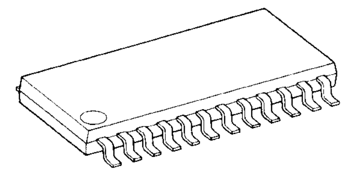
TOSHIBA Bi-CMOS Integrated Circuit Silicon Monolithic

TB6551F/FG

3-PHASE FULL-WAVE SINE-WAVE PWM BRUSHLESS MOTOR CONTROLLER

Features

- Sine-wave PWM control
- Built-in triangular-wave generator (carrier cycle = f_{osc}/252 (Hz))
- Built-in lead angle control function (0° to 58° in 32 steps)
- Built-in dead time function (setting 2.6 μs or 3.8 μs)
- Supports bootstrap circuit
- Over-current protection signal input pin
- Built-in regulator (V_{ref} = 5 V (typ.), 30 mA (max))
- Operating supply voltage range: V_{CC} = 6 V to 10 V

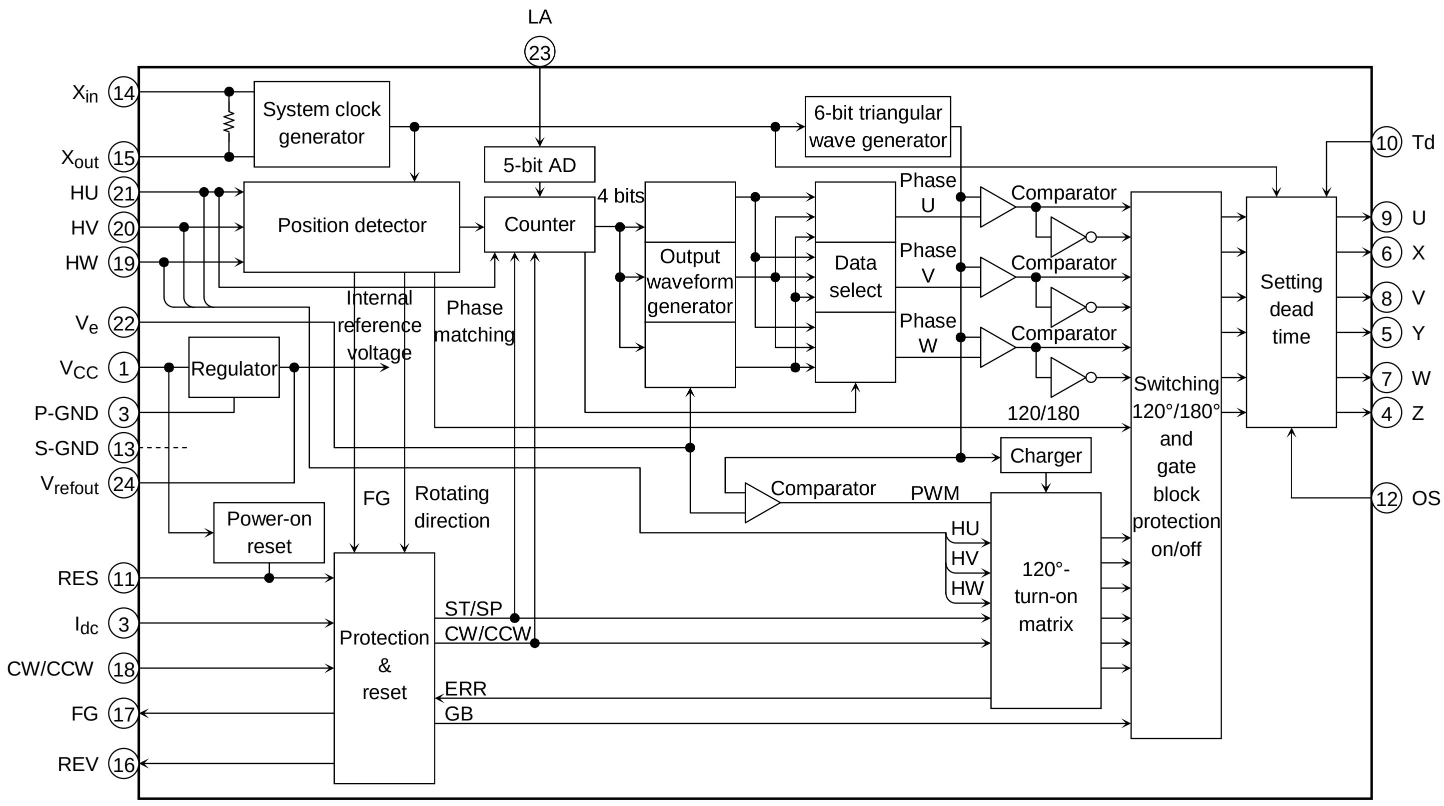


Weight: 0.33 g (typ.)

TB6551FG:
The TB6551FG is a Pb-free product.
The following conditions apply to solderability:
*Solderability

1. Use of Sn-63Pb solder bath
   *solder bath temperature = 230°C
   *dipping time = 5 seconds
   *number of times = once
   *use of R-type flux
2. Use of Sn-3.0Ag-0.5Cu solder bath
   *solder bath temperature = 245°C
   *dipping time = 5 seconds
   *number of times = once
   *use of R-type flux

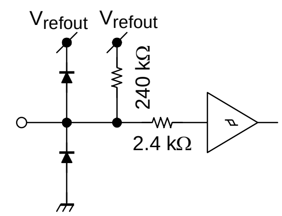
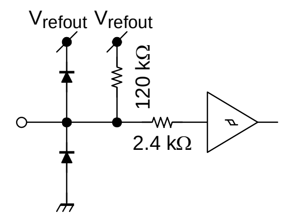
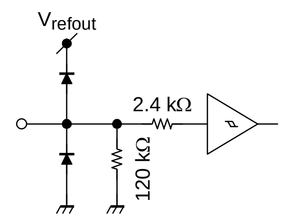
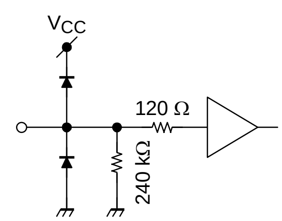
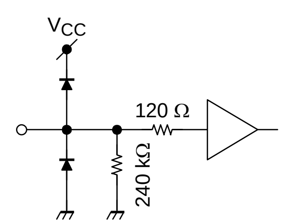
Block Diagram

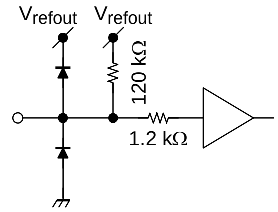
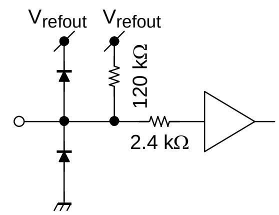
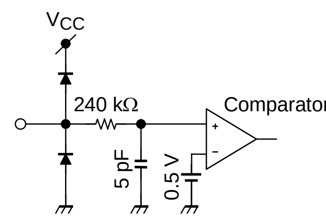
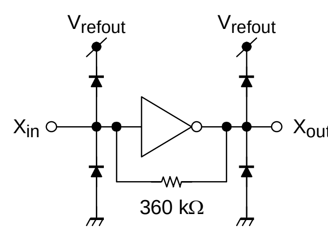
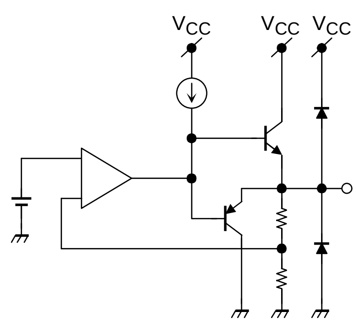


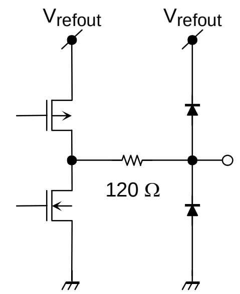
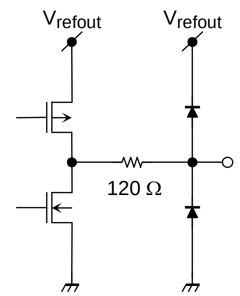
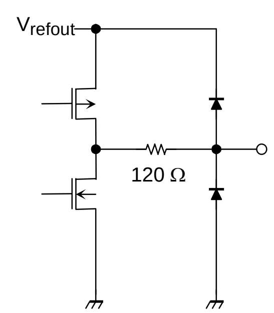
Pin Description

Pin No.	Symbol	Description	Remarks
21	HU	Positional signal input pin U	When positional signal is HHH or LLL, gate block protection operates. With built-in pull-up resistor
20	HV	Positional signal input pin V	
19	HW	Positional signal input pin W	
18	CW/CCW	Rotation direction signal input pin	L: Forward H: Reverse
11	RES	Reset-signal-input pin	L: Reset (output is non-active) Operation/Halt operation Also used for gate block protection
22	V_e	Inputs voltage instruction signal	With built-in pull-down resistor
23	LA	Lead angle setting signal input pin	Sets 0° to 58° in 32 steps
12	OS	Inputs output logic select signal	L: Active low H: Active high
3	I_{dc}	Inputs over-current-protection-signal	Inputs DC link current. Reference voltage: 0.5 V With built-in filter ($\simeq$ 1 μs)
14	X_{in}	Inputs clock signal	With built-in feedback resistor
15	X_{out}	Outputs clock signal	
24	V_{refout}	Outputs reference voltage signal	5 V (typ.), 30 mA (max)
17	FG	FG signal output pin	Outputs 3PPR of positional signal
16	REV	Reverse rotation detection signal	Detects reverse rotation.
9	U	Outputs turn-on signal	Select active high or active low using the output logic select pin.
8	V	Outputs turn-on signal	
7	W	Outputs turn-on signal	
6	X	Outputs turn-on signal	
5	Y	Outputs turn-on signal	
4	Z	Outputs turn-on signal	
1	V_{CC}	Power supply voltage pin	V_{CC} = 6 V~10 V
10	Td	Inputs setting dead time	L: 3.8 μs, H or Open: 2.6 μs
2	P-GND	Ground for power supply	Ground pin
13	S-GND	Ground for signals	Ground pin

Input/Output Equivalent Circuits

Pin Description	Symbol	Input/Output Signal	Input/Output Internal Circuit
Positional signal input pin U Positional signal input pin V Positional signal input pin W	HU HV HW	Digital With Schmitt trigger Hysteresis 300 mV (typ.) L: 0.8 V (max) H: V_{refout} − 1 V (min)	
Forward/reverse switching input pin L: Forward (CW) H: Reverse (CCW)	CW/CCW	Digital With Schmitt trigger Hysteresis 300 mV (typ.) L: 0.8 V (max) H: V_{refout} − 1 V (min)	
Reset input L: Stops operation (reset). H: Operates.	RES	Digital With Schmitt trigger Hysteresis 300 mV (typ.) L: 0.8 V (max) H: V_{refout} − 1 V (min)	
Voltage instruction signal input pin Turn on the lower transistor at 0.2 V or less. (X, Y, Z pins: On duty of 8%)	V_e	Analog Input range 0 V to 5.0 V Input voltage of Vrefout or higher is clipped to Vrefout.	
Lead angle setting signal input pin 0 V: 0° 5 V: 58° (5-bit AD)	LA	Analog Input range 0 V to 5.0 V Input voltage of V_{refout} or higher is clipped to V_{refout}.	

Pin Description	Symbol	Input/Output Signal	Input/Output Internal Circuit
Setting dead time input pin L: 3.8 μs H or Open: 2.6 μs	Td	Digital L: 0.8 V (max) H: V_{refout} − 1 V (min)	
Output logic select signal input pin L: Active low H: Active high	OS	Digital L: 0.8 V (max) H: V_{refout} − 1 V (min)	
Over-current protection signal input pin	I_{dc}	Analog Gate block protected at 0.5 V or higher (released at carrier cycle)	
Clock signal input pin	X_{in}	Operating range 2 MHz to 8 MHz (crystal oscillation)	
Clock signal output pin	X_{out}		
Reference voltage signal output pin	Vrefout	5 ± 0.5 V (max 30 mA)	

Pin Description	Symbol	Input/Output Signal	Input/Output Internal Circuit
Reverse-rotation-detection signal output pin	REV	Digital Push-pull output: ± 1 mA (max)	
FG signal output pin	FG	Digital Push-pull output: ± 1 mA (max)	
Turn-on signal output pin U Turn-on signal output pin V Turn-on signal output pin W Turn-on signal output pin X Turn-on signal output pin Y Turn-on signal output pin Z	U V W X Y Z	Analog Push-pull output: ± 2 mA (max) L: 0.78 V (max) H: V_{refout} − 0.78 V (min)	

Maximum Ratings (Ta = 25°C)

Characteristics	Symbol	Rating	Unit
Supply voltage	V_{CC}	12	V
Input voltage	$V_{in\ (1)}$	−0.3~V_{CC} (Note 1)	V
	$V_{in\ (2)}$	−0.3~5.5 (Note 2)	
Turn-on signal output current	I_{OUT}	2	mA
Power Dissipation	P_D	0.9 (Note 3)	W
Operating temperature	T_{opr}	−30~115 (Note 4)	°C
Storage temperature	T_{stg}	−50~150	°C

Note 1: $V_{in\ (1)}$ pin: V_e, LA

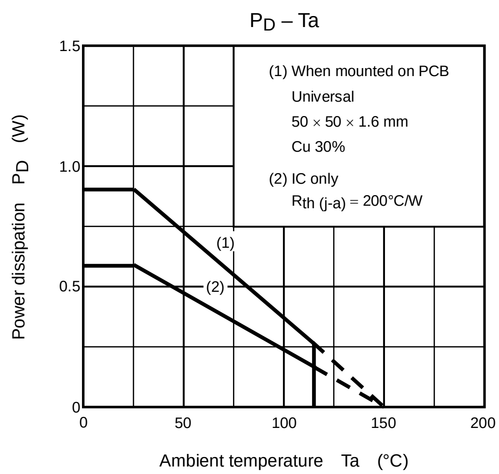
Note 2: $V_{in\ (2)}$ pin: HU, HV, HW, CW/CCW, RES, OS, I_{dc}, Td

Note 3: When mounted on a PCB (universal 50 × 50 × 1.6 mm, Cu 30%)

Note 4: Operating temperature range is determined by the P_D − Ta characteristic.

Recommended Operating Conditions (Ta = 25°C)

Characteristics	Symbol	Min	Typ.	Max	Unit
Supply voltage	V_{CC}	6	7	10	V
Crystal oscillation frequency	X_{in}	2	4	8	MHz

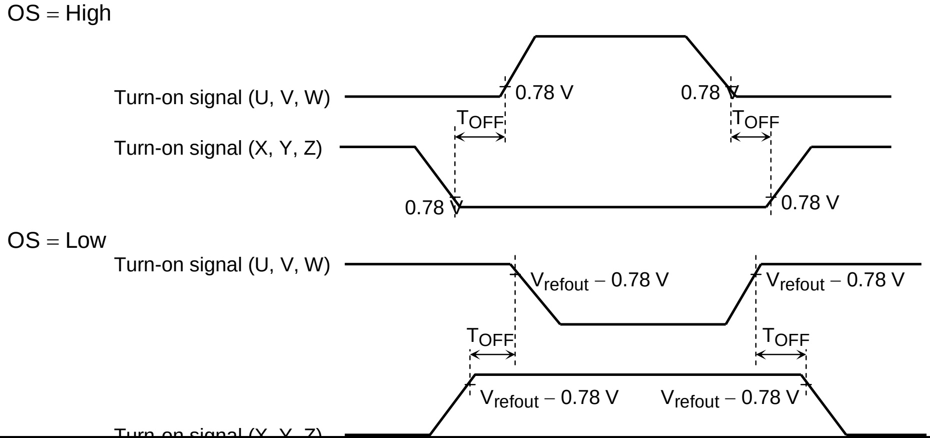


Electrical Characteristics (Ta = 25°C, V_{CC} = 7 V)

Characteristics	Symbol		Test Circuit	Test Condition		Min	Typ.	Max	Unit
Supply current	I_{CC}		—	V_{refout} = open		—	3	6	mA
Input current	$I_{in\ (1)}$		—	V_{in} = 5 V	V_e, LA	—	20	40	μA
	$I_{in\ (2)}$-1			V_{in} = 0 V	HU, HV, HW	–40	–20	—	
	$I_{in\ (2)}$-2			V_{in} = 0 V	CW/CCW, OS, Td	–80	–40	—	
	$I_{in\ (2)}$-3			V_{in} = 5 V	RES	—	40	80	
Input voltage	V_{in}	High	—	HU, HV, HW, CW/CCW, RES, OS, Td		V_{refout} − 1	—	V_{refout}	V
		Low				—	—	0.8	
Input hysteresis voltage	V_H		—	HU, HV, HW, CW/CCW, RES		—	0.3	—	V
Output voltage	$V_{OUT\ (H)}$-1		—	I_{OUT} = 2 mA	U, V, W, X, Y, Z	V_{refout} − 0.78	V_{refout} − 0.4	—	V
	$V_{OUT\ (L)}$-1			I_{OUT} = −2 mA	U, V, W, X, Y, Z	—	0.4	0.78	
	$V_{REV\ (H)}$			I_{OUT} = 1 mA	REV	V_{refout} − 1.0	V_{refout} − 0.5	—	
	$V_{REV\ (L)}$			I_{OUT} = −1 mA	REV	—	0.5	1.0	
	$V_{FG(H)}$			I_{OUT} = 1 mA	FG	V_{refout} − 1.0	V_{refout} − 0.5	—	
	$V_{FG(L)}$			I_{OUT} = −1 mA	FG	—	0.5	1.0	
	V_{refout}			I_{OUT} = 30 mA	V_{refout}	4.5	5.0	5.5	
Output leakage current	$I_{L\ (H)}$		—	V_{OUT} = 0 V	U, V, W, X, Y, Z	—	0	10	μA
	$I_{L\ (L)}$			V_{OUT} = 3.5 V	U, V, W, X, Y, Z	—	0	10	
Output off-time by upper/lower transistor (Note 1)	$T_{OFF(H)}$		—	Td = High or open, X_{in} = 4.19 MHz, I_{OUT} = ± 2 mA, OS = High/Low		2.2	2.6	—	μs
	$T_{OFF(L)}$			Td = Low, X_{in} = 4.19 MHz, I_{OUT} = ± 2 mA, OS = High/Low		3.0	3.8	—	
Over-current detection	V_{dc}		—	I_{dc}		0.46	0.5	0.54	V
Lead angle correction	$T_{LA\ (0)}$			L_A = 0 V or Open, Hall IN = 100 Hz		—	0	—	°
	$T_{LA\ (2.5)}$			L_A = 2.5 V, Hall IN = 100 Hz		27.5	32	34.5	
	$T_{LA\ (5)}$			L_A = 5 V, Hall IN = 100 Hz		53.5	59	62.5	
V_{CC} monitor	$V_{CC\ (H)}$			Output start operation point		4.2	4.5	4.8	V
	$V_{CC\ (L)}$			No output operation point		3.7	4.0	4.3	
	V_H			Input hysteresis width		—	0.5	—	

Note 5: T_{OFF}

OS = High



Functional Description

1. Basic operation

On start-up, the motor is driven by the square-wave turn-on signal based on a positional signal. When the positional signal reaches number of rotations f = 5 Hz or higher, the rotor position is inferred from the positional signal and a modulation wave is generated. The modulation wave and the triangular wave are compared; the sine-wave PWM signal is then generated and the motor is driven.

From start to 5 Hz: When driven by square wave (120° turn-on) $f = f_{osc}/(2^{12} \times 32 \times 6)$

5 Hz~: When driven by sine-wave PWM (180° turn-on) When f_{osc} = 4 MHz, approx. 5 Hz

2. Function to stabilize bootstrap voltage

(1) When voltage instruction is input at $V_e \leqq 0.2$ V:
The lower transistor is turned on at the regular (carrier) cycle. (On duty is approx. 8%.)

(2) When voltage instruction is input at $V_e > 0.2$ V:
During sine-wave drive, the drive signal is output as it is.
During square-wave drive, the lower transistor is forcibly turned on at the regular (carrier) cycle. (On duty is approx. 8%.)

Note: At startup, to charge the upper transistor gate power supply, turn the lower transistor on for a fixed time with $V_e \leqq 0.2$ V.

3. Dead time function: upper/lower transistor output off-time

When the motor is driven by a sine-wave PWM, dead time is generated digitally in the IC to prevent any short circuit caused by the simultaneous turning on of upper and lower external power devices.

When a square wave is generated in full duty cycle mode, the dead time function is turned on to prevent a short circuit.

Td Pin	Internal Counter	T_{OFF}
High or Open	$11/f_{osc}$	2.6 μs
Low	$16/f_{osc}$	3.8 μs

T_{OFF} values above are obtained when fosc = 4.19 MHz.
f_{osc} = reference clock (crystal oscillation)

4. Correcting lead angle

The lead angle can be corrected in the turn-on signal range from 0 to 58° in relation to the induced voltage.

Analog input from LA pin (0 V to 5 V divided by 32):
0 V = 0°
5 V = 58° (when more than 5 V is input, 58°)

5. Setting carrier frequency

This feature sets the triangular wave cycle (carrier cycle) necessary for generating the PWM signal.

(The triangular wave is used for forcibly turning on the lower transistor when the motor is driven by square wave.)

Carrier cycle = $f_{osc}/252$ (Hz) f_{osc} = Reference clock (crystal oscillation)

6. Switching the output of turn-on signal

This function switches the output of the turn-on signal between high and low.

Pin OS:
High = active high
Low = active low

7. Outputting reverse rotation detection signal

The direction of motor rotation is detected for every electrical angle of 360°. (The output is high immediately after reset.)

The REV terminal increases to a 180° turn-on mode at the time of low.

CW/CCW Pin	Actual Motor Rotating Direction	REV Pin
Low (CW)	CW (forward)	Low
	CCW (reverse)	High
High (CCW)	CW (forward)	High
	CCW (reverse)	Low

8. Protecting input pin

1. Over-current protection (Pin I_{dc})

   When the DC-link-current exceeds the internal reference voltage, gate block protection is performed. Over-current protection is released for each carrier frequency.

   Reference voltage = 0.5 V (typ.)

2. Gate block protection (Pin RES)

   When the input signal level is Low, the output is turned off; when the signal is High, the output is restarted.

   Abnormalities are detected externally, and the signal is input to the pin RES.

RES Pin	OS Pin	Output Turn-on Signal (U, V, W, X, Y, Z)
Low	Low	High
	High	Low

   (When RES = Low, bootstrap capacitor charging stops.)

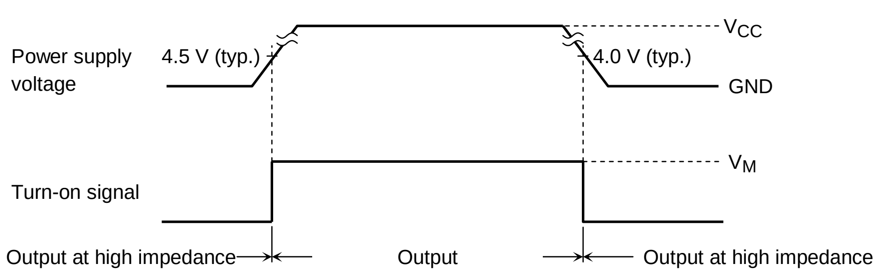
3. Internal protection

   - Positional signal abnormality protection

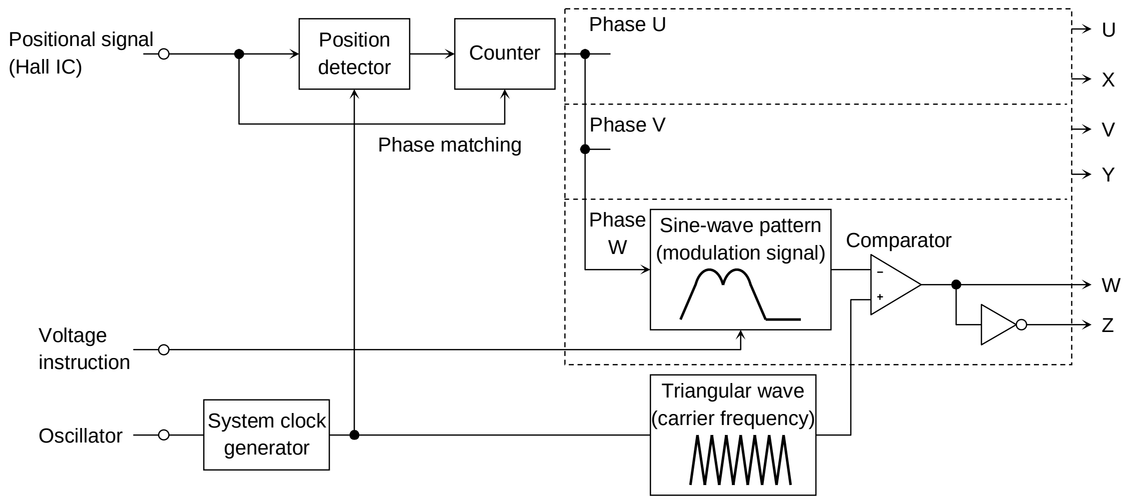
     When the positional signal is HHH or LLL, the output is turned off; otherwise, the output is restarted.

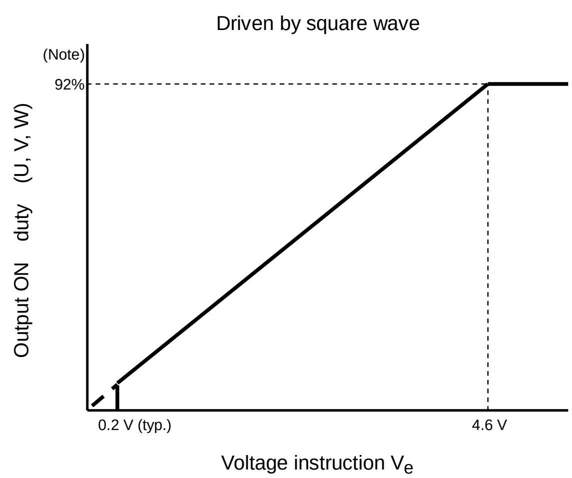
   - Low power supply voltage protection (V_{CC} monitor)

     Outside the operating voltage range, the turn-on signal output is kept at high impedance to prevent damage caused by short-circuiting of power components when the power supply is turned on or off.

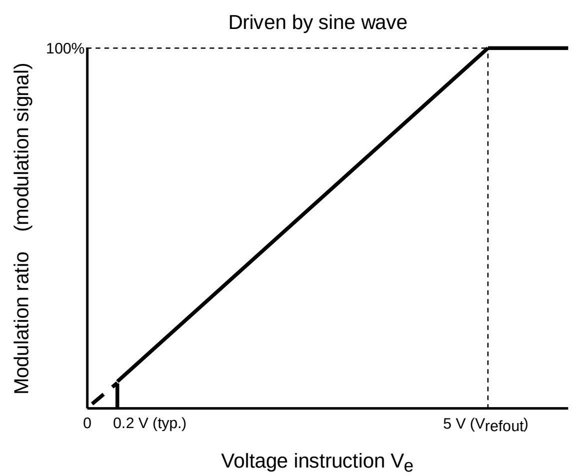


Operation Flow





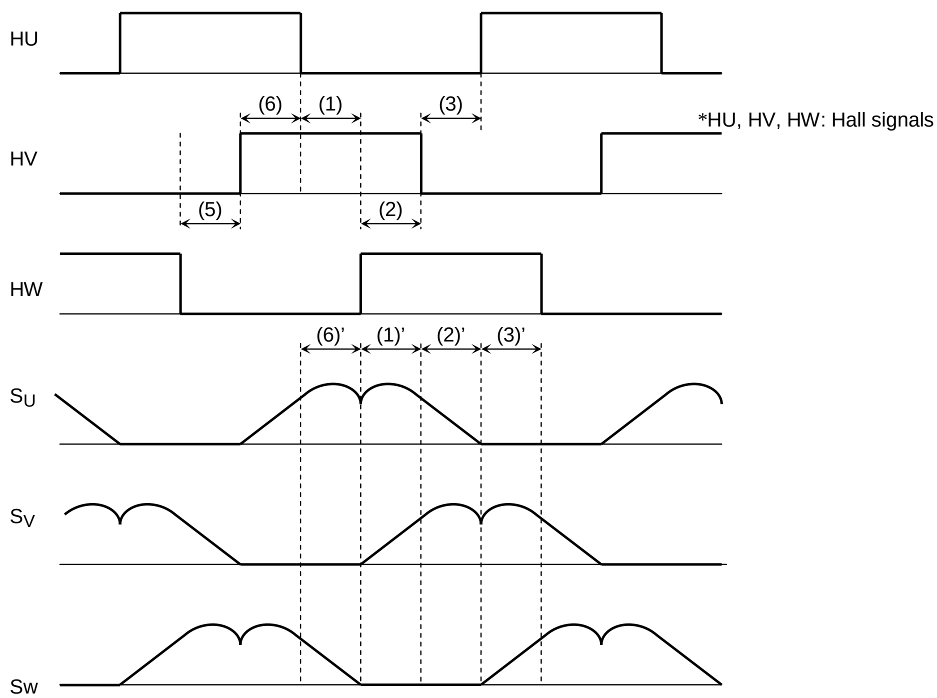
Note: Output ON time is decreased by the dead time (carrier frequency × 92% − T_d × 2).



The modulation waveform is generated using Hall signals. The modulation waveform is then compared with the triangular wave and a sine-wave PWM signal is generated.

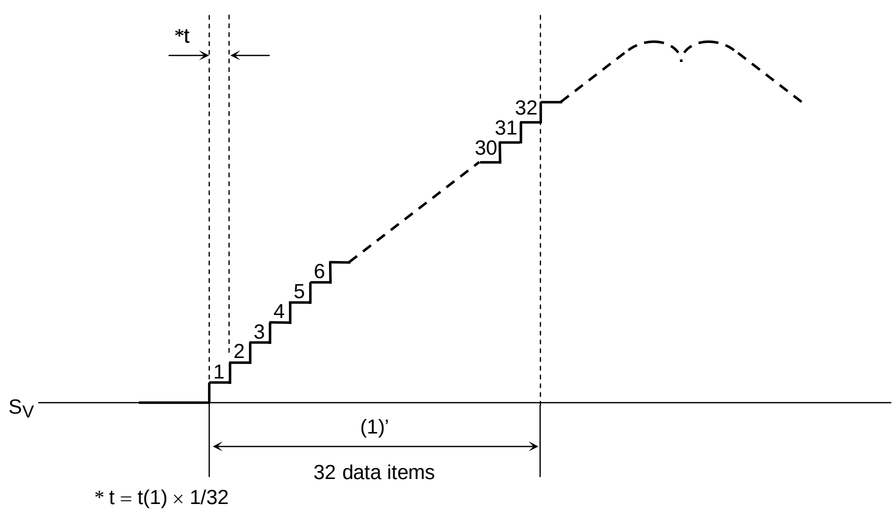
The time (electrical angle: 60°) from the rising (or falling) edges of the three Hall signals to the next falling (or rising) edges is counted. The counted time is used as the data for the next 60° phase of the modulation waveform.

There are 32 items of data for the 60° phase of the modulation waveform. The time width of one data item is 1/32 of the time width of the 60° phase of the previous modulation waveform. The modulation waveform moves forward by this width.



In the above diagram, the modulation waveform (1)' data moves forward by the 1/32 time width of the time (1) from HU: ↑ to HW: ↓. Similarly, data (2)' moves forward by the 1/32 time width of the time (2) from HW: ↓ to HV: ↑.

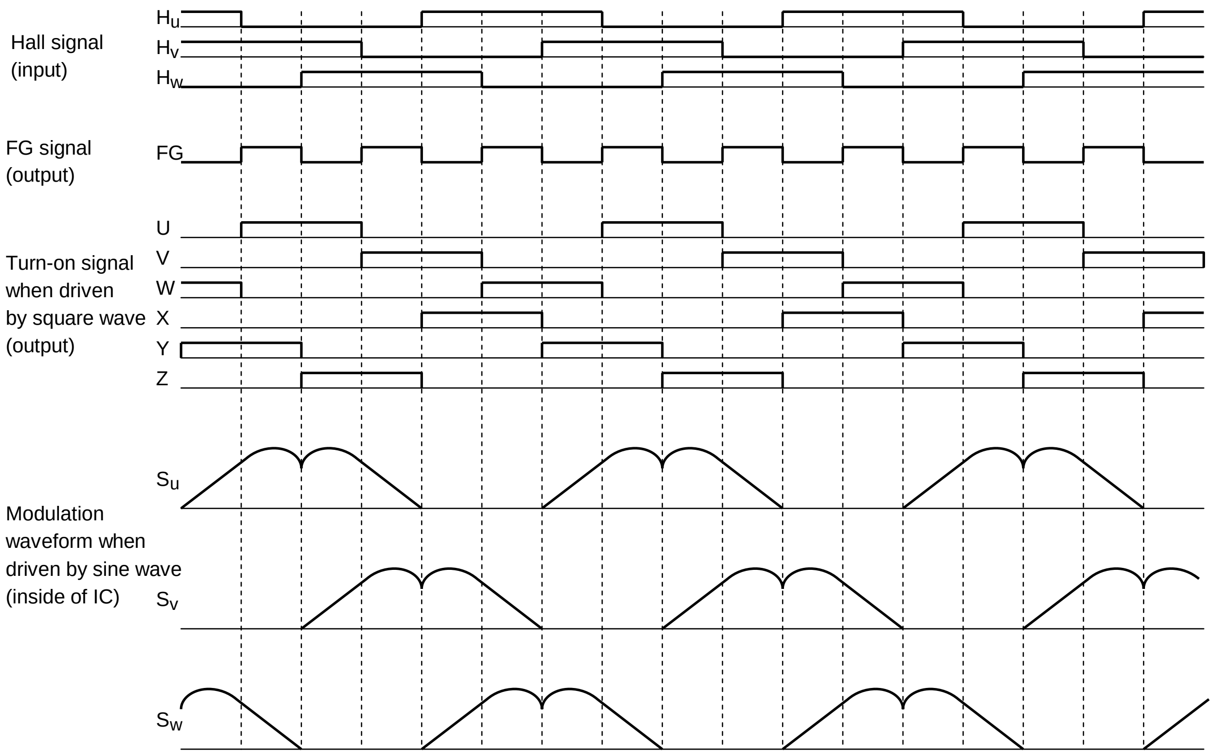
If the next edge does not occur after the 32 data items end, the next 32 data items move forward by the same time width until the next edge occurs.



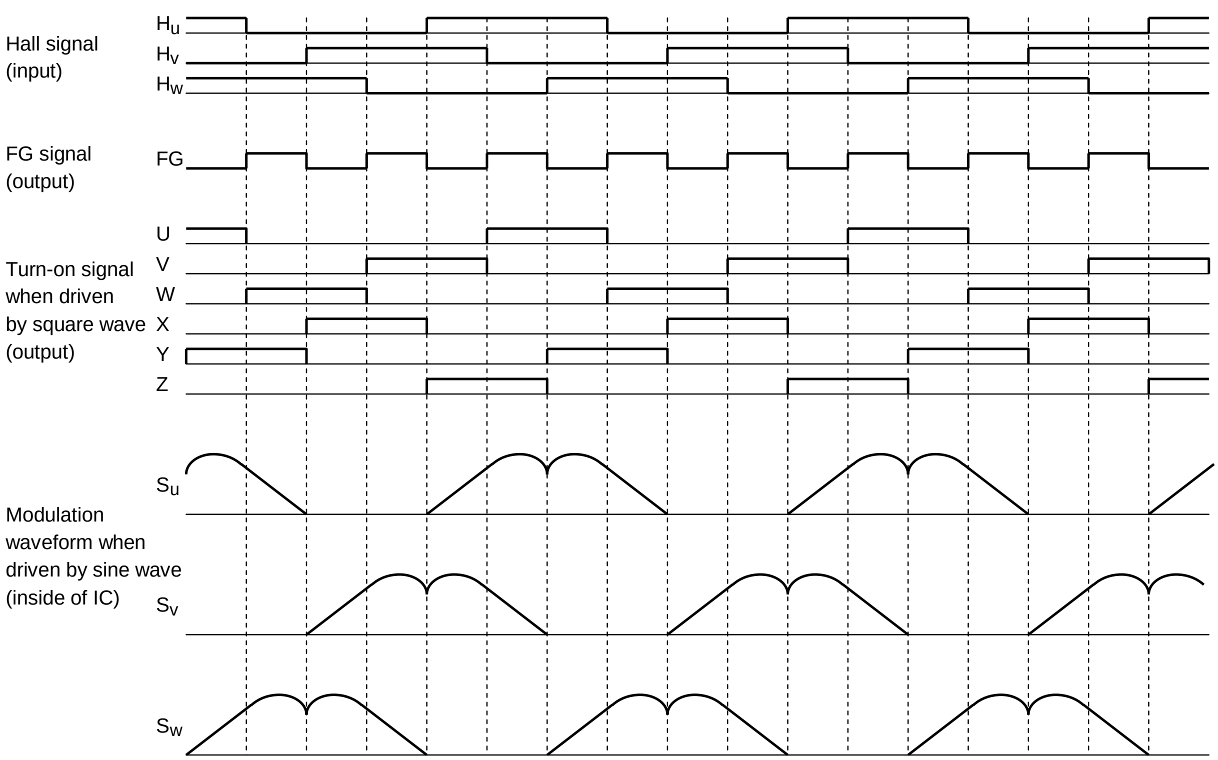
The modulation wave is brought into phase with every zero-cross point of the Hall signal.

The modulation wave is reset in synchronization with the rising and falling edges of the Hall signal at every electrical angle of 60°. Thus, when the Hall device is not placed in the correct position or during accelerating or decelerating, the modulation waveform is not continuous at every reset.

Timing Charts

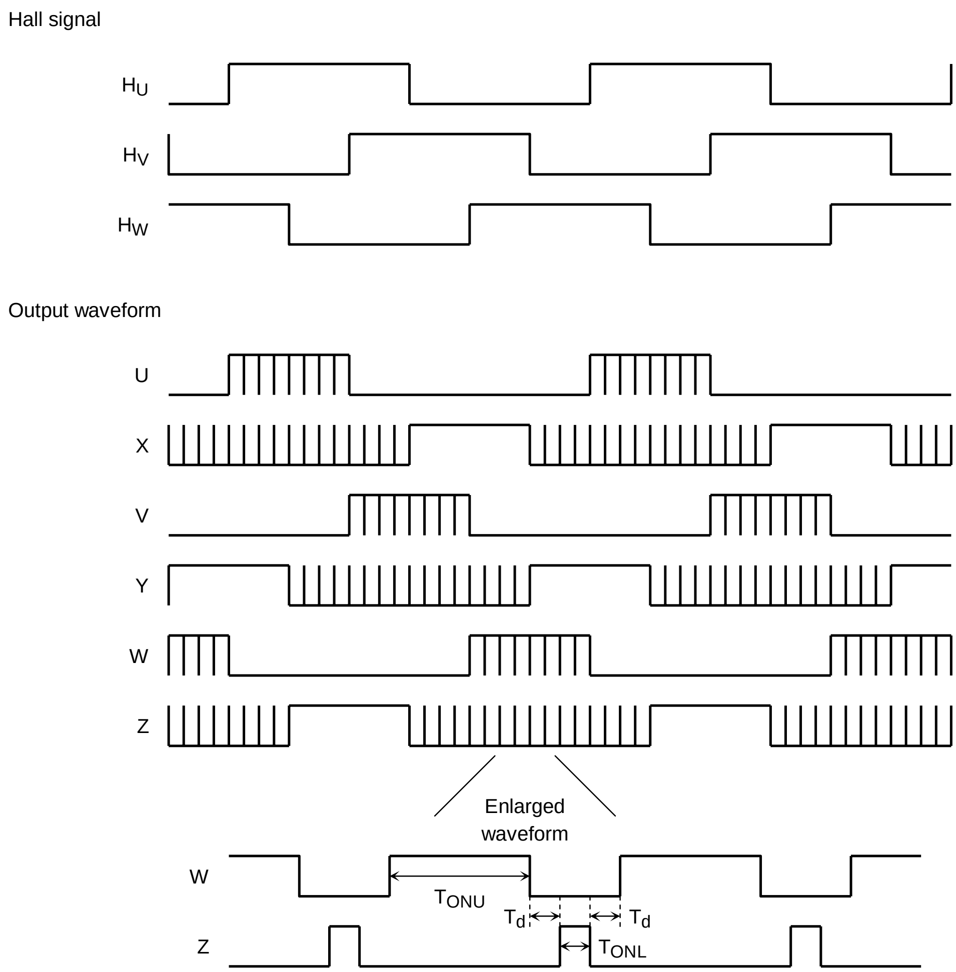


Forward



Reverse

Operating Waveform When Driven by Square Wave (CW/CCW = Low, OS = High)



To stabilize the bootstrap voltage, the lower outputs (X, Y, and Z) are always turned on at the carrier cycle even during off time. At that time, the upper outputs (U, V, and W) are assigned dead time and turned off at the timing when the lower outputs are turned on. (T_d varies with input V_e.)

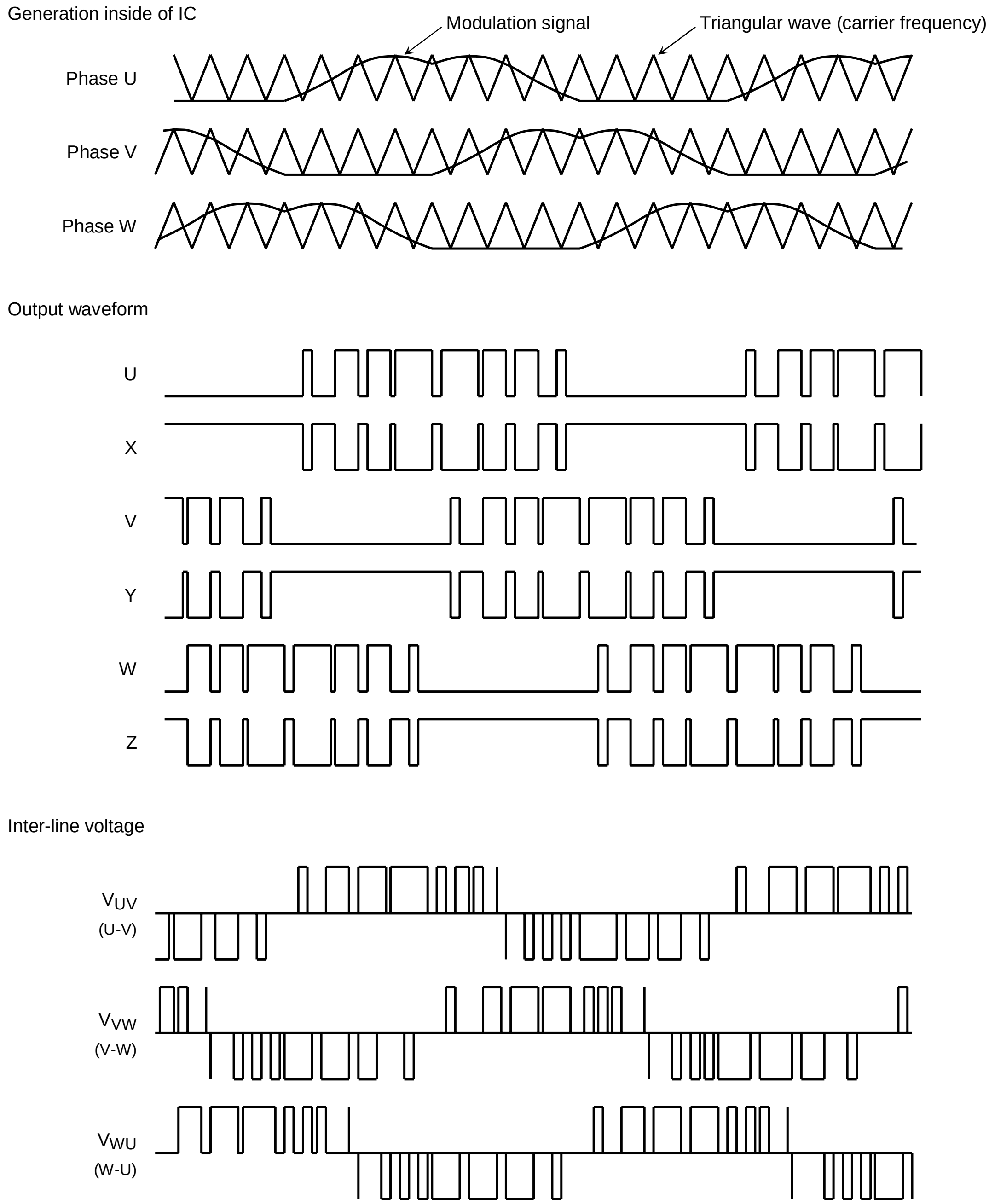
Carrier cycle = f_{osc}/252 (Hz) Dead time: T_d = 16/f_{osc} (s) (when V_e = 4.6 V or more)

T_{ONL} = carrier cycle × 8% (s) (uniform regardless of Ve input)

When the motor is driven by a square wave, acceleration or deceleration is determined by voltage V_e. The motor accelerates or decelerates according to the On duty of T_{ONU}. (See the diagram for output On duty on page 11.)

Note: The motor is driven by a square wave if REV = High, i.e., if the Hall signals at start-up are 5 Hz (f_{osc} = 4 MHz) or lower and the motor is rotating in the reverse direction to that of the TB6551F/FG setting.

Operating Waveform When Driven by Sine-Wave PWM (CW/CCW = Low, OS = High)

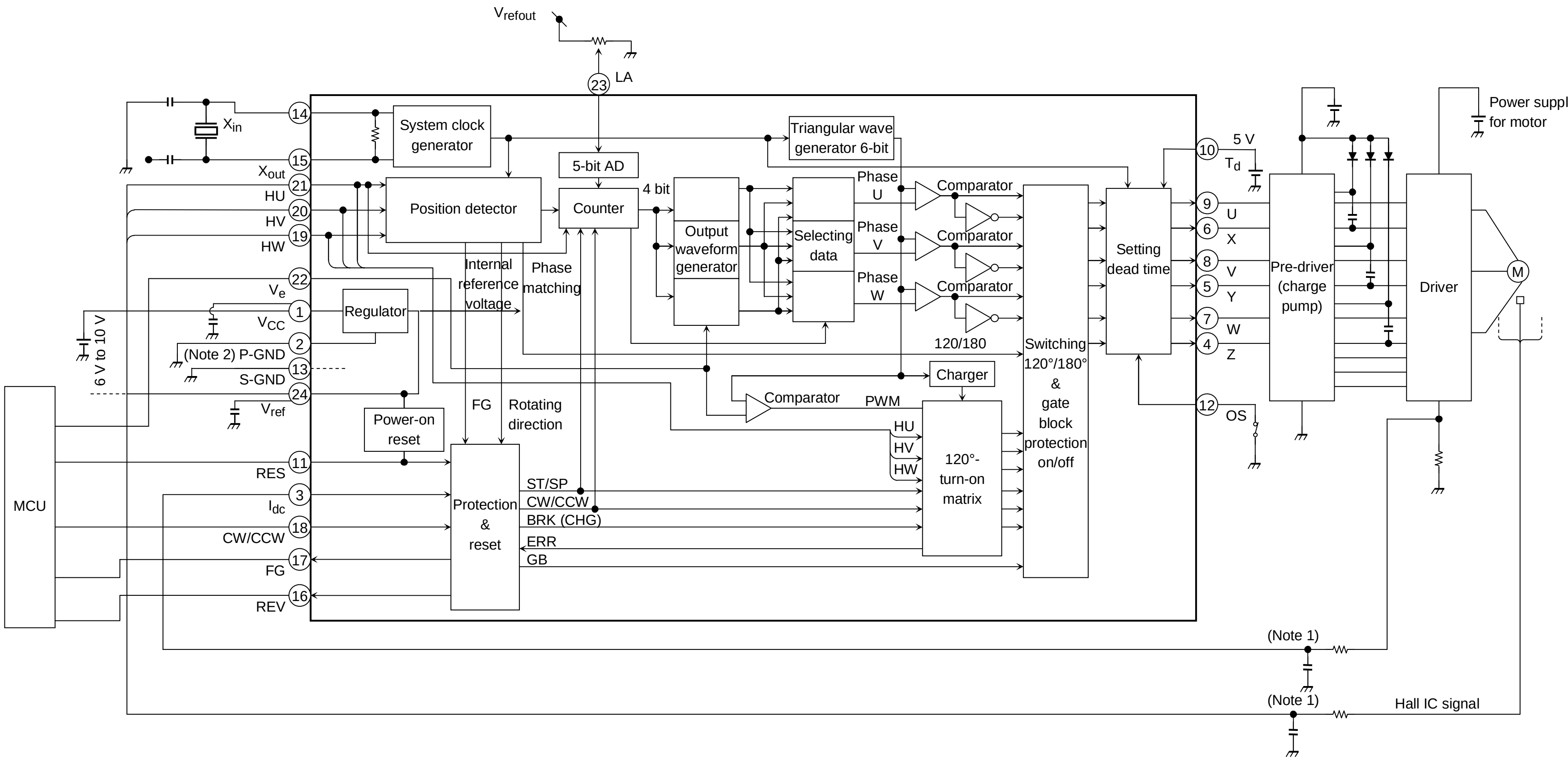


When the motor is driven by a sine wave, the motor is accelerated or decelerated according to the On duty of T_{ONU} when the amplitude of the modulation symbol changes by voltage V_e (see the diagram of output On duty on page 11):

Triangular wave frequency = carrier frequency = $f_{osc}/252$ (Hz).

Note: The motor is driven by a sine wave if REV = Low, i.e., if the Hall signals at start-up are 5 Hz (fosc = 4 MHz) or higher and the motor is rotating in the same direction as that of the TB6551F/FG setting.

Example of Application Circuit



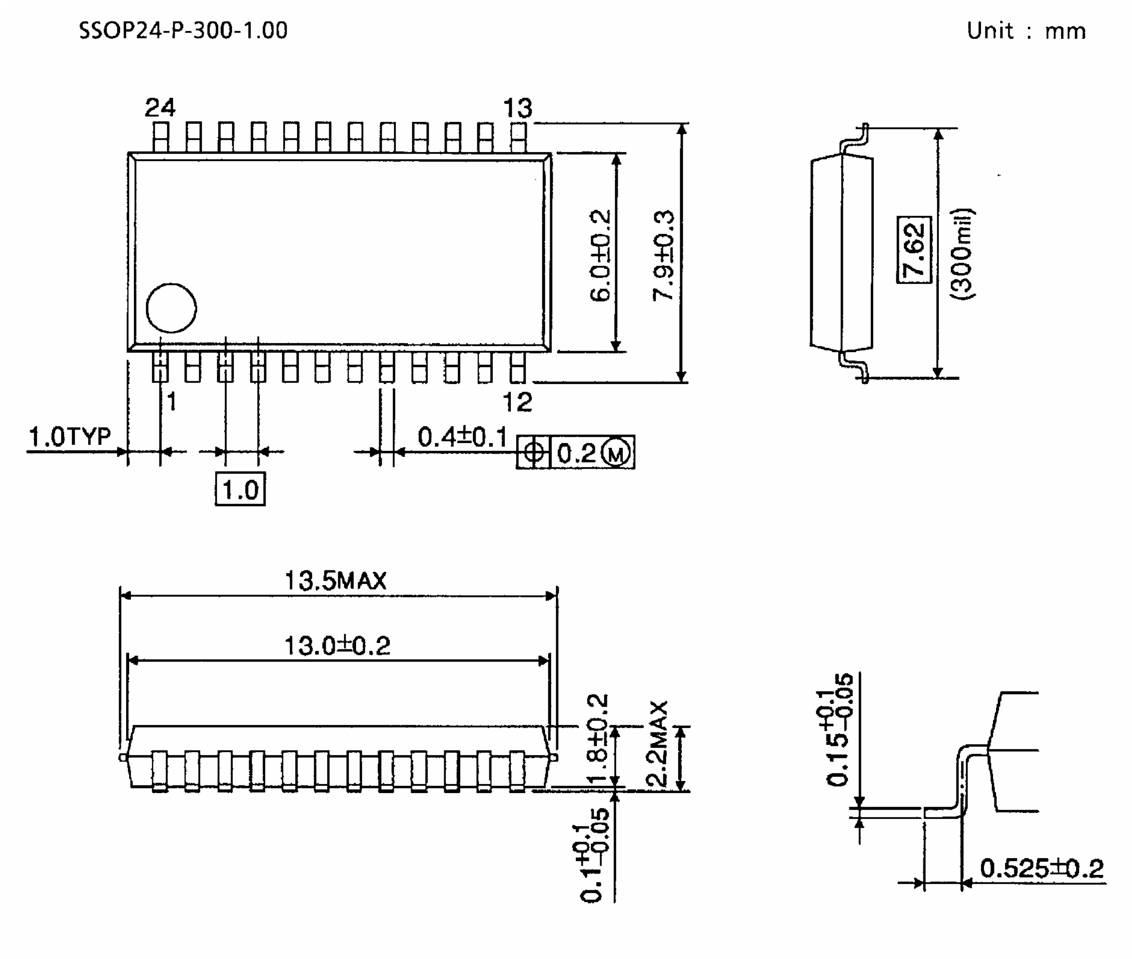
Note 1: Connect as required to the ground to prevent IC malfunction due to noise.

Note 2: Connect P-GND to signal ground on the application circuit.

Note 3: A short circuit between the outputs, or between output and supply or ground may damage the device. Peripheral parts may also be damaged by over-voltage and over-current. Design the output, V_{CC} and GND lines so that short circuits do not occur.

Also be careful not to insert the IC in the wrong direction because this could destroy the IC.

Package Dimensions



Weight: 0.33 g (typ.)

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. Maximum Ratings

The absolute maximum ratings of a semiconductor device are a set of specified parameter values that must not be exceeded during operation, even for an instant.

If any of these ratings are exceeded during operation, the electrical characteristics of the device may be irreparably altered, in which case the reliability and lifetime of the device can no longer be guaranteed.

Moreover, any exceeding of the ratings during operation may cause breakdown, damage and/or degradation in other equipment. Applications using the device should be designed so that no maximum rating will ever be exceeded under any operating conditions.

Before using, creating and/or producing designs, refer to and comply with the precautions and conditions set forth in this document.

5. Application Circuits

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

In furnishing these examples of application circuits, Toshiba does not grant the use of any industrial property rights.

6. Test Circuits

Components in test circuits are used only to obtain and confirm device characteristics. These components and circuits are not guaranteed to prevent malfunction or failure in application equipment.

Handling of the IC

Ensure that the product is installed correctly to prevent breakdown, damage and/or degradation in the product or equipment.

Over-current protection and heat protection circuits

These protection functions are intended only as a temporary means of preventing output short circuits or other abnormal conditions and are not guaranteed to prevent damage to the IC.

If the guaranteed operating ranges of this product are exceeded, these protection features may not operate and some output short circuits may result in the IC being damaged.

The over-current protection feature is intended to protect the IC from temporary short circuits only.

Short circuits persisting over long periods may cause excessive stress and damage the IC. Systems should be configured so that any over-current condition will be eliminated as soon as possible.

Counter-electromotive force

When the motor reverses or stops, the effect of counter-electromotive force may cause the current to flow to the power source.

If the power supply is not equipped with sink capability, the power and output pins may exceed the maximum rating.

The counter-electromotive force of the motor will vary depending on the conditions of use and the features of the motor. Therefore make sure there will be no damage to or operational problem in the IC, and no damage to or operational errors in peripheral circuits caused by counter-electromotive force.

RESTRICTIONS ON PRODUCT USE

030619EBA

- The information contained herein is subject to change without notice.
- The information contained herein is presented only as a guide for the applications of our products. No responsibility is assumed by TOSHIBA for any infringements of patents or other rights of the third parties which may result from its use. No license is granted by implication or otherwise under any patent or patent rights of TOSHIBA or others.
- TOSHIBA is continually working to improve the quality and reliability of its products. Nevertheless, semiconductor devices in general can malfunction or fail due to their inherent electrical sensitivity and vulnerability to physical stress. It is the responsibility of the buyer, when utilizing TOSHIBA products, to comply with the standards of safety in making a safe design for the entire system, and to avoid situations in which a malfunction or failure of such TOSHIBA products could cause loss of human life, bodily injury or damage to property.
  In developing your designs, please ensure that TOSHIBA products are used within specified operating ranges as set forth in the most recent TOSHIBA products specifications. Also, please keep in mind the precautions and conditions set forth in the "Handling Guide for Semiconductor Devices," or "TOSHIBA Semiconductor Reliability Handbook" etc..
- The TOSHIBA products listed in this document are intended for usage in general electronics applications (computer, personal equipment, office equipment, measuring equipment, industrial robotics, domestic appliances, etc.). These TOSHIBA products are neither intended nor warranted for usage in equipment that requires extraordinarily high quality and/or reliability or a malfunction or failure of which may cause loss of human life or bodily injury ("Unintended Usage"). Unintended Usage include atomic energy control instruments, airplane or spaceship instruments, transportation instruments, traffic signal instruments, combustion control instruments, medical instruments, all types of safety devices, etc.. Unintended Usage of TOSHIBA products listed in this document shall be made at the customer's own risk.
- The products described in this document are subject to the foreign exchange and foreign trade laws.
- TOSHIBA products should not be embedded to the downstream products which are prohibited to be produced and sold, under any law and regulations.