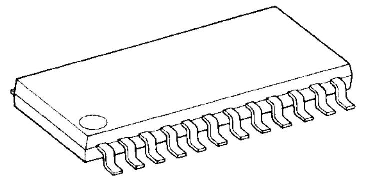
TOSHIBA Bi-CMOS Integrated Circuit Silicon Monolithic

# TB6551F

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

## Features

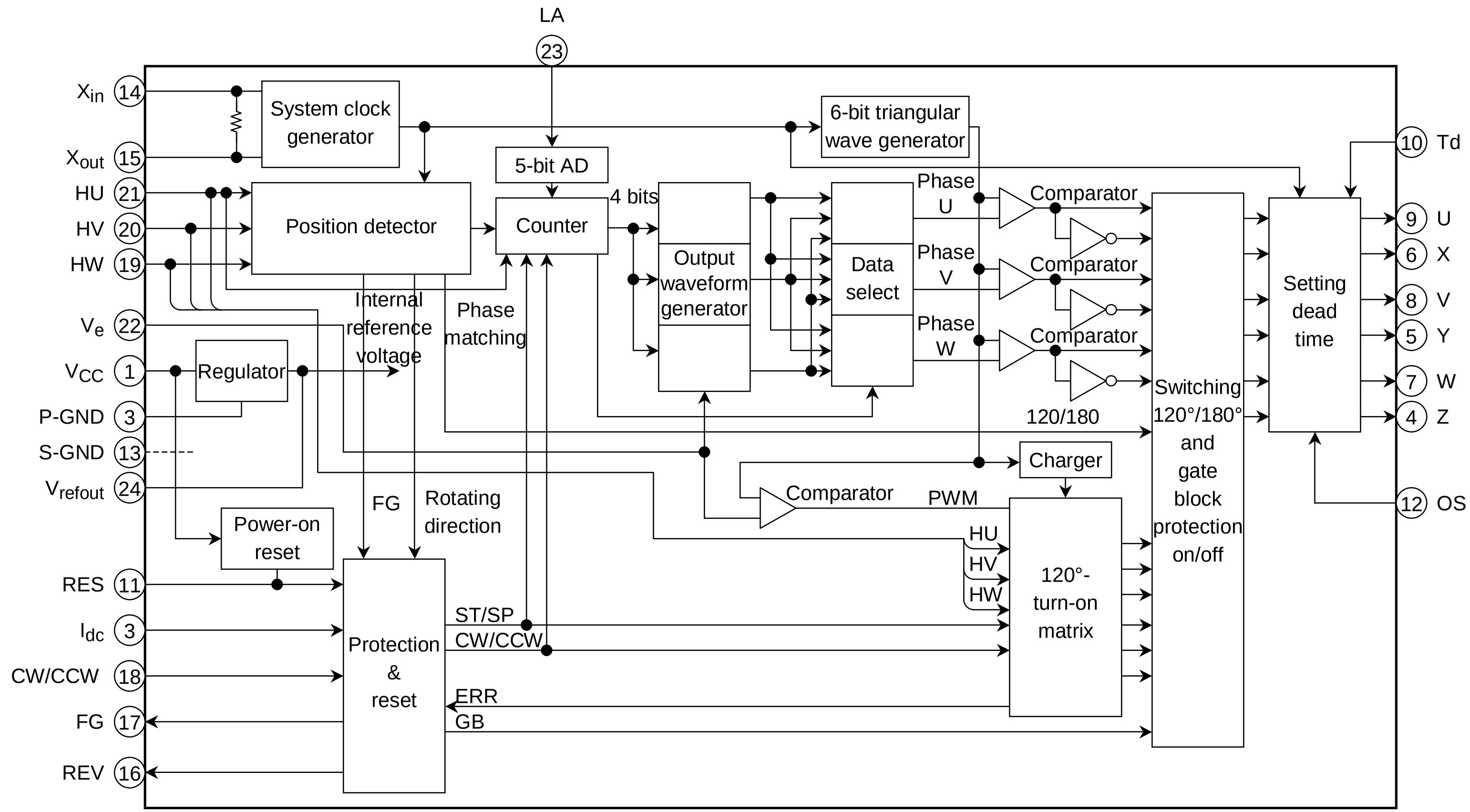
- Sine-wave PWM control
- Built-in triangular-wave generator (carrier cycle = $f_{osc}$/252 (Hz))
- Built-in lead angle control function (0° to 58° in 32 steps)
- Built-in dead time function (setting 2.6 μs or 3.8 μs)
- Supports bootstrap circuit
- Overcurrent protection signal input pin
- Built-in regulator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



SSOP24-P-300-1.00

Weight: 0.33 g (typ.)

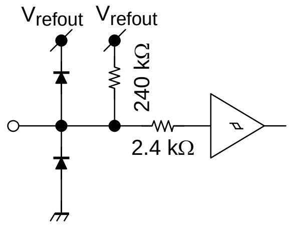
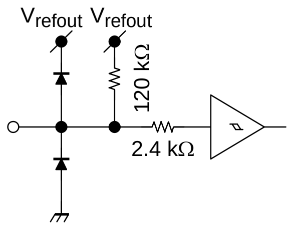
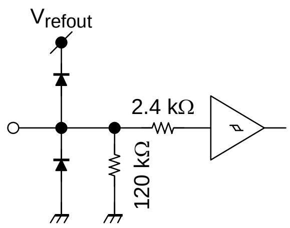
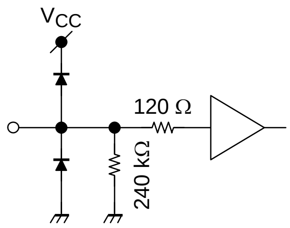
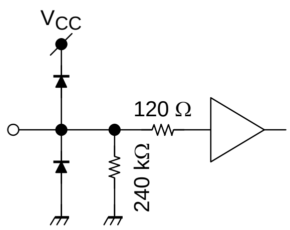
## Block Diagram

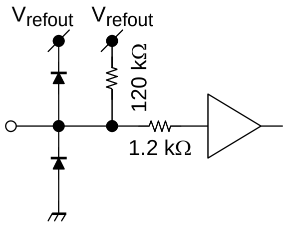
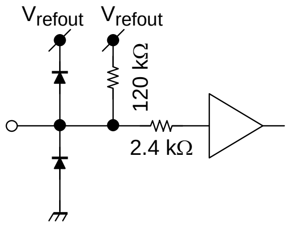
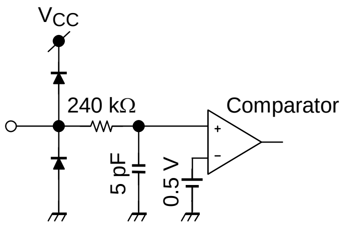
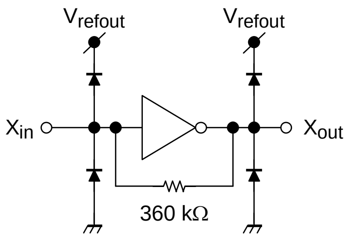
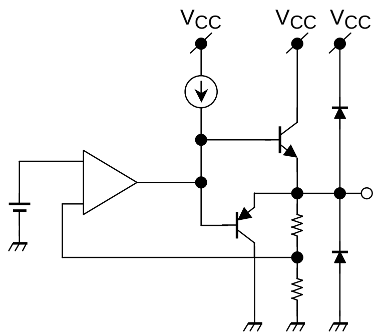


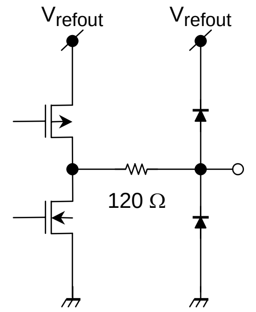
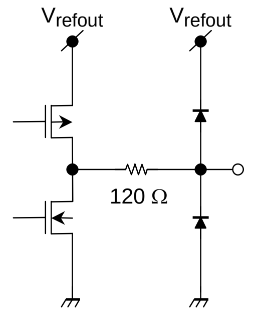
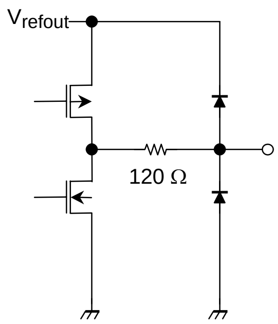
## Pin Description

| Pin No. | Symbol | Description | Remarks |
|---|---|---|---|
| 21 | HU | Positional signal input pin U | When positional signal is HHH or LLL, gate block protection operates.<br>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<br>H: Reverse |
| 11 | RES | Reset-signal-input pin | L: Reset (Output is non-active)<br>Operation/Halt operation<br>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<br>H: Active high |
| 3 | $I_{dc}$ | Inputs overcurrent-protection-signal | Inputs DC link current.<br>Reference voltage: 0.5 V<br>With built-in filter ( $\simeq$ 1 $\mu$s) |
| 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 $\mu$s, H or Open: 2.6 $\mu$s |
| 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<br>Positional signal input pin V<br>Positional signal input pin W | HU<br>HV<br>HW | Digital<br>With Schmitt trigger<br>Hysteresis 300 mV (typ.)<br>L: 0.8 V (max)<br>H: $V_{refout}$ − 1 V (min) |  |
| Forward/reverse switching input pin<br>L: Forward (CW)<br>H: Reverse (CCW) | CW/CCW | Digital<br>With Schmitt trigger<br>Hysteresis 300 mV (typ.)<br>L: 0.8 V (max)<br>H: $V_{refout}$ − 1 V (min) |  |
| Reset input<br>L: Stops operation (reset).<br>H: Operates. | RES | Digital<br>With Schmitt trigger<br>Hysteresis 300 mV (typ.)<br>L: 0.8 V (max)<br>H: $V_{refout}$ − 1 V (min) |  |
| Voltage instruction signal input pin<br>Turn on the lower transistor at 0.2 V or less.<br>(X, Y, Z pins: On duty of 8%) | $V_e$ | Analog<br>Input range 0 V to 5.0 V<br>Input voltage of Vrefout or higher is clipped to Vrefout. |  |
| Lead angle setting signal input pin<br>0 V: 0°<br>5 V: 58°<br>(5-bit AD) | LA | Analog<br>Input range 0 V to 5.0 V<br>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<br>L: 3.8 μs<br>H or Open: 2.6 μs | Td | Digital<br><br>L: 0.8 V (max)<br>H: $V_{refout}$ − 1 V (min) |  |
| Output logic select signal input pin<br><br>L: Active low<br>H: Active high | OS | Digital<br><br>L: 0.8 V (max)<br>H: $V_{refout}$ − 1 V (min) |  |
| Overcurrent protection signal input pin | $I_{dc}$ | Analog<br><br>Gate block protected at 0.5 V or higher (released at carrier cycle) |  |
| Clock signal input pin | $X_{in}$ | Operating range<br><br>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<br><br>Push-pull output: ± 1 mA (max) |  |
| FG signal output pin | FG | Digital<br><br>Push-pull output: ± 1 mA (max) |  |
| Turn-on signal output pin U<br>Turn-on signal output pin V<br>Turn-on signal output pin W<br>Turn-on signal output pin X<br>Turn-on signal output pin Y<br>Turn-on signal output pin Z | U<br>V<br>W<br>X<br>Y<br>Z | Analog<br><br>Push-pull output: ± 2 mA (max)<br><br>L : 0.78 V (max)<br>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

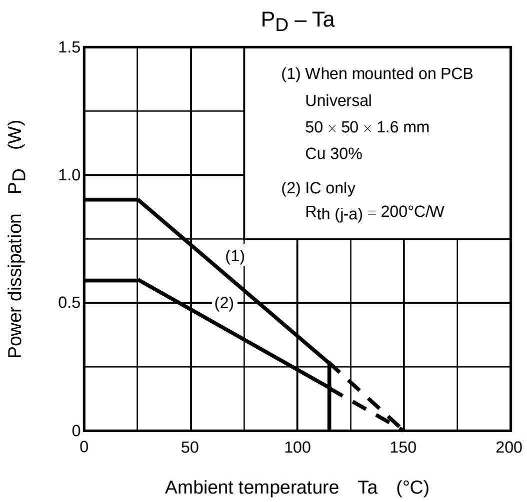
Note 2: $V_{in\ (2)}$ pin: HU, HV, HW, CW/CCW, RES, OS, $I_{dc}$, Td

Note 3: When mounted on 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 |

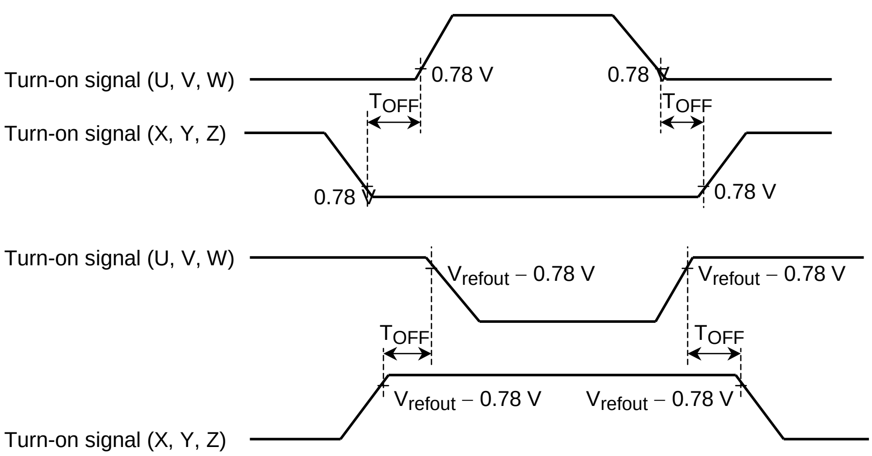


## Electrical Characteristics (Ta = 25°C, $V_{CC}$ = 15 V)

| 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 | — | |
| Overcurrent 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

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.
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

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 degrees of 360°. (The output is high immediately after reset)

REV terminal increases with 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 |

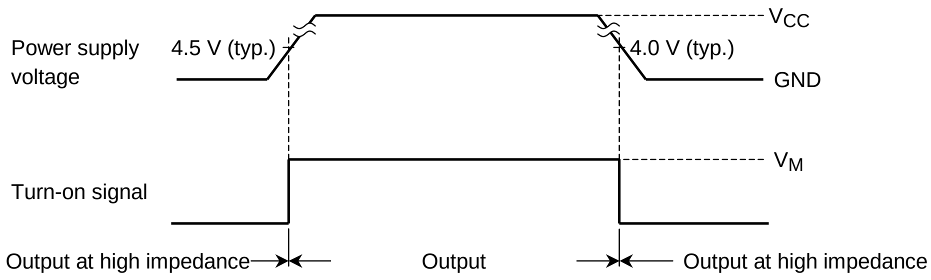
## 8. Protecting input pin

1. 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.

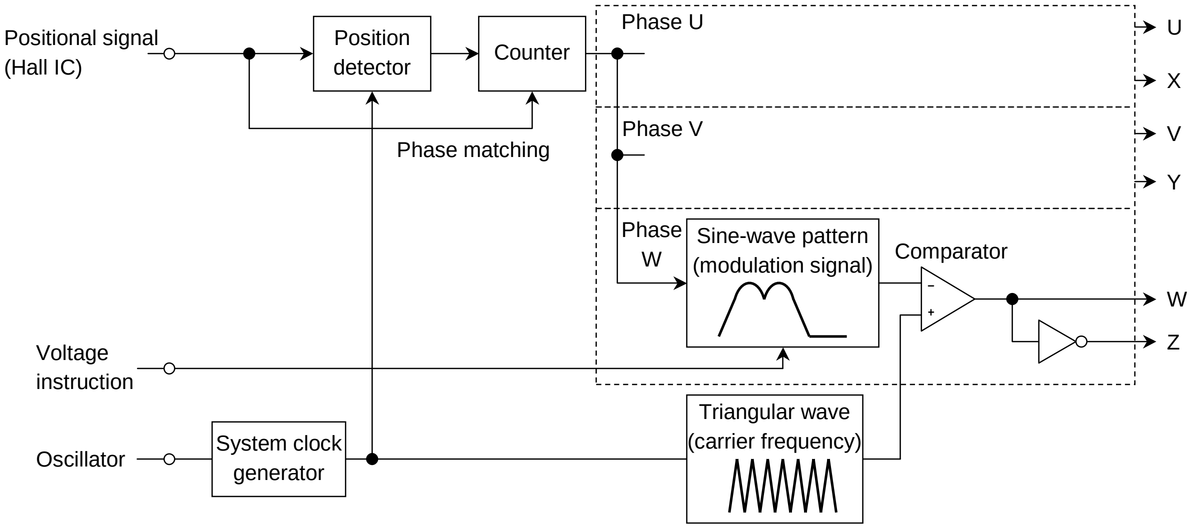
| RES Pin | OS Pin | Output Turn-on Signal (U, V, W, X, Y, Z) |
|---|---|---|
| Low | Low | High |
| | High | Low |

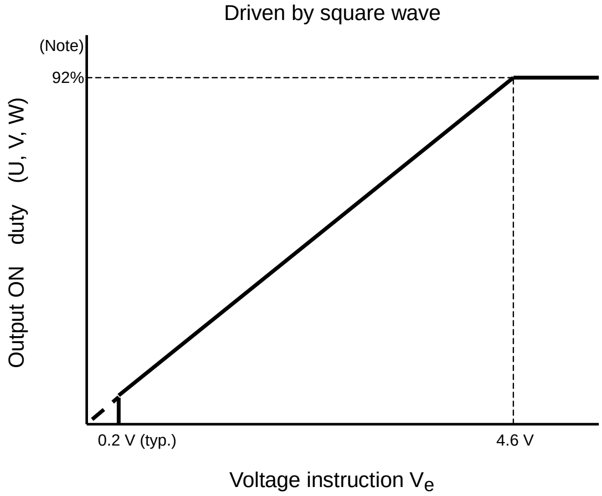
(When RES = Low, bootstrap capacitor charging stops.)

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.

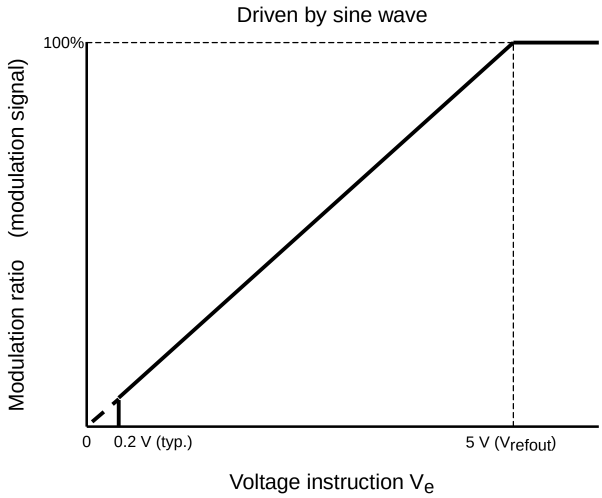


## Operation Flow



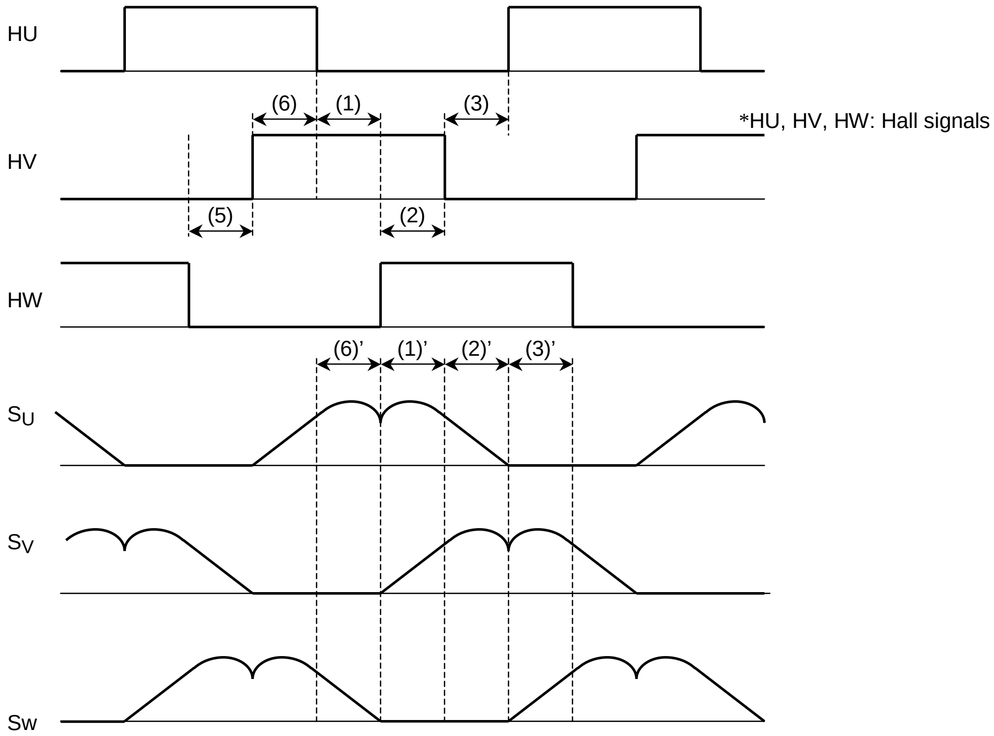

Note: Output ON time is decreased by the dead time.
(carrier frequency × 92% − $T_d$ × 2)



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.

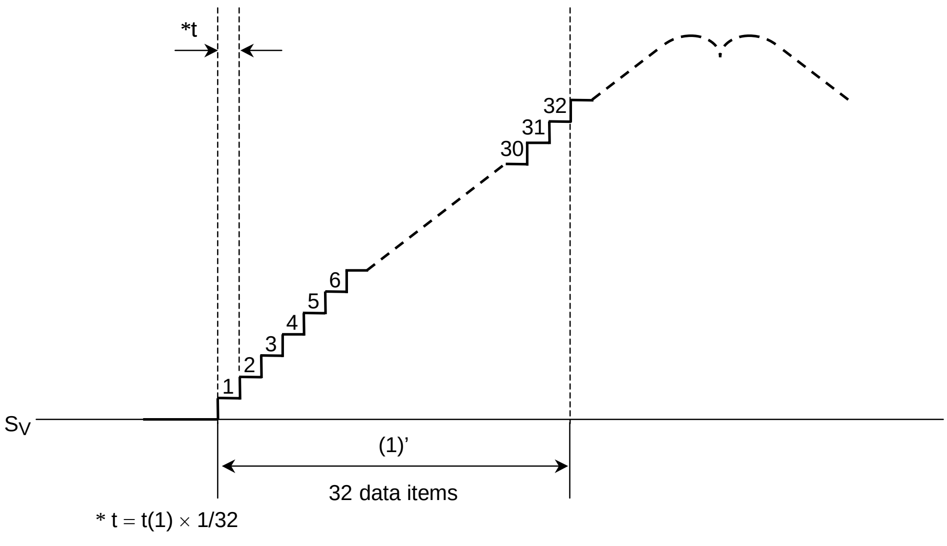
The time (electrical degrees: 60°) from the rising (or falling) edges of the three Hall signals to the next falling (or rising) edges are counted. The counted time is used as the data for the next 60° phase of the modulation waveform.

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.




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: ↑.

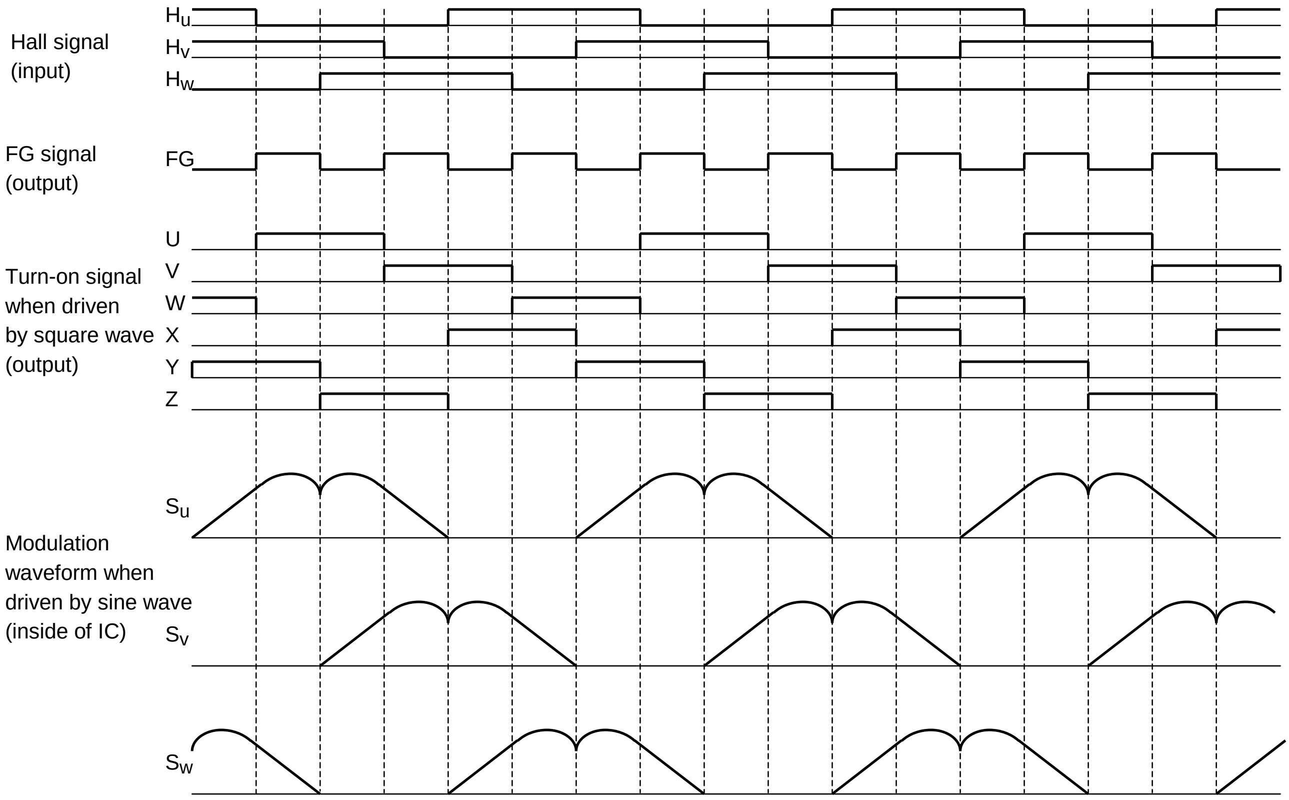
If the next edge does not occur after the 32 data items end, the next 32 data items move forward by the same time width until the next edge occurs.



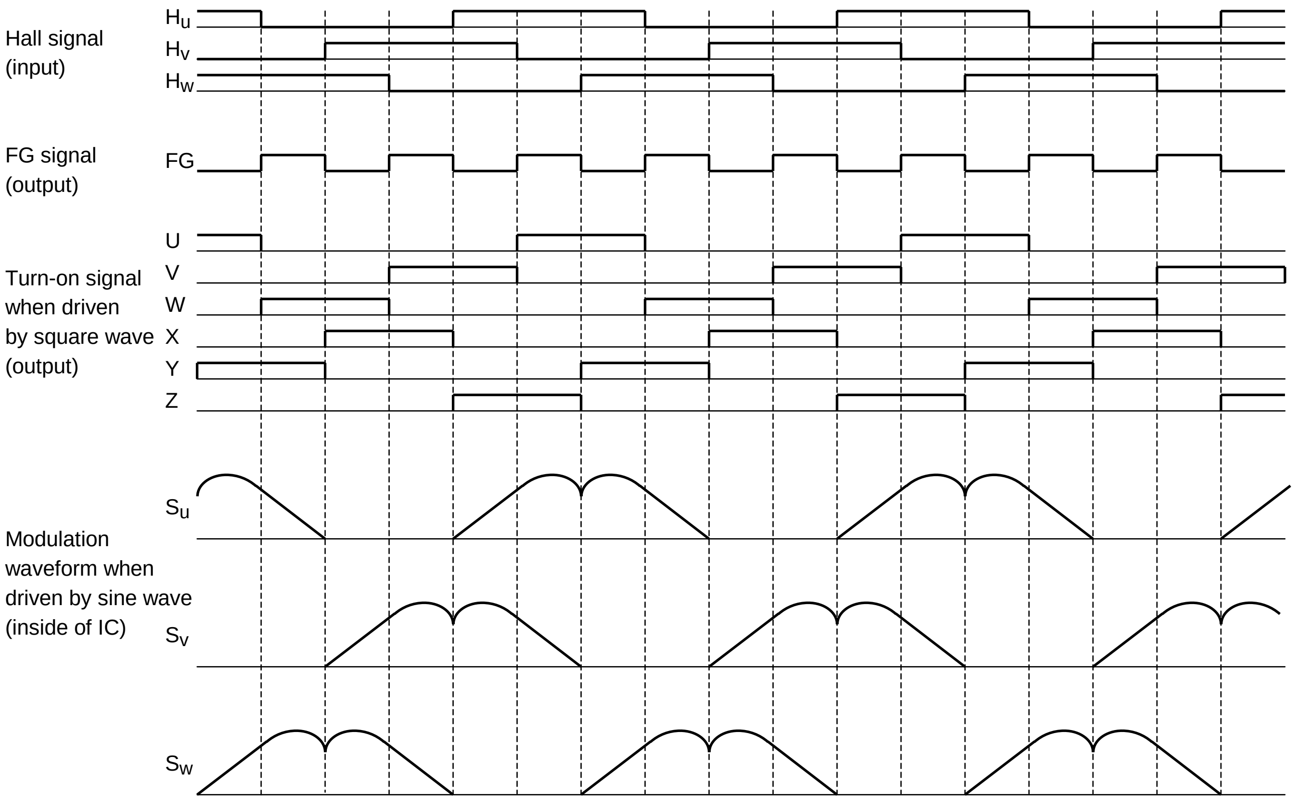

The modulation wave is brought into phase with every zero-cross point of the Hall signal.

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

## Timing Charts

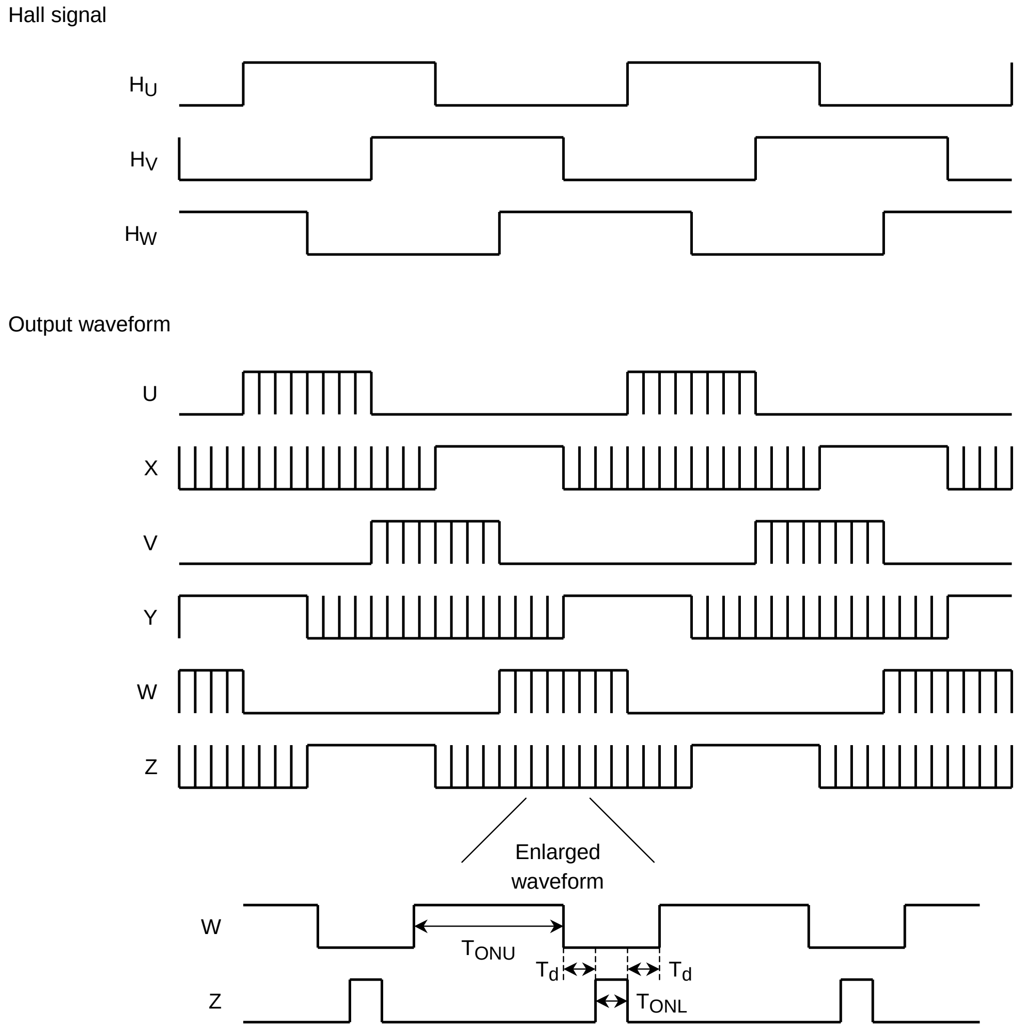



Forward




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 $V_e$)

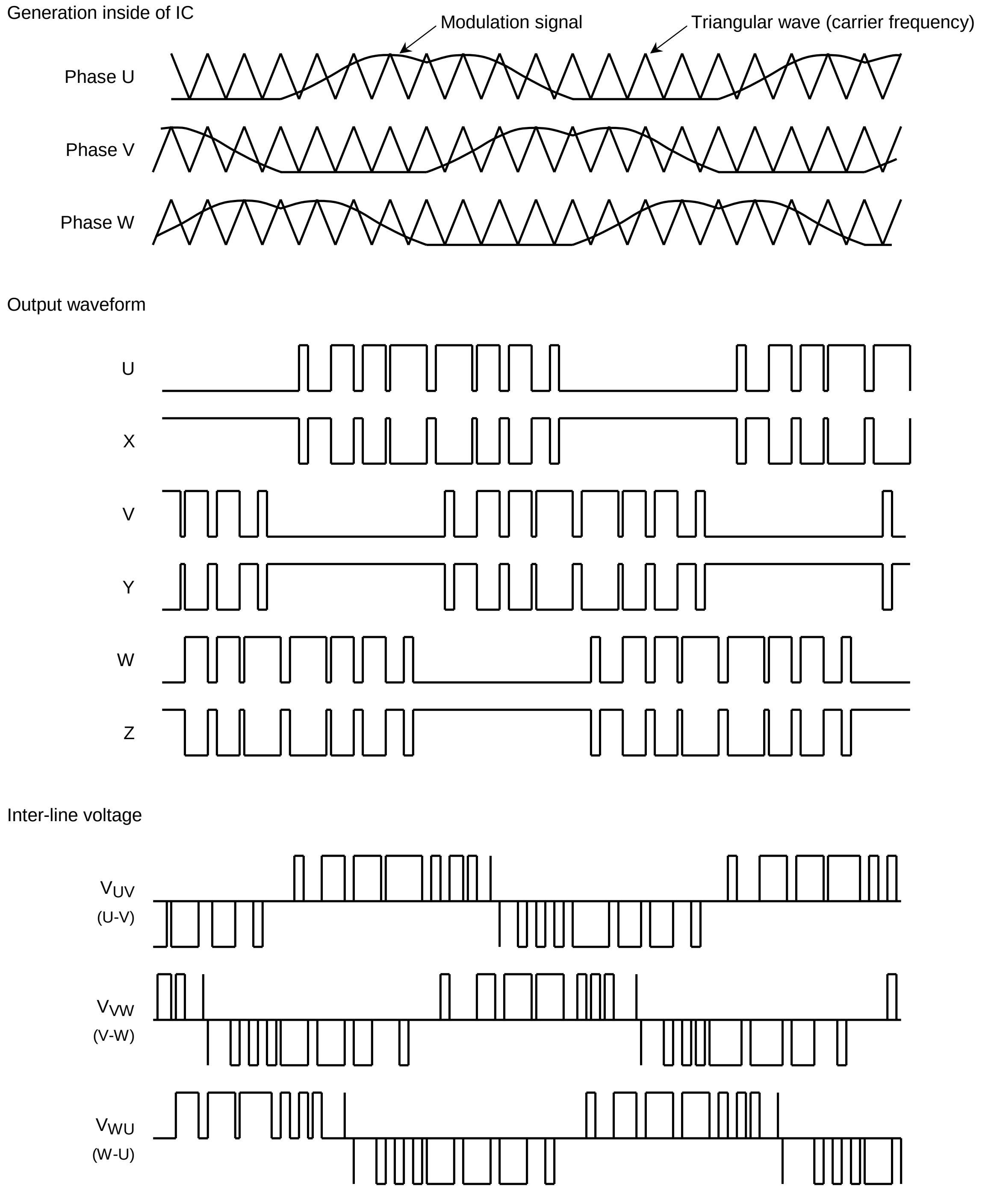
Carrier cycle = $f_{osc}/252$ (Hz)    Dead time: $T_d = 16/f_{osc}$ (s) (In more than $V_e$ = 4.6 V)

$T_{ONL}$ = 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)

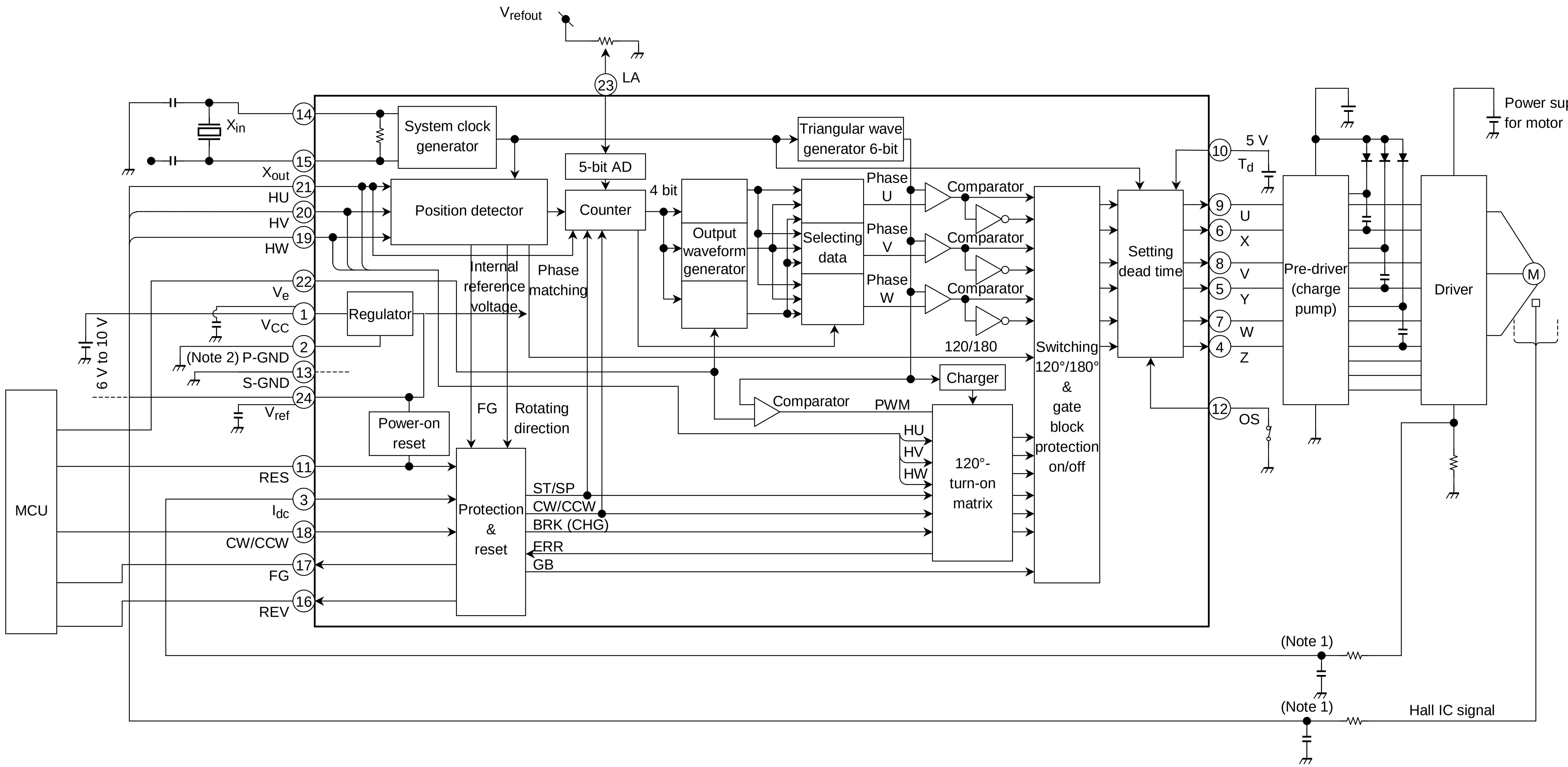



When the motor is driven by a sine wave, the motor is accelerated/decelerated according to the On duty of $T_{ONU}$ when the amplitude of the modulation symbol changes by voltage $V_e$ (see the diagram of output On duty on page 11).

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).

## Example of Application Circuit



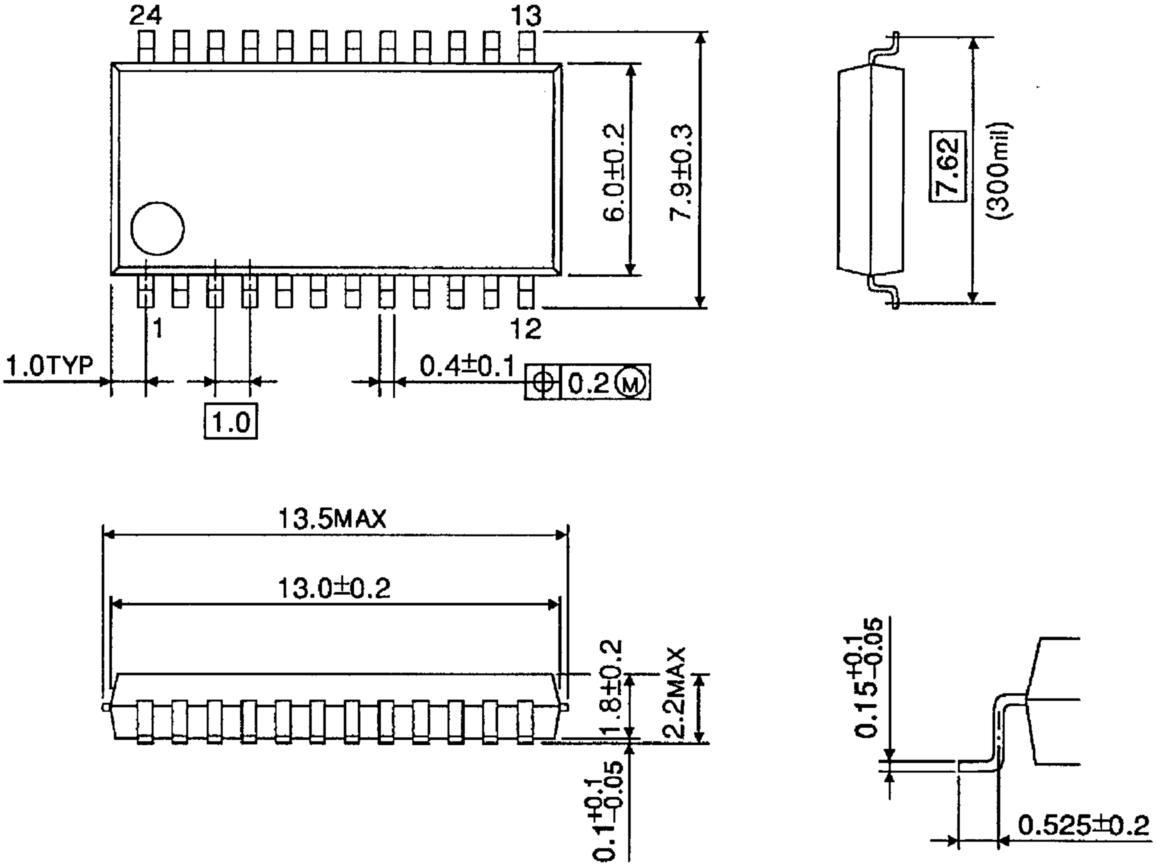

Note 1: For preventing the IC from misoperation caused by noise for example connect to ground as required.

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

Note 3: A short circuit between the outputs, or between output and supply or ground may damage the device. Periferal parts may also be dameged by overvoltage and overcurrent. Design the output lines, $V_{CC}$ 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

SSOP24-P-300-1.00 Unit : mm




Weight: 0.33 g (typ.)

## RESTRICTIONS ON PRODUCT USE