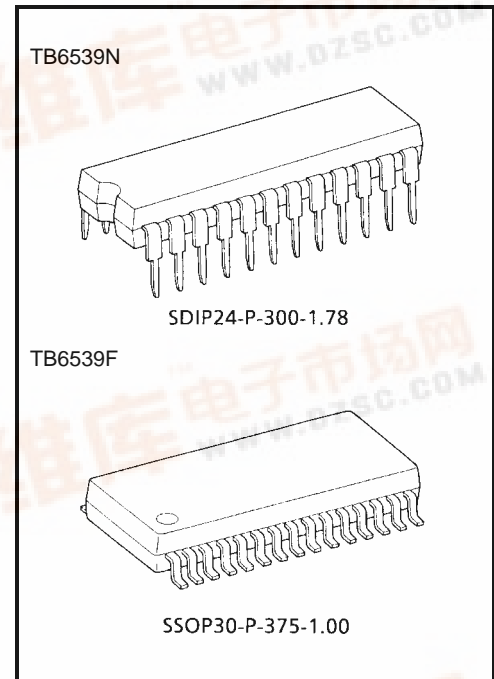# TOSHIBA

TOSHIBA Bi-CMOS Integrated Circuit   Silicon Monolithic

TB6539N,TB6539F

3-Phase Full-Wave Sine-Wave PWM Brushless Motor Control

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
- Supports bootstrap circuit
- Overcurrent protection signal input pin
- Built-in regulator ($V_{refout} = 5$ V (typ.), 30 mA (max))
- Operating supply voltage range: $V_{CC} = 10$ to 18 V
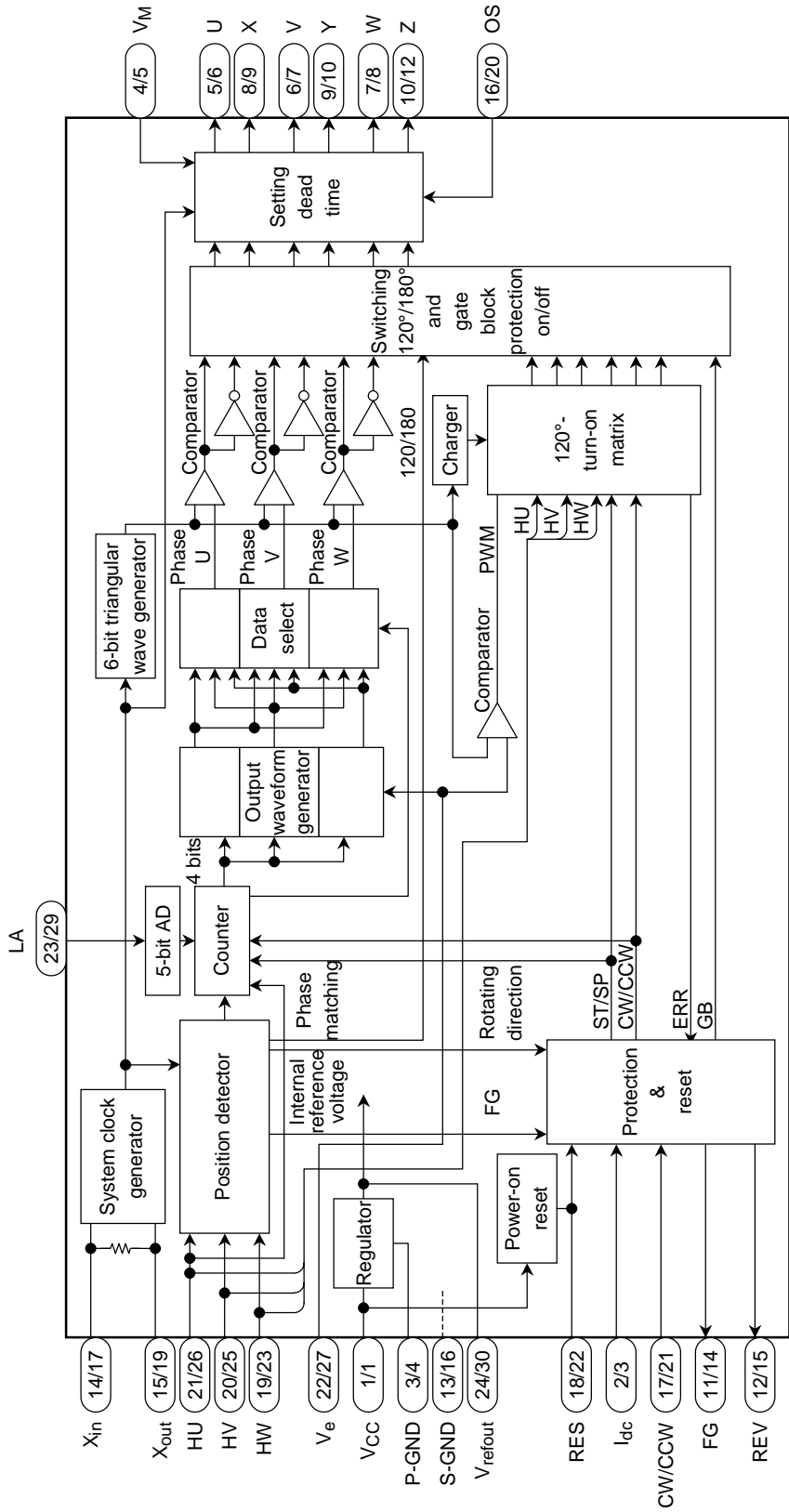 $V_M = 4.5$ to 18 V

TB6539N

SDIP24-P-300-1.78

TB6539F

SSOP30-P-375-1.00

Weight
SDIP24-P-300-1.78   : 1.62 g (typ.)
SSOP30-P-375-1.00 : 0.63 g (typ.)

TOSHIBA

Block Diagram

System clock generator

Position detector

Regulator

Power-on reset

Internal reference voltage

Phase matching

Rotating direction

FG

Protection & reset

5-bit AD

Counter — 4 bits

Output waveform generator

Data select

6-bit triangular wave generator

Phase U

Phase V

Phase W

Comparator

Comparator

Comparator

Comparator PWM

Charger

120/180

Switching 120°/180° and gate block protection on/off

Setting dead time

120°-turn-on matrix

HU
HV
HW

ST/SP
CW/CCW
ERR
GB

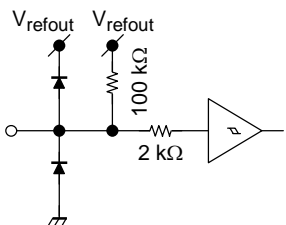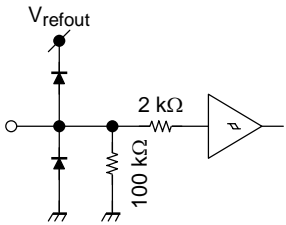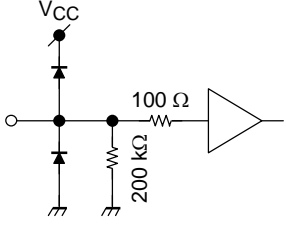| Pin	Signal
14/17	X_{in}
15/19	X_{out}
21/26	HU
20/25	HV
19/23	HW
22/27	V_e
1/1	V_{CC}
3/4	P-GND
13/16	S-GND
24/30	V_{refout}
18/22	RES
2/3	I_{dc}
17/21	CW/CCW
11/14	FG
12/15	REV
23/29	LA
4/5	V_M
5/6	U
8/9	X
6/7	V
9/10	Y
7/8	W
10/12	Z
16/20	OS

※ The pin numbers shown above are for the TB6539N/TB6539F
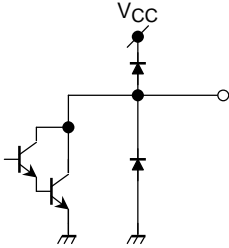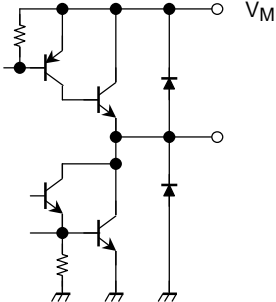
Pin Description

Pin No. TB6539N	Pin No. TB6539F	Symbol	Description	Remarks
21	26	HU	Positional signal input pin U	When positional signal is HHH or LLL, gate block protection operates. With built-in pull-up resistor
20	25	HV	Positional signal input pin V	
19	13	HW	Positional signal input pin W	
17	21	CW/CCW	Rotation direction signal input pin	L: Forward H: Reverse
18	22	RES	Reset-signal-input pin	L: Reset (Output is non-active) Operation/Halt operation Also used for gate block protection
22	27	V_e	Inputs voltage instruction signal	With built-in pull-down resistor
23	29	LA	Lead angle setting signal input pin	Sets 0 to 58° in 32 steps
16	20	OS	Inputs output logic select signal	L: Active low H: Active high
2	3	I_{dc}	Inputs overcurrent-protection-signal	Inputs DC link current. Reference voltage: 0.5 V With built-in filter ($\simeq$ 1 μs)
14	17	X_{in}	Inputs clock signal	With built-in feedback resistor
15	19	X_{out}	Outputs clock signal	
24	30	V_{refout}	Outputs reference voltage signal	5 V (typ.), 30 mA (max)
11	14	FG	FG signal output pin	Outputs 3PPR of positional signal
12	15	REV	Reverse rotation detection signal	Detects reverse rotation.
5	6	U	Outputs turn-on signal	Select active high or active low using the output logic select pin.
6	7	V	Outputs turn-on signal	
7	8	W	Outputs turn-on signal	
8	9	X	Outputs turn-on signal	
9	10	Y	Outputs turn-on signal	
10	12	Z	Outputs turn-on signal	
1	1	V_{CC}	Power supply voltage pin	V_{CC} = 10~18 V
4	5	V_M	Apply power supply for output circuit.	V_M = 4.5~18 V
3	4	P-GND	Ground for power supply	Ground pin
13	16	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 to 5.0 V Input voltage of V_{refout} or higher is clipped to V_{refout}.	
Lead angle setting signal input pin 0 V: 0° 5 V: 58° (5-bit AD)	LA	Analog Input range 0 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
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)	
Overcurrent 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 to 8 MHz (crystal oscillation)	
Clock signal output pin	X_{out}		
Reference voltage signal output pin	Vrefout	5 ± 0.5 V (max 30 mA)	
Reverse-rotation-detection signal output pin	REV	Digital Open collector output: 20 mA (max)	

Pin Description	Symbol	Input/Output Signal	Input/Output Internal Circuit
FG signal output pin	FG	Digital Open collector output: 20 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: 20 mA (max) L: 1.3 V (max) H: $V_M - 1.3$ V (min)	

Maximum Ratings (Ta = 25°C)

Characteristics		Symbol	Rating		Unit
Supply voltage		V_{CC}	18		V
		V_M	18		
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}	20		mA
Power dissipation	N T y p e	P_D	1.75	(Note 3)	W
	F T y p e		1.50	(Note 4)	
Operating temperature		T_{opr}	−30~115	(Note 5)	°C
Storage temperature		T_{stg}	−50~150		°C

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

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

Note 3: When mounted on PCB (universal 125 × 180 × 1.6 mm)

Note 4: When mounted on PCB (universal 50 × 50 × 1.6 mm)

Note 5: 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}	10	15	18	V
	V_M	4.5	5	18	
Crystal oscillation frequency	X_{in}	2	4	8	MHz
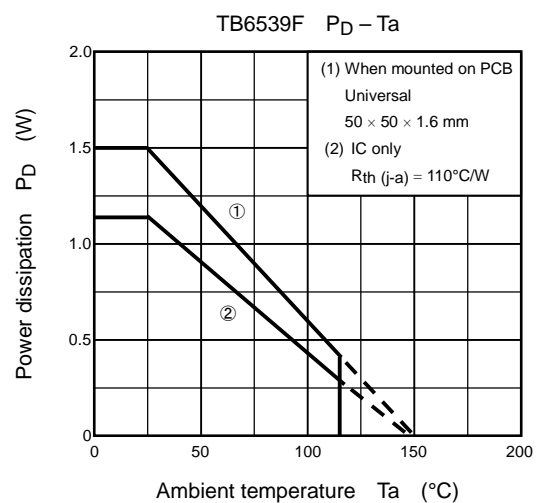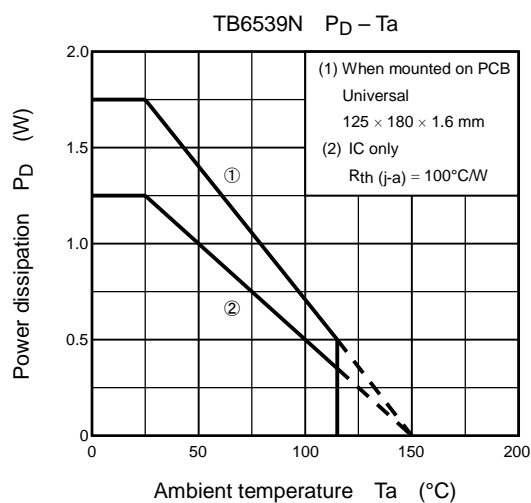
Electrical Characteristics (Ta = 25°C, V_{CC} = 15 V)

Characteristics	Symbol		Test Circuit	Test Condition	Min	Typ.	Max	Unit
Supply current	I_{CC}		—	V_{refout} = OPEN	—	20	30	mA
	I_M			V_M = 5 V	—	8	12	
Input current	$I_{in (1)}$		—	V_{in} = 5 V V_e, LA	—	25	40	μA
	$I_{in (2)}$-1			V_{in} = 0 V HU, HV, HW	−40	−25	—	
	$I_{in (2)}$-2			V_{in} = 0 V CW/CCW, OS	−80	−50	—	
	$I_{in (2)}$-3			V_{in} = 5 V RES	—	50	80	
Input voltage	V_{in}	High	—	HU, HV, HW, CW/CCW, RES, OS	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} = 20 mA U, V, W, X, Y, Z V_M = 5 V	V_M − 1.3	V_M − 1.0	—	V
	$V_{OUT (L)}$-1			I_{OUT} = −20 mA U, V, W, X, Y, Z V_M = 5 V	—	1.0	1.3	
	V_{REV}			I_{OUT} = −20 mA REV	—	1.0	1.3	
	V_{refout}			I_{OUT} = 30 mA V_{refout}	4.5	5.0	5.5	
	V_{FG}			I_{OUT} = −20 mA FG	—	1.0	1.3	
Output leakage current	$I_{L (H)}$		—	V_M = 15 V, V_{OUT} = 0 V U, V, W, X, Y, Z	—	0	10	μA
	$I_{L (L)}$			V_M = 15 V, V_{OUT} = 15 V U, V, W, X, Y, Z	—	0	10	
Output off-time by upper/lower transistor	T_{OFF}		—	V_M = 5 V/15 V, I_{OUT} = ± 20 mA OS = High/Low, X_{in} = 4.19 MHz (Note 1)	3.0	3.8	—	μs
Overcurrent detection	V_{dc}		—	I_{dc}	0.45	0.5	0.55	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	7.5	8.5	9.5	V
	$V_{CC (L)}$			No output operation point	6.5	7.5	8.5	
	V_{HYS}				—	1.0	—	

Note 1:
     OS = High
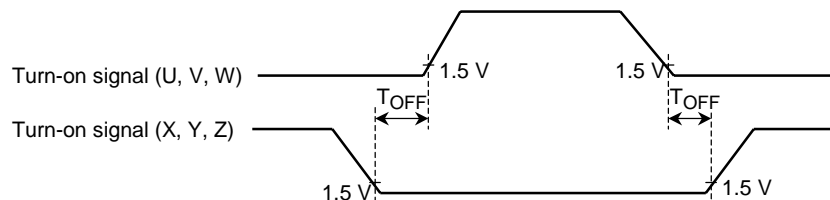
     OS = Low
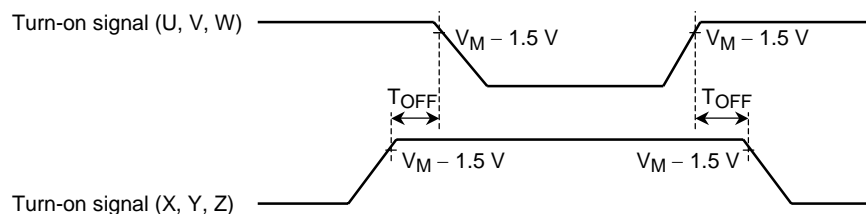
Functional Description

1. Basic operation

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 assumed according to the positional signal and a modulation wave is generated. The modulation wave and the triangular wave are compared then the sine-wave PWM signal is 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:
Turns on the lower transistor at regular (carrier) cycle. (On duty is approx. 8%)
(2)   When voltage instruction is input at $V_e > 0.2$ V:
During sine-wave drive, outputs drive signal as it is.
During square-wave drive, forcibly turns on the lower transistor at 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 driving the motor by sine-wave PWM, to prevent a short circuit caused by simultaneously turning on upper and lower external power devices, digitally generates dead time in the IC.

Dead time: $T_d = 16/f_{osc}$ (s)   When f_{osc} = 4 MHz, approx. T_d = 4 µs.
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 to 5 V divided by 32)
0 V = 0°
5 V = 58° (when more than 5 V is input, 58°)

5. Setting carrier frequency

Sets triangular wave cycle (carrier cycle) necessary for generating PWM signal.
(The triangular wave is used for forcibly turning on the lower transistor when driving the motor by square wave.)
Carrier cycle = $f_{osc}/252$ (Hz) f_{osc} = reference clock (crystal oscillation)

6. Switching the output of turn-on signal

Switches the output of turn-on signal between high and low.
Pin OS:
High = active high
Low = active low

7. Outputting reverse rotation detection signal

Detects motor rotation direction every electrical angle of 360°. (The output is high immediately after reset)
REV terminal increases with a 180° turn-on mode at the time of High-Z.

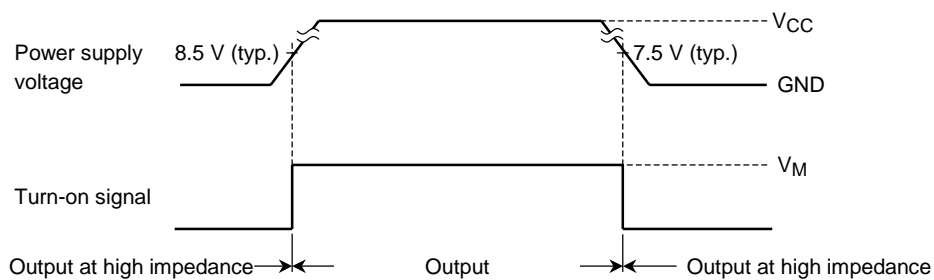| CW/CCW Pin	Actual Motor Rotating Direction	REV Pin
Low (CW)	CW (forward)	High-Z
	CCW (reverse)	Low
High (CCW)	CW (forward)	Low
	CCW (reverse)	High-Z

8. Protecting input pin

1. Overcurrent protection (Pin I_{dc})

When the DC-link-current exceeds the internal reference voltage, performs gate block protection.
Overcurrent 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, turns off the output; when High, restarts the output.
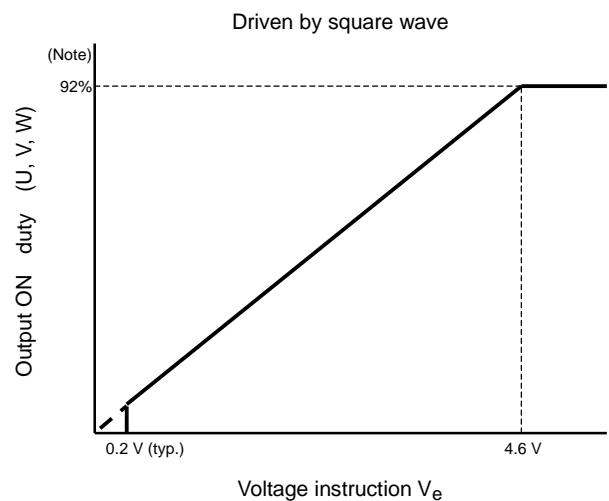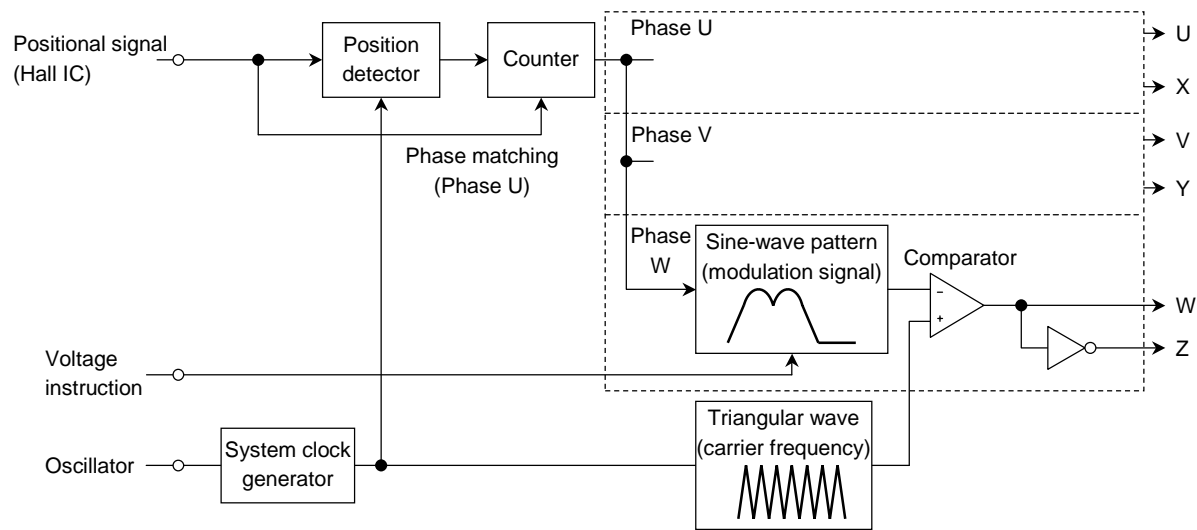Detects abnormality externally and inputs the signal to the pin RES.

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, turns off the output; otherwise, restarts the output.

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

    When power supply is on/off, prevents damage caused by short-circuiting power device by keeping the turn-on signal output at high impedance outside the operating voltage range.

Operation Flow

Positional signal (Hall IC)

Position detector

Counter

Phase U → U
→ X

Phase matching (Phase U)

Phase V → V
→ Y

Phase W

Sine-wave pattern (modulation signal)

Comparator

→ W
→ Z

Voltage instruction

Oscillator

System clock generator

Triangular wave (carrier frequency)

Driven by square wave

(Note)
92%

Output ON duty (U, V, W)

0.2 V (typ.)   4.6 V

Voltage instruction V_e

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

Driven by sine wave

100%

Modulation ratio (modulation signal)

0   0.2 V (typ.)   5 V (V_{refout})

Voltage instruction V_e
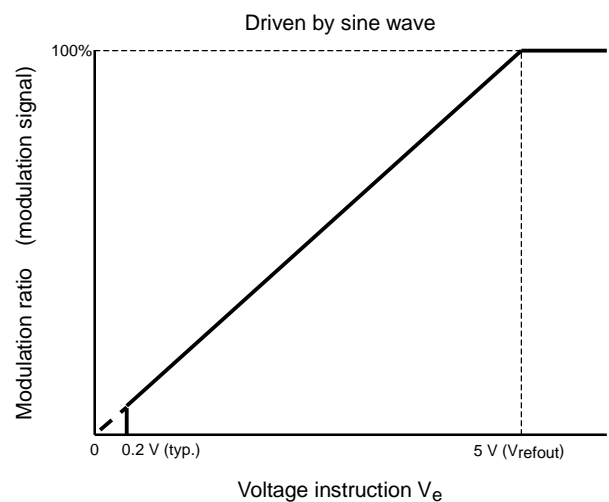
The modulation waveform is generated using Hall signals. Then, the modulation waveform is compared with the triangular wave and a sine-wave PWM signal is generated.

The time (electrical angle: 60°) from the rising (or falling) edges of the three Hall signals to the next rising (or rising) edges are 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 the width.

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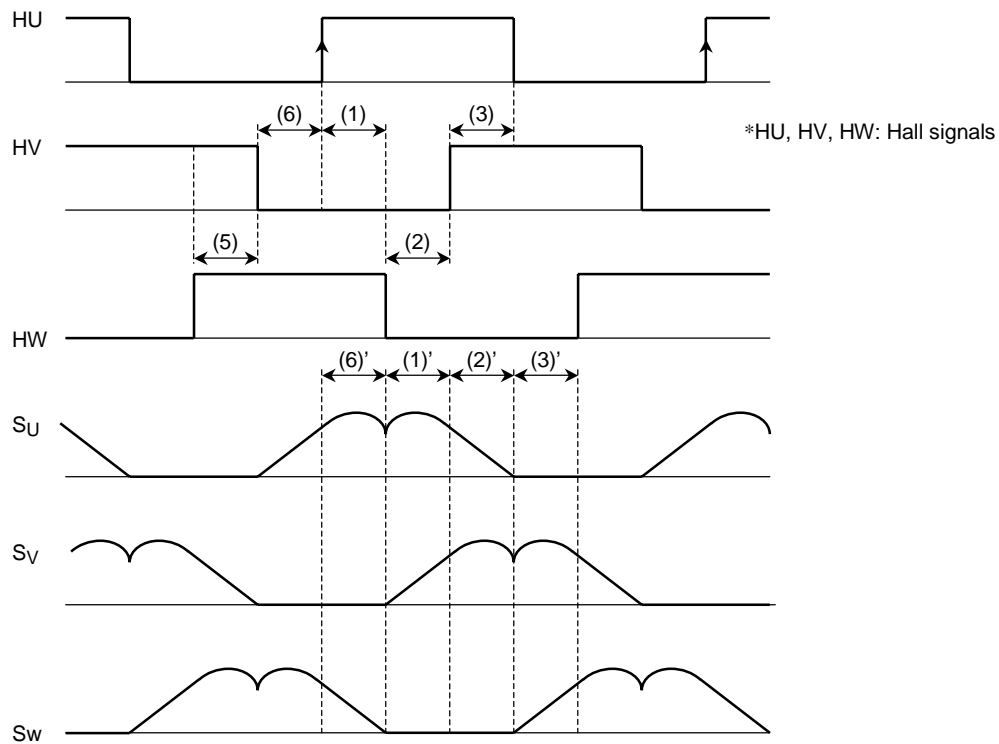
In the above diagram, the modulation waveform (1)' data moves forward by the 1/32 time width of the time (1) from HU: ↑ to HW: ↓. Similarly, data (2)' moves forward by the 1/32 time width of the time (2) from HW: ↓ to HV: ↑.

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.

$* t = t(1) \times 1/32$
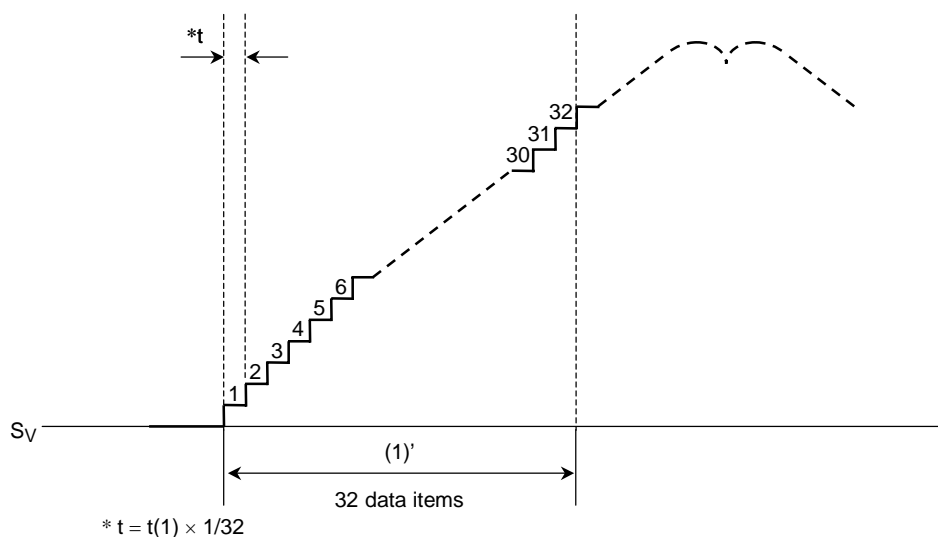
The phases are matched between every rising edge of the HU signal and the modulation waveform. The modulation waveform is reset in sync with the rising edge of the HU signal at every electrical angle of 360°. Thus, when the Hall signal rising edge is mispositioned or at acceleration/deceleration, the modulation waveform is non-consecutive at every reset.

Timing Charts

Hall signal (input): H_u, H_v, H_w

FG signal (output): FG

Turn-on signal when driven by square wave (output): U, V, W, X, Y, Z

Modulation waveform when driven by sine wave (inside of IC): S_u, S_v, S_w

Forward

Hall signal (input): H_u, H_v, H_w

FG signal (output): FG

Turn-on signal when driven by square wave (output): U, V, W, X, Y, Z

Modulation waveform when driven by sine wave (inside of IC): S_u, S_v, S_w
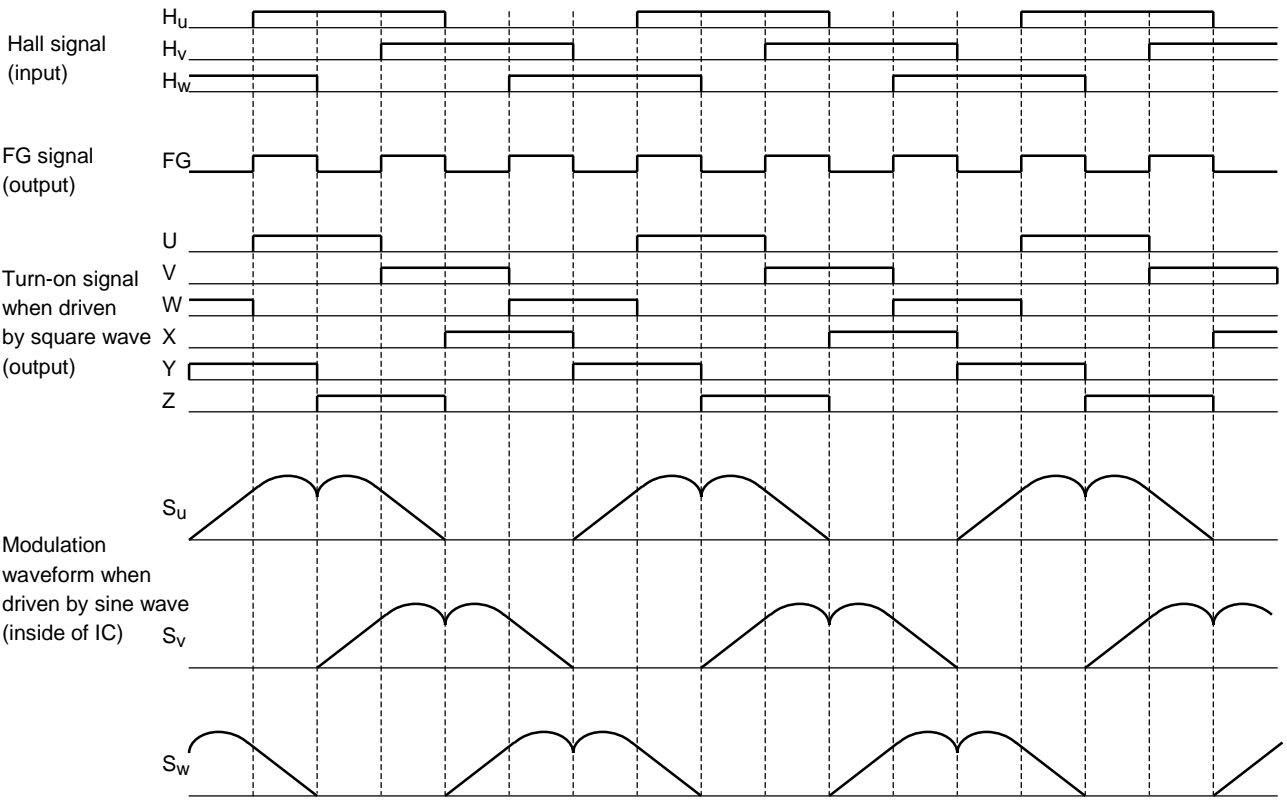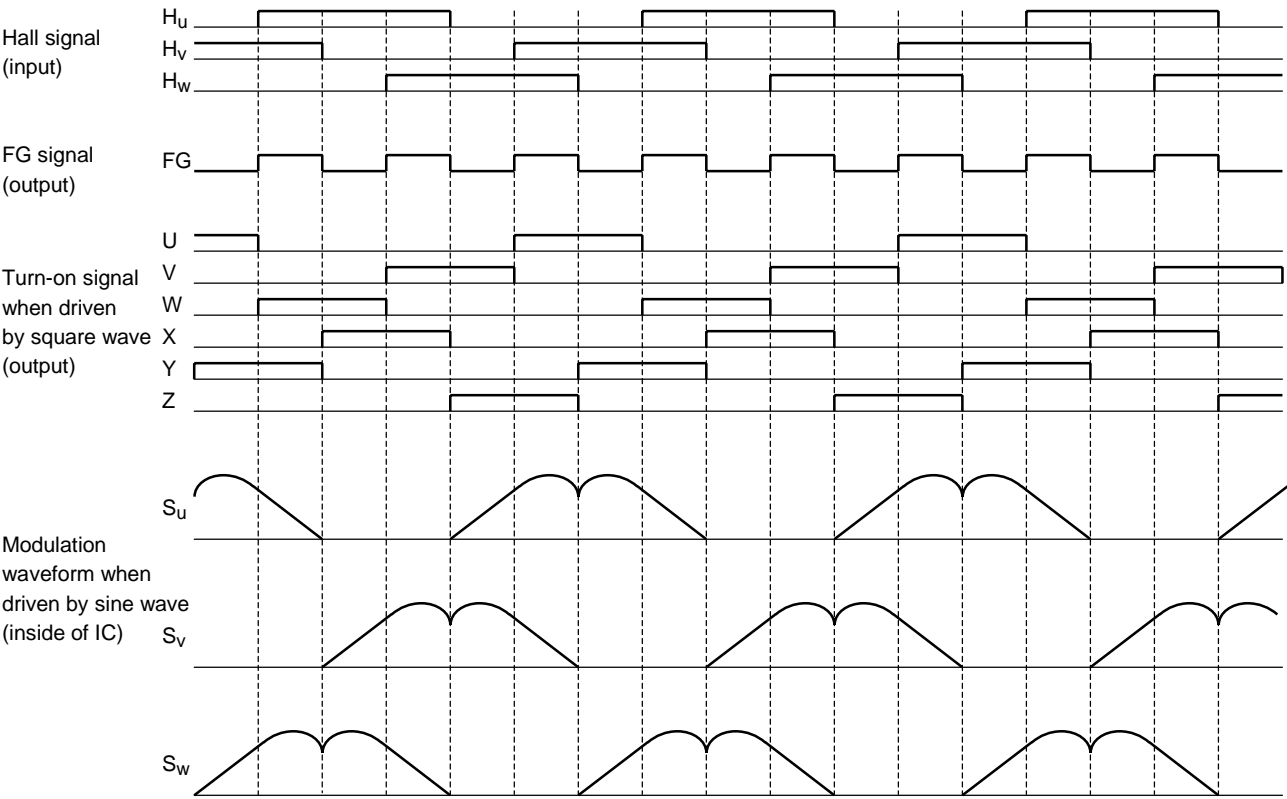
Reverse

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

Hall signal
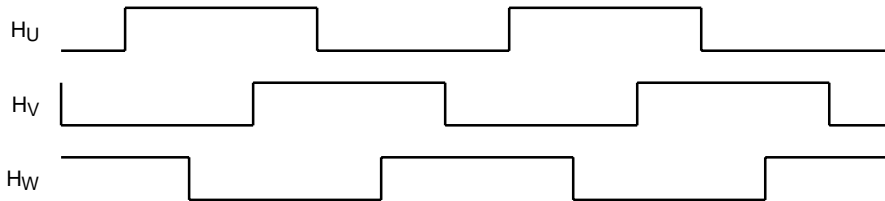
Output waveform

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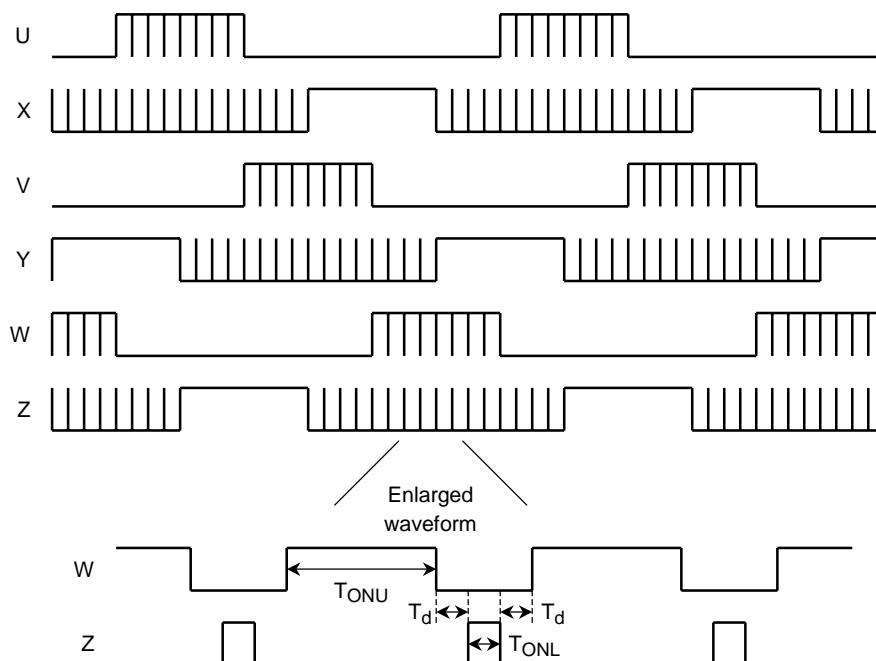
To stabilize the bootstrap voltage, the lower outputs (X, Y, and Z) are always turned on at the carrier cycle even during off time. At that time, the upper outputs (U, V, and W) are assigned dead time and turned off at the timing when the lower outputs are turned on. (T_d varies with input V_e)

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

T_{ONL} = carrier cycle × 8% (s) (Uniformity)

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

Note: At startup, the motor is driven by a square wave when the Hall signals are 5 Hz or lower (f_{osc} = 4 MHz) and the motor is rotating in the reverse direction as the TB6551F controls it (REV = High).

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

Generation inside of IC

Modulation signal   Triangular wave (carrier frequency)

Phase U

Phase V

Phase W

Output waveform

U

X

V

Y

W

Z
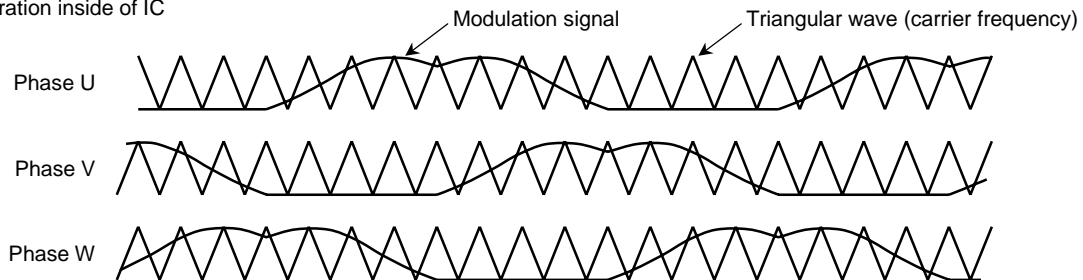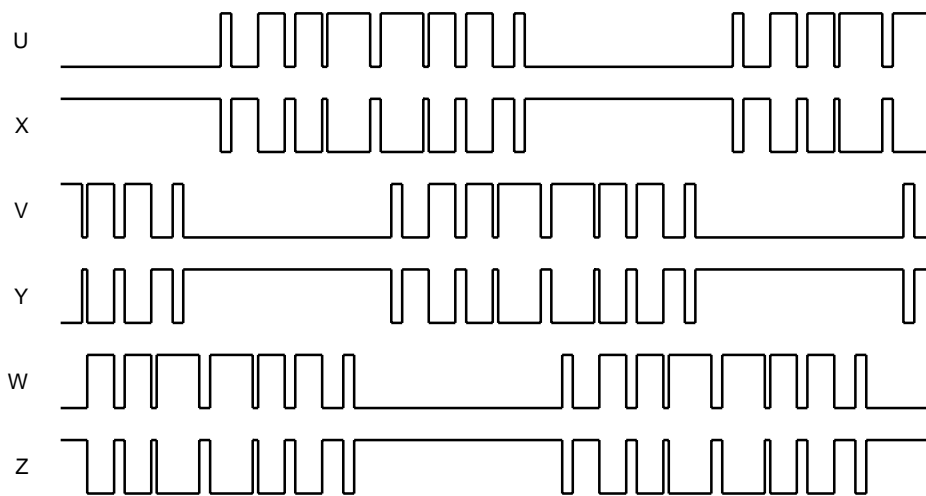
Inter-line voltage

V_{UV}
(U−V)

V_{VW}
(V−W)

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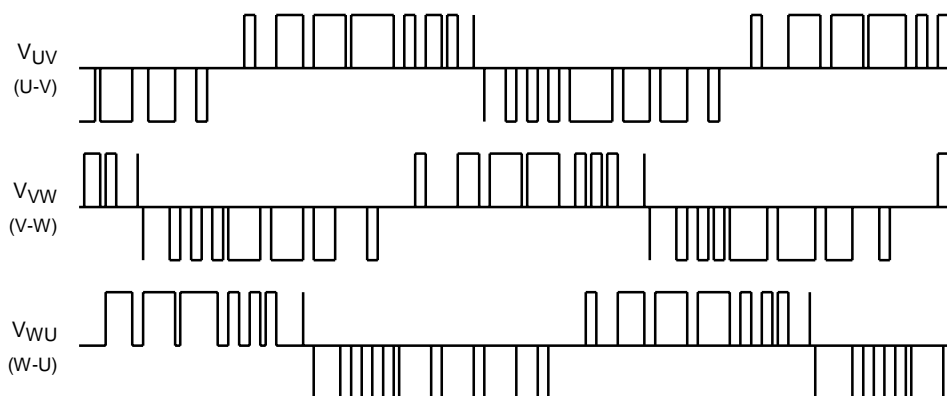
When the motor is driven by a sine wave, the motor is accelerated/decelerated according to the On duty of T_{ONU} when the amplitude of the modulation symbol changes by voltage V_e (see the diagram of output On duty on page 11).

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

Note: At startup, the motor is driven by a sine wave when the Hall signals are 5 Hz or higher (f_{osc} = 4 MHz) and the motor is rotating in the same direction as the TB6551F controls it (REV = Low).

TOSHIBA

Example of Application Circuit

Note 1: For preventing the IC from misoperation caused by noise for example connect to ground as required.
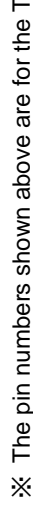
Note 2: Connect P-GND to signal ground on an application circuit.

※ The pin numbers shown above are for the T

Package Dimensions

SDIP24-P-300-1.78   Unit : mm
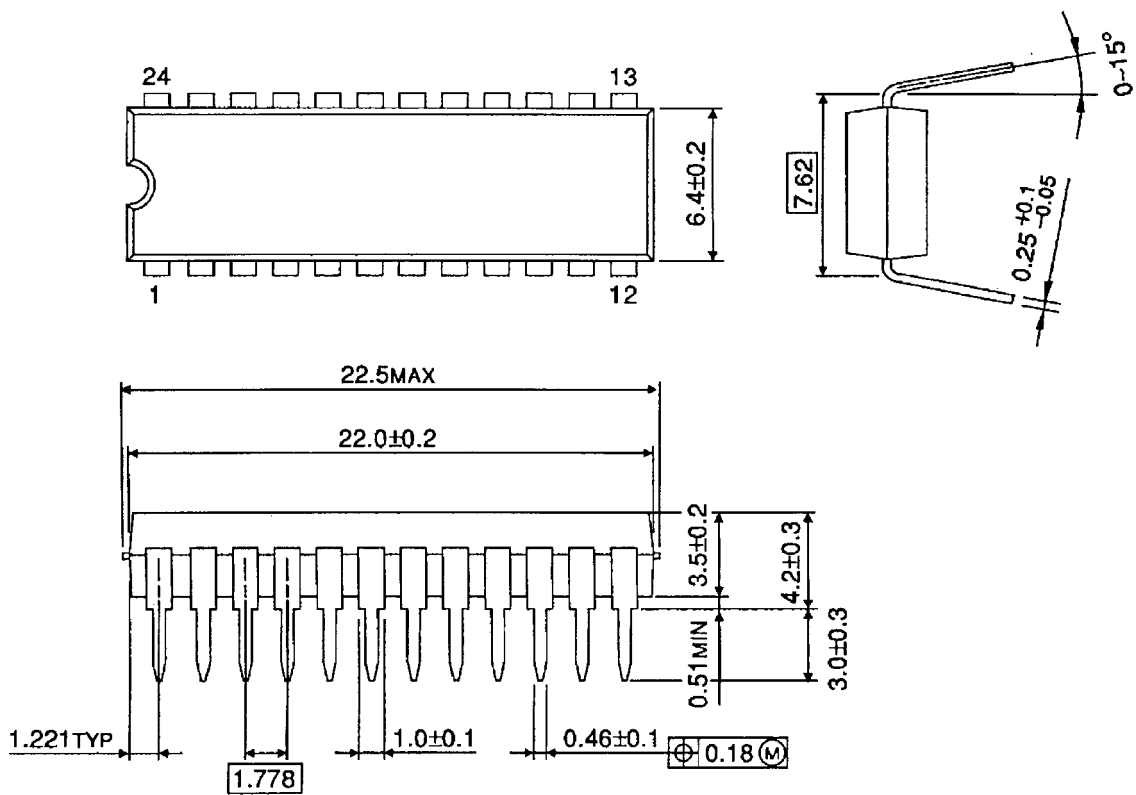
Weight: 1.62 g (typ.)

Package Dimensions

SSOP30-P-375-1.00

Unit : mm
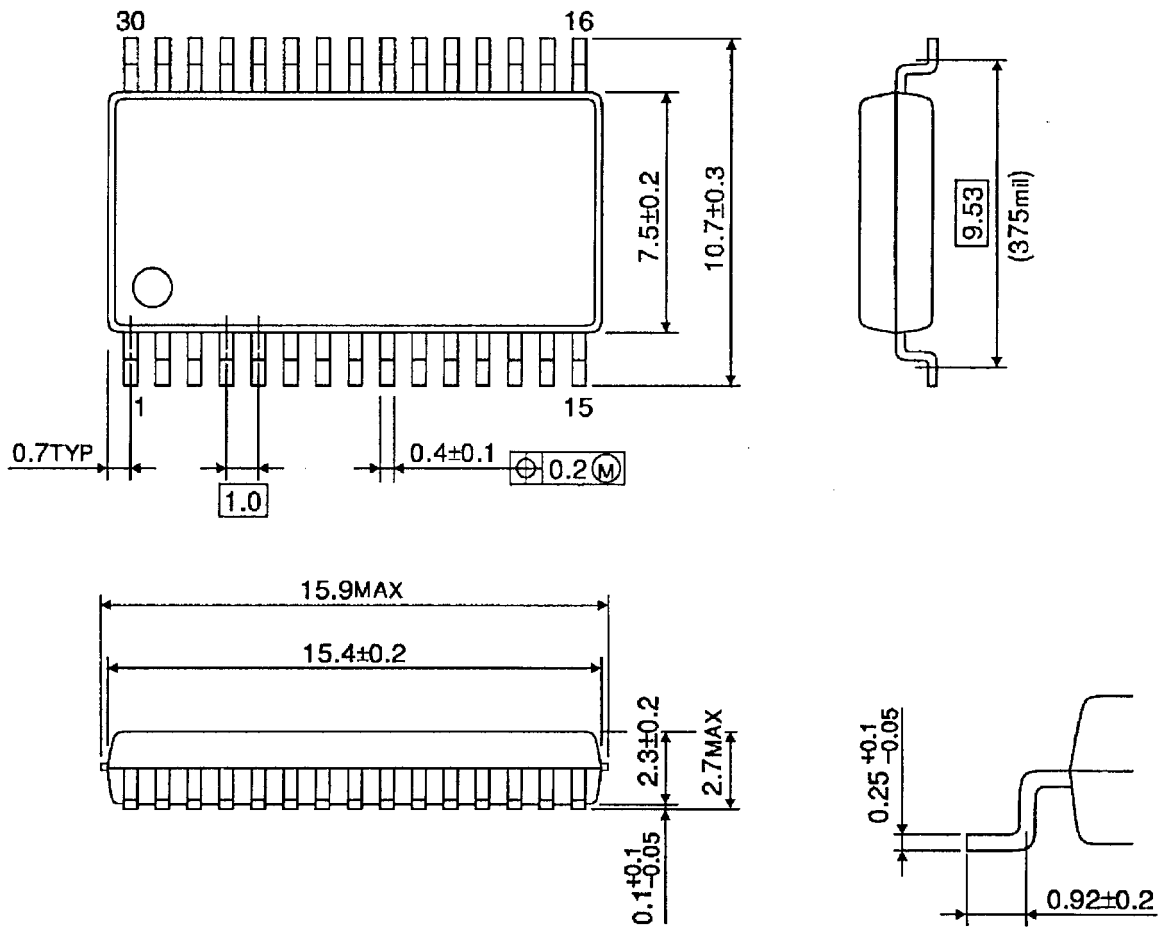
Weight: 0.63 g (typ.)

RESTRICTIONS ON PRODUCT USE