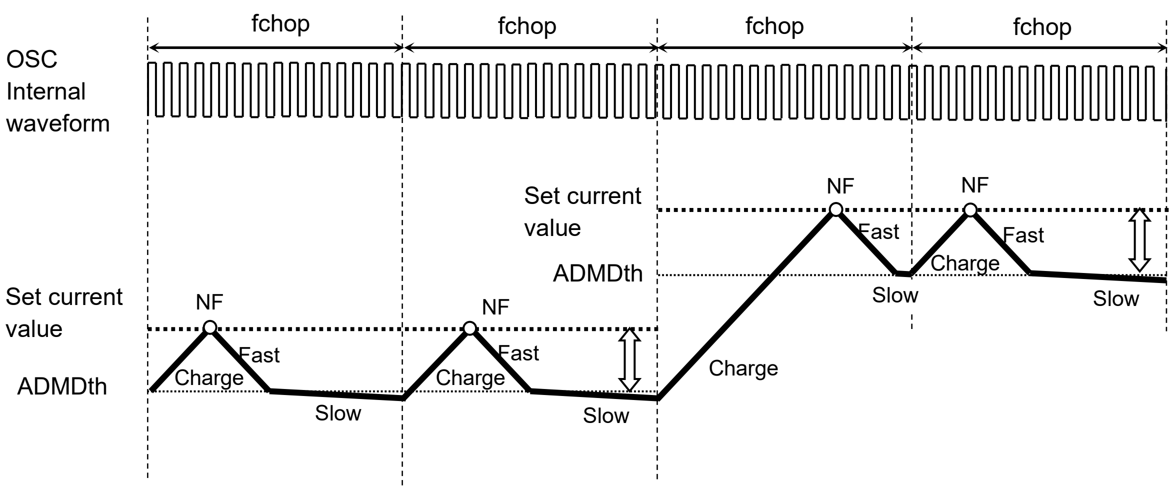


Figure 6.18 When the next current value is increased

6.9.1.2. When Charge period ≥ 1 f_{CHOP} cycle

When the period until the motor current value reaches the next seting value (Charge priod) such as switching

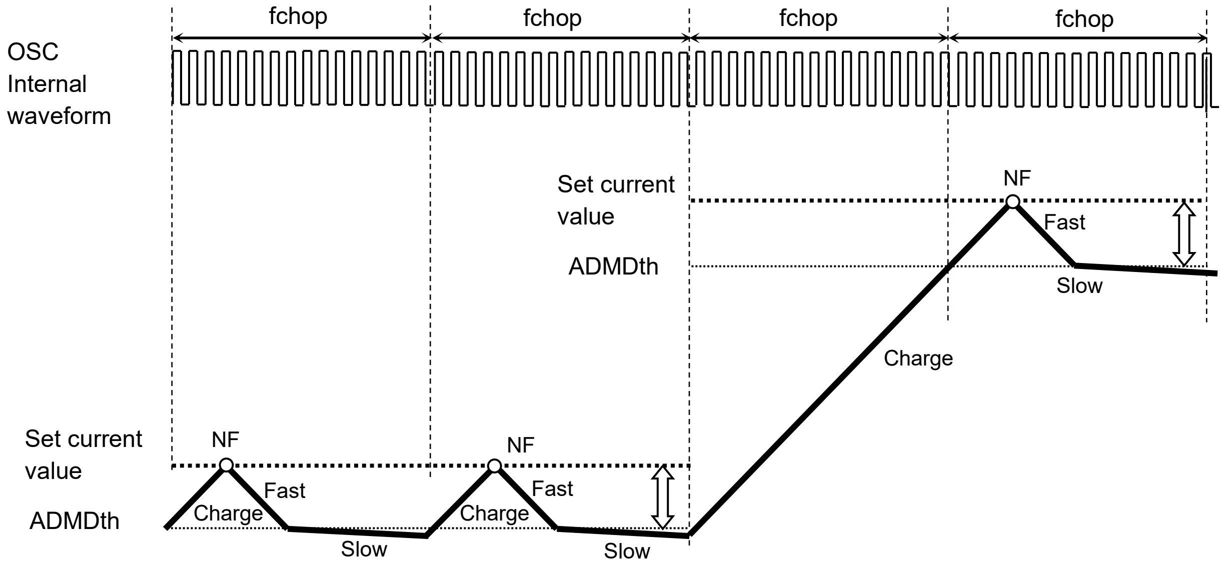


Figure 6.19 When Charge period ≥ 1 f_{CHOP} cycle

Note: Timing charts may be simplified for explanatory purpose.

6.9.1.3. When the next current value is decreased

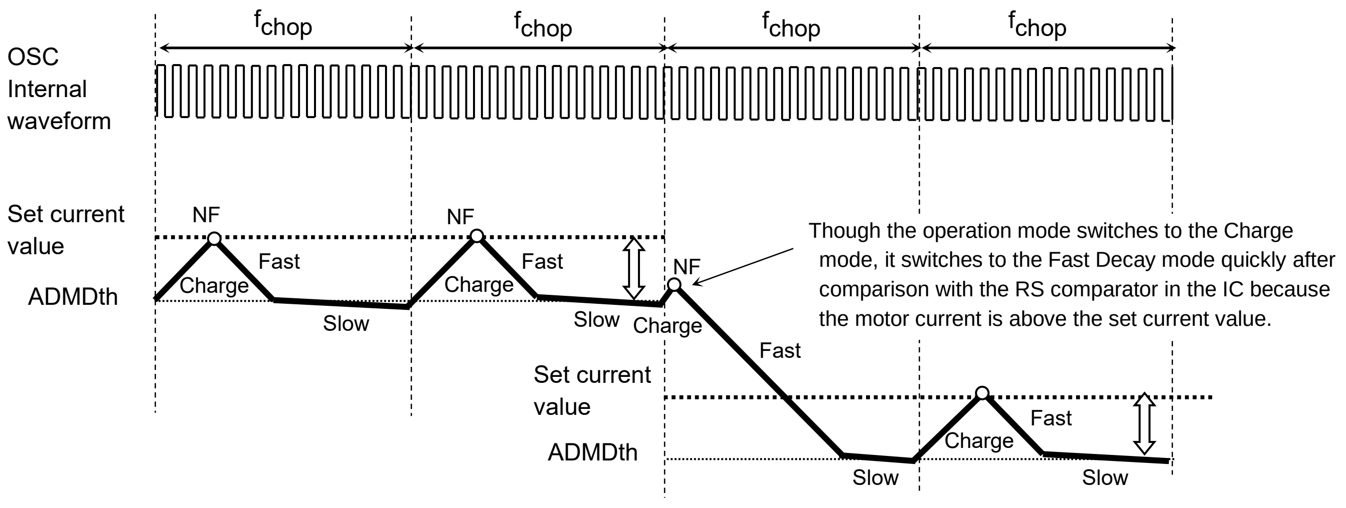


Figure 6.20 When the next current value is decreased

6.9.1.4. Fast period > 1 f_{CHOP} cycle
(The motor current does not reach the ADMD threshold during 1 f_{CHOP} cycle.)

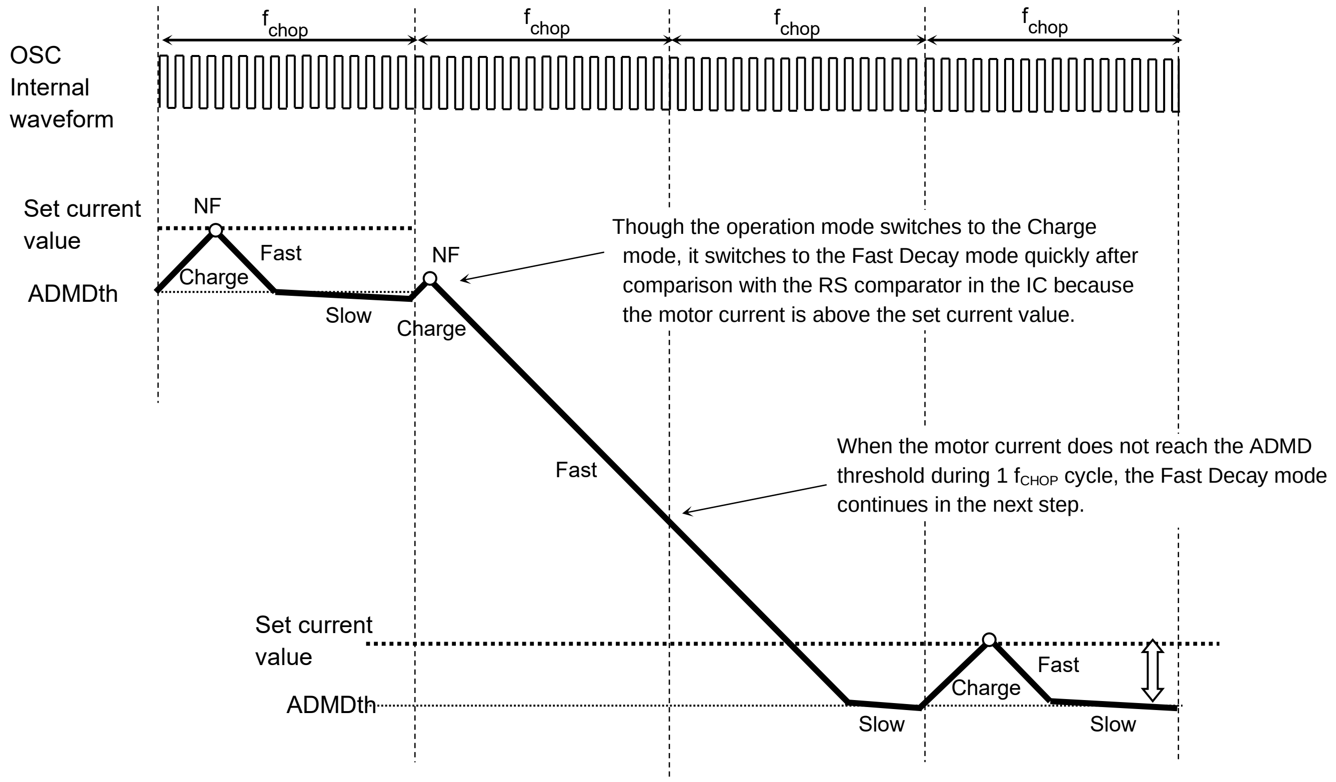


Figure 6.21 Fast period > 1 f_{CHOP} cycle

Note: Timing charts may be simplified for explanatory purpose.

6.10. RESET function

The RESET pin initializes the internal electrical angles.

Table 6.8 RESET function

RESET	Function
H	Set the electrical angle to the initial state
L	Normal operation

The current of each channel (while the RESET pin is applied) is as follows.

Step resolution	A ch current	B ch current	Initial electrical angle
Full step resolution	100 %	100 %	45 °
Half step resolution (a)	100 %	100 %	45 °
Half step resolution (b)	71 %	71 %	45 °
Quarter step resolution	71 %	71 %	45 °
1/8 step resolution	71 %	71 %	45 °
1/16 step resolution	71 %	71 %	45 °
1/32 step resolution	71 %	71 %	45 °

6.11. Torque function

TRQ pins set the torque of the motor.

Table 6.9 Torque function

TRQ1 pin input	TRQ0 pin input	Function
L	L	Torque setting: 100 %
L	H	Torque setting: 75 %
H	L	Torque setting: 50 %
H	H	Torque setting: 25 %

6.12. MO function

The MO pin confirms the internal electrical angles. The output of the MO pin should be connected to 3.3V or 5 V power supply with a pull-up resistor in the range of 10 k to 100 kΩ.

Table 6.10 MO function

MO	Function
H (Pull-up)	Elecrical angle: Except initial value
L	Elecrical angle: Initial value

6.13. LO (Error detection flag output) function

The LO function outputs signals when the error detection operates.
Both pins are open drain type. Therefore, to use function properly, the LO1 and LO2 pins should be connected to 3.3V or 5V power supply with a pull-up resistor in the range of 10k to 100 kΩ.
During normal operation, the LO1 pin is high-impedance (the internal MOSFET is OFF). When the error detections (thermal shutdown (TSD) and over-current detection (ISD)) operate, the pins output Low (the internal MOSFET is ON).
When reasserting the VM power or using the SLEEP mode to release the error detection status, the LO pins return to “normal operation mode” again. When the LO pins are not used, the pins should be open. The LO2 pin outputs Low only when the TSD is detected.

Table 6.11 LO function

LO1 pin output	Function
H (Pull-up)	Normal status (Normal operation)
L	Detected over-current (ISD) and over-temperature (TSD) status

LO2 pin output	Function
H (Pull-up)	Normal status (Normal operation)
L	Detected over-temperature (TSD) status

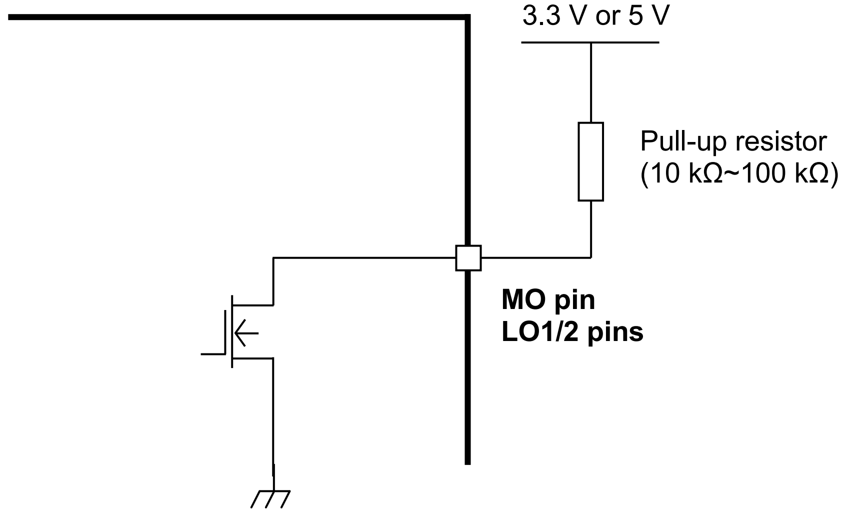


Figure 6.22 LO function Equivalent Circuit

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

6.14. Output Transistor Function mode (Advanced Dynamic Mixed Decay)

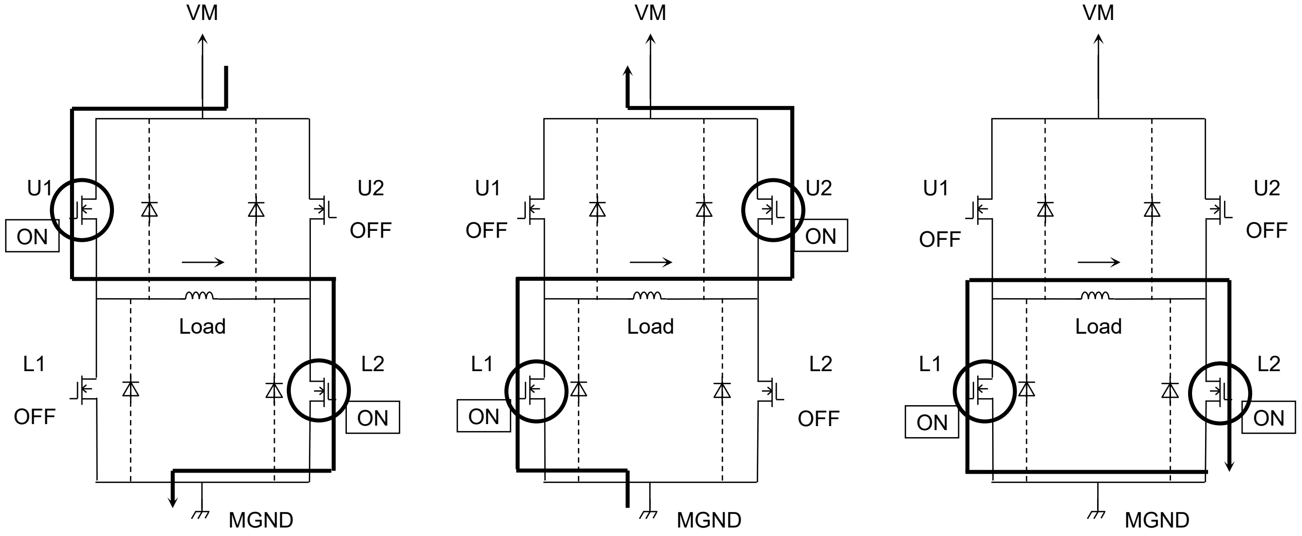


Figure 6.23 Output Transistor Function mode

Note: When the output switches, cross-conduction protection time is provided in the IC to avoid penetrating current.

Table 6.12 Output transistor function

Mode	U1	U2	L1	L2
CHARGE	ON	OFF	OFF	ON
FAST	OFF	ON	ON	OFF
SLOW	OFF	OFF	ON	ON

Note: This table shows an example of when the current flows as indicated by the arrows in the above figures. When the current flows in the opposite direction, refer to the following table.

Mode	U1	U2	L1	L2
CHARGE	OFF	ON	ON	OFF
FAST	ON	OFF	OFF	ON
SLOW	OFF	OFF	ON	ON

This IC controls the motor current to be constant by 3 modes listed above.
Note: The equivalent circuit diagrams may be simplified or some parts of them may be omitted for explanatory purposes.

6.15. Set current value (I_{OUT})

The setting current value in the PWM constant-current control mode is determined by the reference voltage (V_{REF}) as follows;

The current value to be set can be calculated by the following formula.

$I_{OUT} = V_{REF} \times 0.556$
e.g.: When V_{REF} = 2.0 V, I_{OUT} = 1.11 A

6.16. Chopping frequency (f_{CHOP})

Chopping frequency of the constant-current control can be configured by the resistor (R_{OSC}) connected to OSCM pin. The IC can operate by the fixed chopping frequency without attaching the external part to OSCM pin.

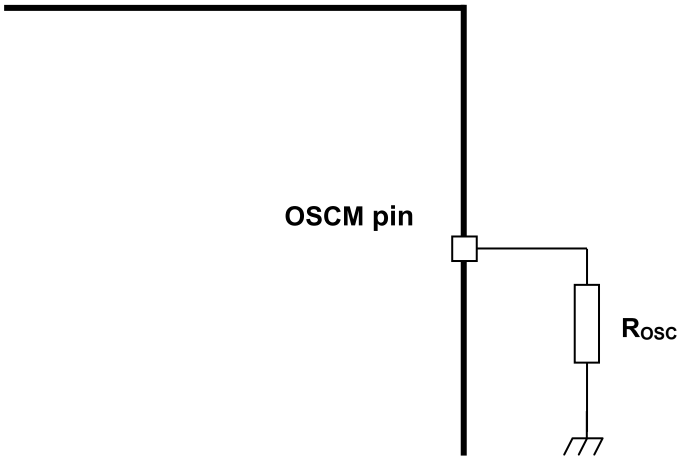


Figure 6.24 OSCM pin Equivalent Circuit

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

Chopping frequency (f_{CHOP}) is calculated from below formula.
Generally, a standard frequency is approximately 70 kHz. A setup in the range of 40 to 100 kHz is recommended.

$f_{CHOP} = f_{OSCM} / 16$
$f_{OSCM} = 1/(\alpha \times Roscm + \beta)$ [MHz] $\alpha = 1.7\times10^{-5}$, $\beta = 0.0285$
e.g.: When R_{OSC}=47 kΩ, f_{OSCM}=1.2 MHz (typ.), f_{CHOP}=75 kHz (typ.)

Under the condition that OSCM pin is open or connected to the GND, the IC operates by the frequency generated automatically (f_{OSCM2}=914 kHz (typ.), f_{CHOP}=57.1 kHz (typ.)).

6.17. 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.

6.17.1. Power consumption of the power transistor

Power of the output block is consumed by the upper and lower MOSFET of the H-Bridge.

Power consumption of the upper or lower transistor of the H-Bridge is calculated from below formula.

P (out) = Iout (A) × VDS (V) = Iout $(A)^2$ × Ron (Ω)……………………………………………………….(1)

When the current waveform of the motor output corresponds to the complete square waveform in the full-step resolution, average power of output block can be provided as follows

When Ron =0.8 Ω , Iout (peak : Max) = 1.0 A, VM = 24 V,
P (out) = 2 (Tr) × 1.0 $(A)^2$ ×0.8(Ω)…………………………………………………………………………..(2)
= 1.6(W)

6.17.2. Power consumption of logic and IM systems

Power consumptions of logic and IM systems are calculated by separating the states (operating and stopping).

I (IM3) =5.4 mA (typ.) : Operatin/axis
I (IM2) = 4.8 mA (typ.) : Stopping/axis
I (IM1) = 0.03 μA (typ.) : Standby/axis

Output system is connected to VM (24 V).(Output system: Current consumed by the circuit connected to VM + Current consumed by switching output stages)

Power consumption is calculated as follows;

P (IM3) = 24 (V) × 0.0054 (A) ………………………………………………………………………………(3)
= 0.13 (W)

6.17.3. Power consumption

Total power consumption P is calculated from the results of “1” and “2” above.

P = P (out) + P (IM3) = 1.73 (W)

Power consumption of 1 axis in standby mode is as follows;

P (Sleep mode) = 24 (V) × 0.03 (μA) = 0.72 (μW)

About the heat design of the board etc., please evaluate it by the actual board enough, and configure the appropriate margin.

6.18. Detection Function

Built-in below detection functions.

Table 6.13 Detection function

Detection	Target	Detection level	Protection method	Resume method from detection state
Thermal shutdown (TSD)	Chip temperature	160 °C (typ.) or more Dead band time of 5.0 μs (typ.)	All outputs are OFF forcedly.	This function is a latch type that maintains the operation at the time of detection. The operation resumes by below process. ･Power supply is reapplied. ･SLEEP mode is set once and normal mode is set again.
Over-current detection (ISD)	Output current	3 A (typ.) or more Dead band time of 1.25 μs (typ.)	All outputs are OFF forcedly.	
Under voltage lockout (UVLO)	Voltage of VM pin	4.0 V (typ.) or less Dead band time of 1.41 μs (typ.)	All outputs are OFF forcedly. Internal circuits are reset.	VM voltage is raised to 4.2 V (typ.) or more.

6.18.1. Thermal shutdown detection

(This function is a latch type that maintains the operation at the time of detection.)

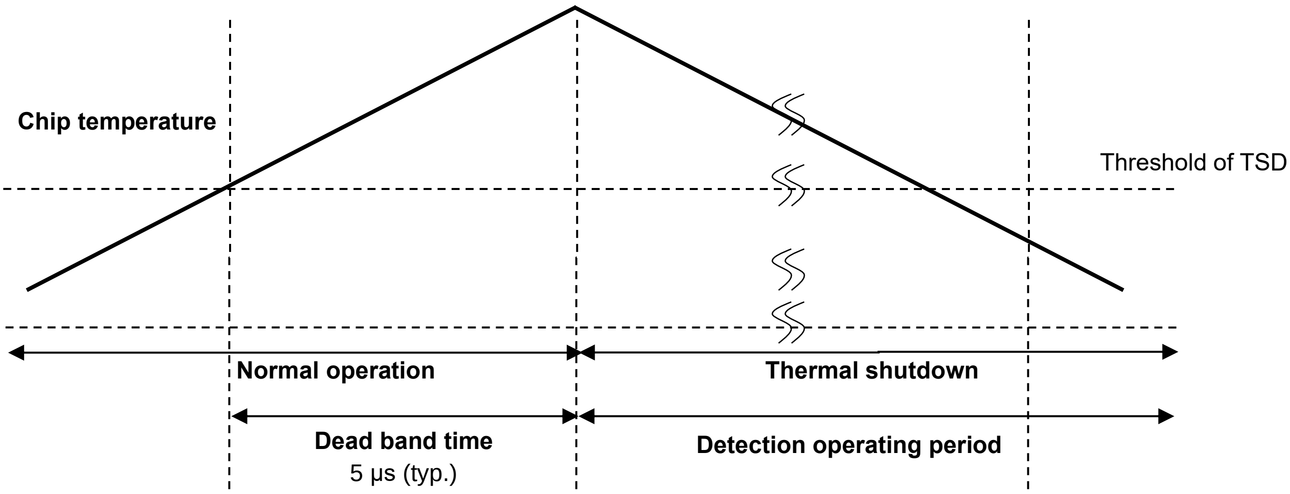
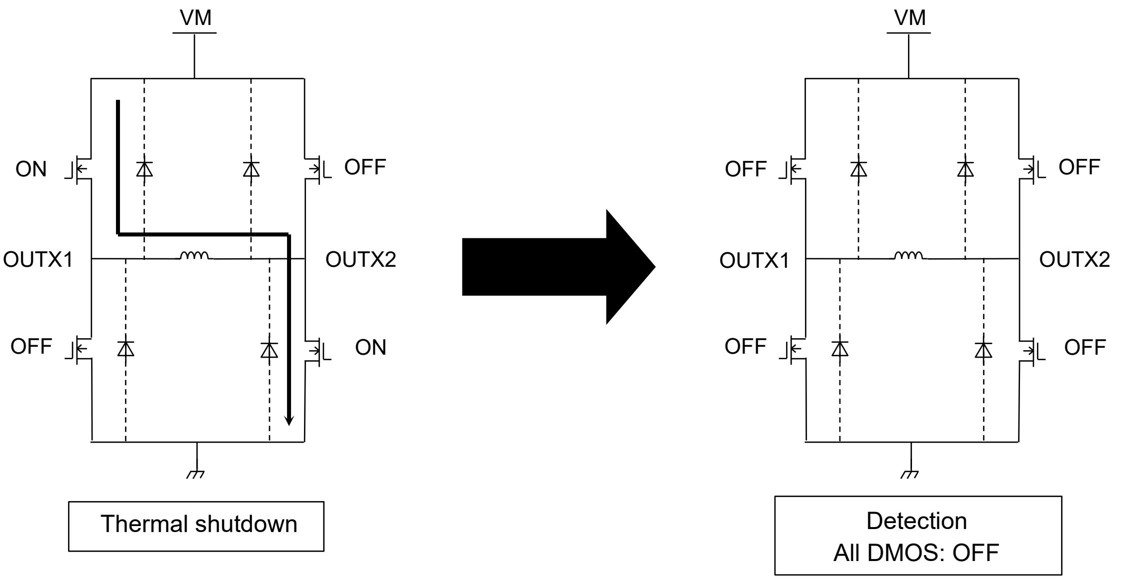


Figure 6.25 Thermal shutdown detection

Note: Timing charts may be simplified for explanatory purposes. The value in the timing chart is the reference value.

6.18.1.1. When over temperature is detected:



X=A or B

Figure 6.26 When over temperature is detected

6.18.2. Over-current detection

(This function is a latch type that maintains the operation at the time of detection.)

This function turns off the IC operation temporarily when the short-circuiting between outputs of motors and the short-circuiting to the power supply or ground occur. It has a dead band time to avoid error detection caused by the spike current which generates in switching and the external noise. When over-current is detected, not only the corresponding channels but both channels are turned off.

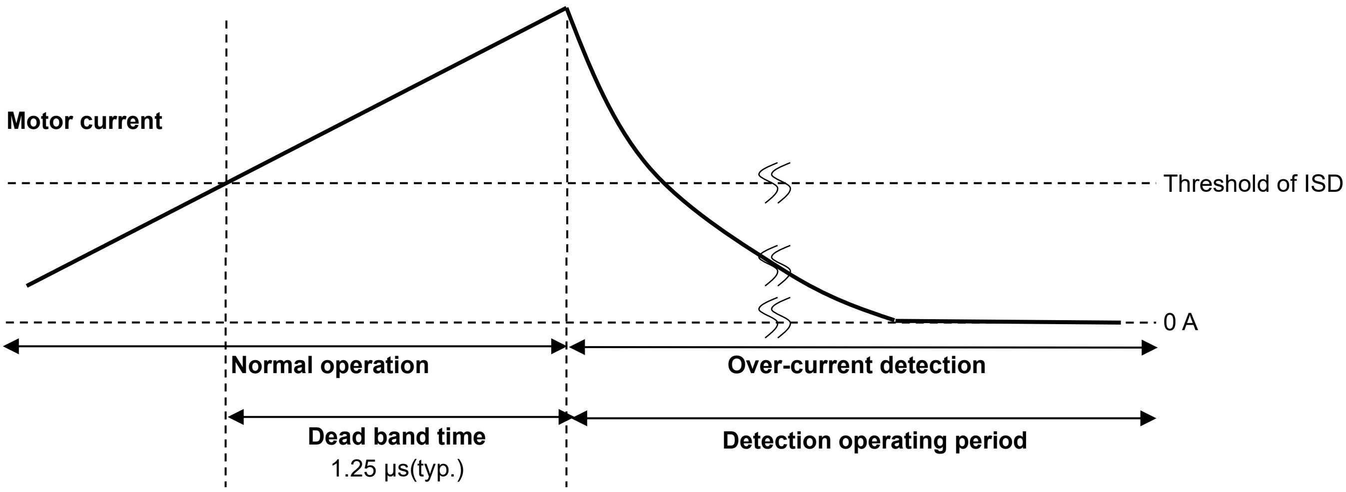
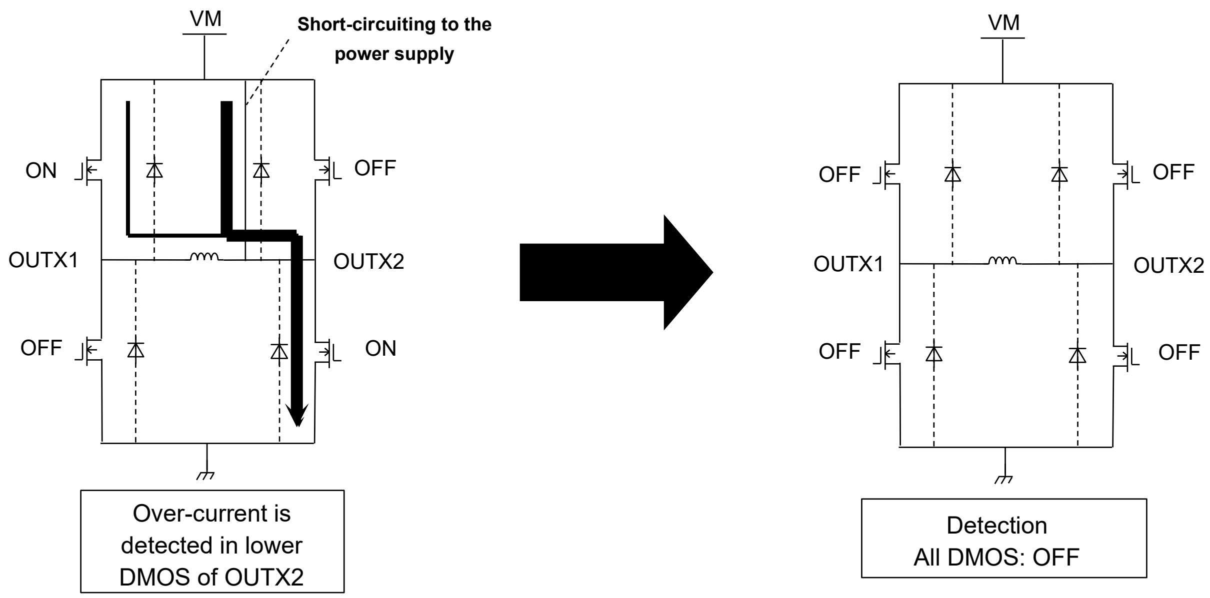


Figure 6.27 Over-current detection timing charts

Note: Timing charts may be simplified for explanatory purposes. The value in the timing chart is the reference value.

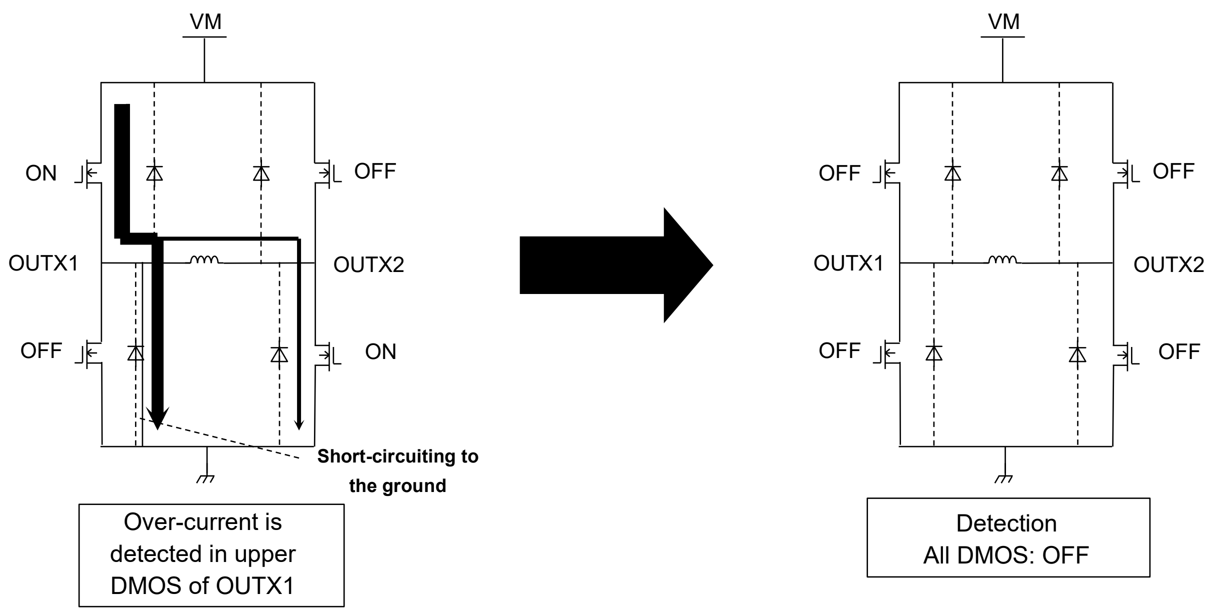
6.18.2.1. When over-current is detected in the lower DMOS of H-bridge by the short-circuiting to the power supply



X=A or B

Figure 6.28 When over-current is detected in the lower DMOS of H-bridge by the short-circuiting to the power supply

6.18.2.2. When over-current is detected in the upper DMOS of H-bridge by the short-circuiting to the ground:



X=A or B

Figure 6.29 When over-current is detected in the upper DMOS of H-bridge by the short-circuiting to the ground

7. Absolute Maximum Ratings

Table 7.1 Absolute Maximum Ratings (Ta = 25°C)

Characteristics	Symbol	Rating	Unit
Motor power supply	V_M	35	V
Motor output voltage	V_{OUT}	40	V
Motor output current (Note1)	I_{OUT}	2.0	A
Voltage for internal regulator	V_{CC}	6.0	V
Logic input pin voltage	V_{IN}	6.0	V
V_{ref} reference voltage	V_{ref}	6.0	V
MO and LO pins voltage	V_{MO}	6.0	V
Power dissipation (Note2)	P_D	1.3	W
Operating temperature	T_{opr}	-40 to 85	°C
Storage temperature	T_{stg}	-55 to 150	°C
Junction temperature	$T_{j(MAX)}$	150	°C

Note1: The maximum current value in normal operation should be kept 1.8 A or less per channel after calculating heat generation. The maximum output current may be further limited in view of the thermal considerations, depending on the ambient temperature and board conditions.

Note2: IC standalone (Ta = 25 °C)
When Ta exceeds 25 °C, derating with 10.4 mW/°C is necessary.

Ta : Ambient temperature of the IC
Topr : Ambient temperature while the IC is active.
Tj : Temperature of the chip while the IC is active. The maximum junction temperature is limited by the thermal shutdown circuit (TSD).

It is advisable to keep the maximum current below a certain level so that the maximum junction temperature, Tj (MAX), will not exceed 120°C.

Absolute maximum ratings

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 device breakdown, damage or deterioration, and may result in injury by explosion or combustion. The value of even one parameter of the absolute maximum ratings should not be exceeded under any circumstances. The TB67S539SFTG does not have overvoltage detection circuit. Therefore, the device is damaged if a voltage exceeding its rated maximum is applied.
All voltage ratings, including supply voltages, must always be followed. The other notes and considerations described later should also be referred to.

PD-Ta graph (reference)

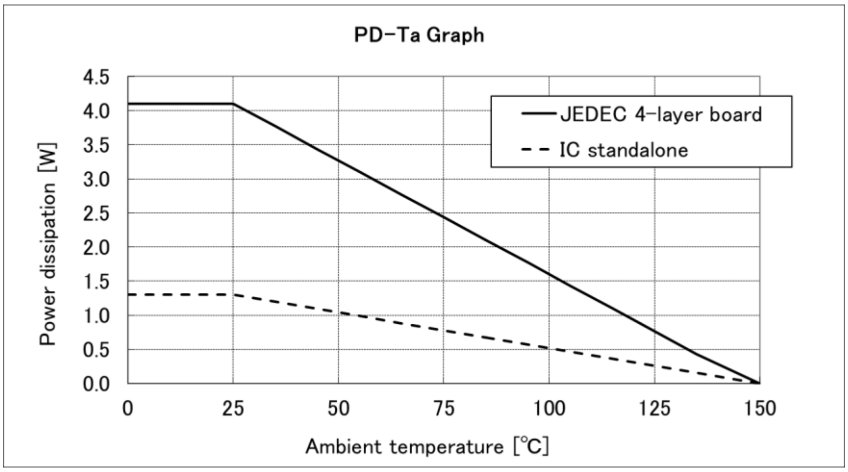


Figure7.1 PD-Ta graph

8. Operating Ranges(Ta = -20 to 85°C)

Table 8.1 Operating Ranges

Characteristics	Symbol	Min	Typ.	Max	Unit	Remarks
Motor power supply (Note1)	V_M	4.5	24.0	33	V	-
Motor output current	I_{OUT}	-	-	1.8	A	Per channel (Note 2)
Logic input voltage	$V_{IN(H)}$	2.0	-	5.5	V	Logic input High level
	$V_{IN(L)}$	-0.5	-	0.8	V	Logic input Low level
Chopping frequency	f_{CHOP}	40	70	150	kHz	-
Clock frequency	f_{CLK}	-	-	250	kHz	-
V_{ref} reference voltage	V_{REF}	0	-	3.6	V	-

Note1: For a slew rate of 0 V to 10 V when the power is turned on, use it under the condition of 1 ms or more.
If you use it under different conditions, please evaluate it thoroughly for your product alone or for the entire system, and decide whether or not it is applicable at your own risk.

Note2: The actual maximum current may be limited by the operating environment (operating conditions such as exciting mode and operating time, or by the surrounding temperature or board heat dissipation). Determine a realistic maximum current by calculating the heat generated under the operating environment.

9. Electrical Characteristics

9.1. Electrical Characteristics 1 (Ta = 25 °C, VM = 24 V, unless otherwise specified)

Table9.1 Electrical Characteristics 1

Characteristics		Symbol	Test condition	Min	Typ.	Max	Unit
Logic input pin Input voltage	High	$V_{IN(H)}$	Logic input pin (Note1)	2.0	-	5.5	V
	Low	$V_{IN(L)}$	Logic input pin (Note1)	-0.5	-	0.8	V
Input hysteresis		$V_{IN(HYS)}$	Logic input pin (Note1)	-	150	-	mV
Logic input pin Input current	High	$I_{IN(H)}$	Test logic input pin: 5 V	35	50	75	μA
	Low	$I_{IN(L)}$	Test logic input pin: 0 V	-	-	1	μA
LO and MO pins output voltage		$V_{OL(MO)}$	IOL=5 mA, Output: Low	-	0.2	0.5	V
Power consumption		I_{M1}	Output: Open, Sleep mode	-	0.03	1	μA
		I_{M2}	Output: Open, SLEEP=H,ENABLE=L	-	4.8	5.5	mA
		I_{M3}	Output: Open (Full step resolution) SLEEP=H, ENABLE=H Chopping frequency: 40 kHz	-	5.4	7	mA
Motor output leakage current	Upper	I_{OH}	V_M = 35 V, V_{OUT} = 0 V	-	-	1	μA
	Lower	I_{OL}	V_M = V_{OUT} = 35 V	1	-	-	μA
Output current differential between channels		ΔI_{OUT1}	Output current differential between channels I_{OUT} = 1.0 A	-5	0	5	%
Output set current accuracy		ΔI_{OUT2}	I_{OUT} = 1.0 A	-5	0	5	%
Output transistor between drain and source On resistance (upper + lower)		$R_{ON(D-S)}$	T_j = 25 °C I_{OUT} = 2.0 A	-	0.8	0.88	Ω

Note1: $V_{IN(H)}$ is defined as the V_{IN} voltage that changes the output voltage by being applied to the test pin and raising this voltage from 0V gradually.
$V_{IN(L)}$ is defined as the V_{IN} voltage that changes the output voltage by being applied to the test pin and lowering this voltage gradually.
The difference between $V_{IN(H)}$ and $V_{IN(L)}$ is defined as $V_{IN(HYS)}$.

9.2. Electrical Characteristics 2 (Ta = 25 °C, VM = 24 V, unless otherwise specified)

Table9.2　Electrical Characteristics 2

Characteristics	Symbol	Test condition	Min	Typ.	Max	Unit
V_{ref} input current	I_{REF}	V_{ref} = 3.6 V	-	0	1	μA
V_{ref} decay ratio	$V_{REF(GAIN)}$	V_{ref} = 2.0 V	0.528	0.556	0.584	-
TSD threshold	T_{jTSD}	-	145	160	175	°C
VM power on reset voltage	V_{MPOR}	-	3.8	4.0	4.2	V
VM power on reset hysteresis	$V_{MPOR(HYS)}$	-	-	200	-	mV
Over-current detection threshold	I_{SD}	-	2.1	3.0	3.6	A

Back-EMF

While a motor is rotating, there is a timing at which power is fed back to the power supply. At that timing, the motor current recirculates back to the power supply due to the effect of the motor back-EMF.
If the power supply does not have enough sink capability, the power supply and output pins of the device might rise above the rated voltages. The magnitude of the motor back-EMF varies with usage conditions and motor characteristics. It must be fully verified that there is no risk that the TB67S539SFTG or other components will be damaged or fail due to the motor back-EMF.

Over-Current Detection (ISD) and Thermal Shutdown (TSD)

- The ISD and TSD circuits are only intended to provide temporary protection against irregular conditions such as an output short-circuit; they do not necessarily guarantee the complete IC safety.
- If the device is used beyond the specified operating ranges, these circuits may not operate properly: then the device may be damaged due to an output short-circuit.
- The ISD circuit is only intended to provide a temporary protection against an output short-circuit. If such a condition persists for a long time, the device may be damaged due to overstress. Over-current conditions must be removed immediately by external hardware.

IC Mounting

Do not insert devices incorrectly or in the wrong orientation. Otherwise, it may cause breakdown, damage and/or deterioration of the device.

9.3. AC Electrical Characteristics (Ta = 25 °C, VM = 24 V)

Table9.3 AC Electrical Characteristics

Characteristics	Symbol	Test condition	Min	Typ.	Max	Unit
Minimum clock pulse width	$t_{CLK(H)}$	-	600	-	-	ns
	$t_{CLK(L)}$	-	600	-	-	ns
Minimum pulse width 1 of logic input signal	$t_{RS(H)}$	RESET, SLEEP_X , DECAY	1.5	-	-	μs
	$t_{RS(L)}$	RESET, SLEEP_X , DECAY	1.5	-	-	μs
Minimum pulse width 2 of logic input signal	$t_{DTE(H)}$	TRQ0/1, ENABLE	600	-	-	ns
	$t_{DTE(L)}$	TRQ0/1, ENABLE	600	-	-	ns
Set-up time	$t_{SU(STEP)}$	CW_CCW, DMODE0/1/2	600	-	-	ns
Hold time	$t_{H(STEP)}$	CW_CCW, DMODE0/1/2	600	-	-	ns
Output transistor Switching characteristics	t_r	-	-	140	-	ns
	t_f	-	-	160	-	ns
	$t_{pLH(CLK)}$	-	-	1000	-	ns
	$t_{pHL(CLK)}$	-	-	1000	-	ns
OSCM oscillation frequency	f_{OSCM1}	R_{OSC}=47 kΩ	1020	1200	1380	kHz
	f_{OSCM2}	OSCM pin: Open or connecting to GND	777	914	1051	kHz
Chopping frequency	f_{CHOP}	f_{OSCM} = 1200 kHz	-	75	-	kHz

AC Electrical Characteristics Timing Chart

TB67S539SFTG (Relation between CLK and output)

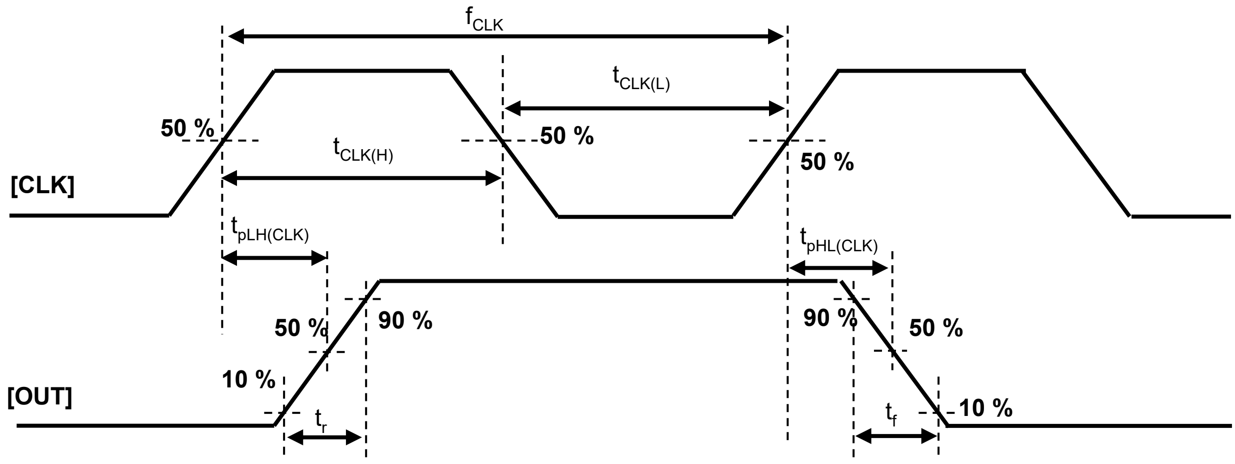


Figure9.1 TB67S539SFTG(Relationship between CLK and output)

Note: Timing charts may be simplified for explanatory purpose.

TB67S539SFTG (Relation between CLK and other control signal)

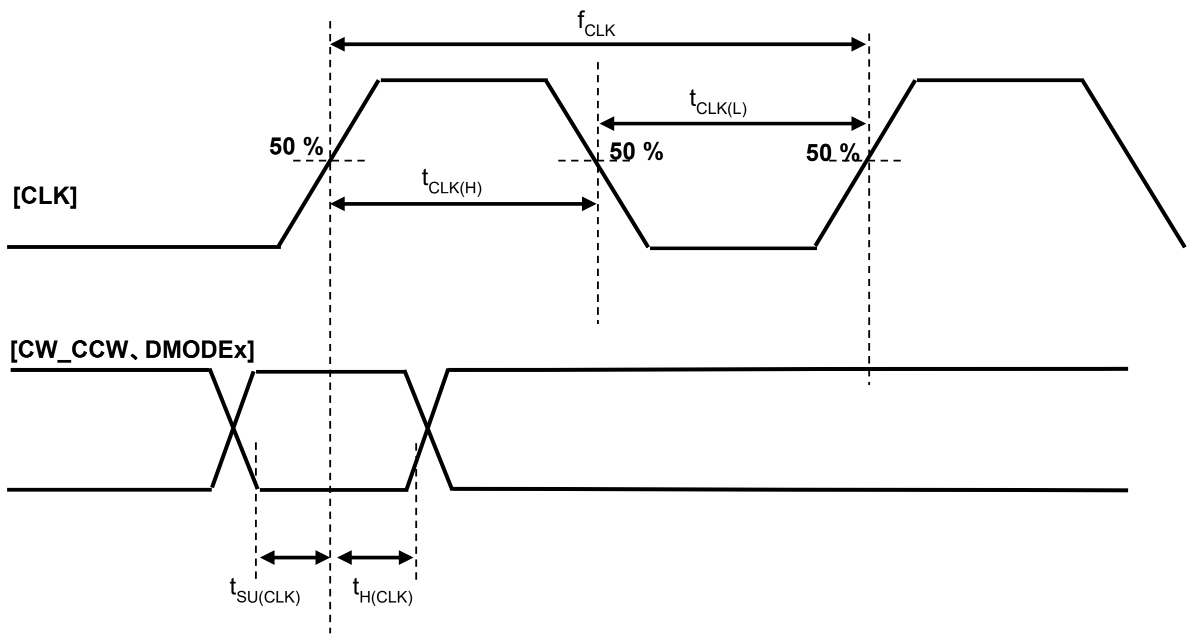


Figure9.2 TB67S539SFTG(Relationship between CLK and other control signals)

Note: Timing charts may be simplified for explanatory purpose.

10. Application Circuit Example

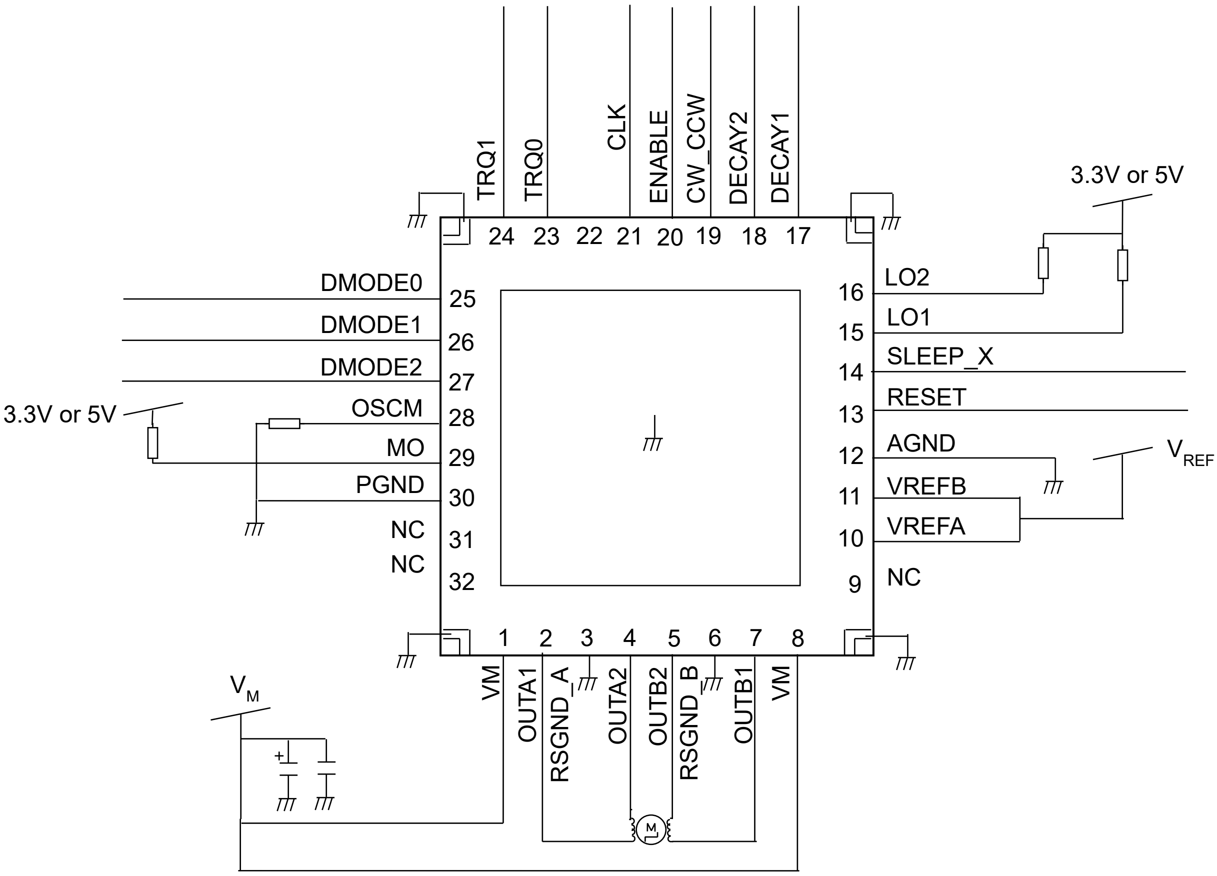


Figure10 Application Circuit Example

Note: Heat dissipation PAD (4 corners and the center part) on the back of the package is recommended to connect to the GND of the board for improved heat dissipation.
The application circuit example may be simplified or some parts of them may be omitted for explanatory purposes.

Note 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. Timing Charts

Timing charts may be simplified for explanatory purposes.

3. Application Circuit Example

The application circuits shown in this document are provided for reference purposes only. Thorough evaluation is required, especially at the mass production design stage.
Providing these application circuit examples does not grant a license for industrial property rights.

11. IC Usage Considerations

11.1. 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, over-current 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.

11.2. Points to Remember on Handling of ICs

(1) Over-current detection circuit

Over-current detection 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 (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.

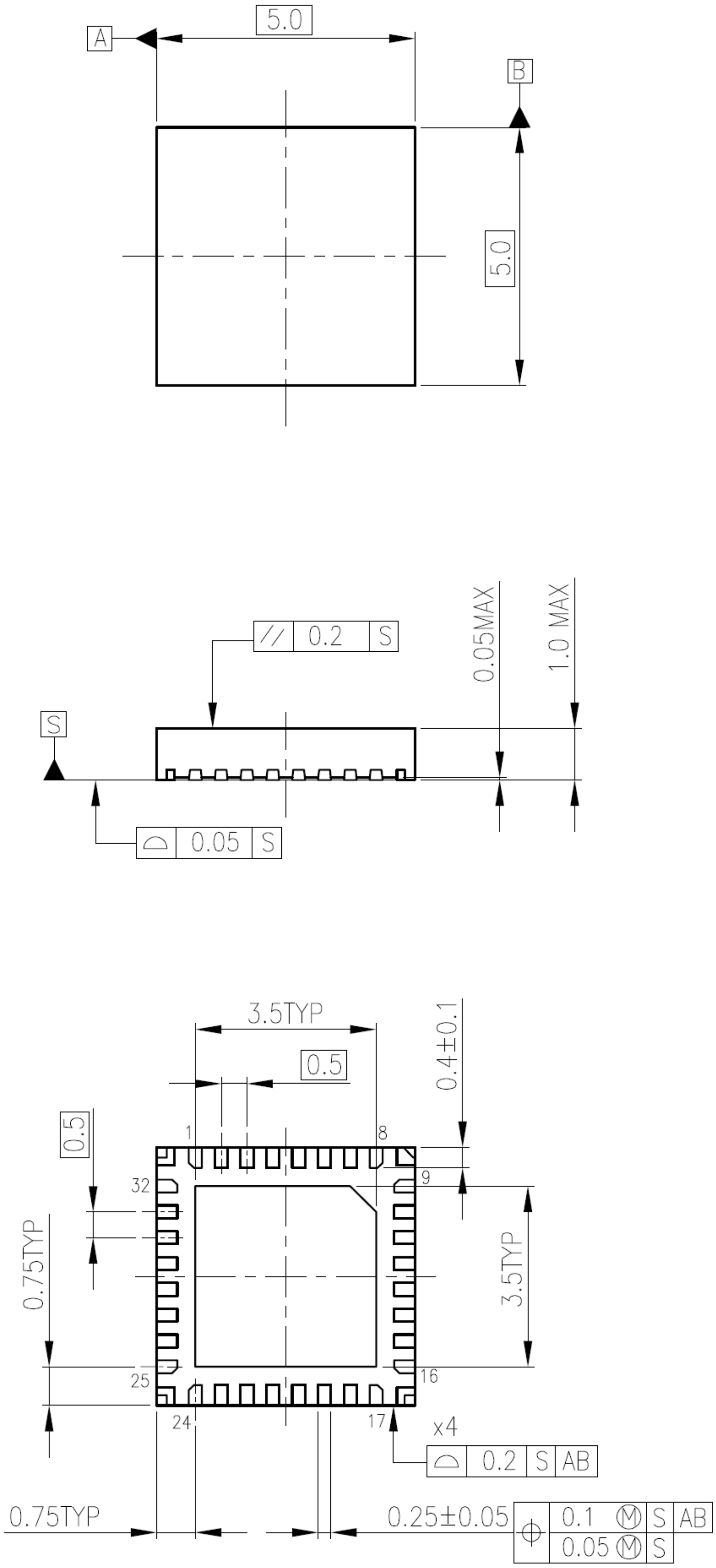
(4) Back-EMF

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.

12. Package Information

12.1. Package Dimensions

P-VQFN32-0505-0.50-004



Weight: 0.066 g (typ.)

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