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

IK6501

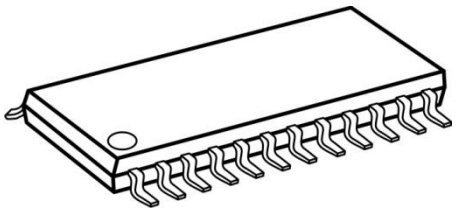
GENERAL DESCRIPTION

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 (Vref = 5 V (typ.), 30 mA (max))
- Operating supply voltage range: V_{CC} = 6 V to 10 V

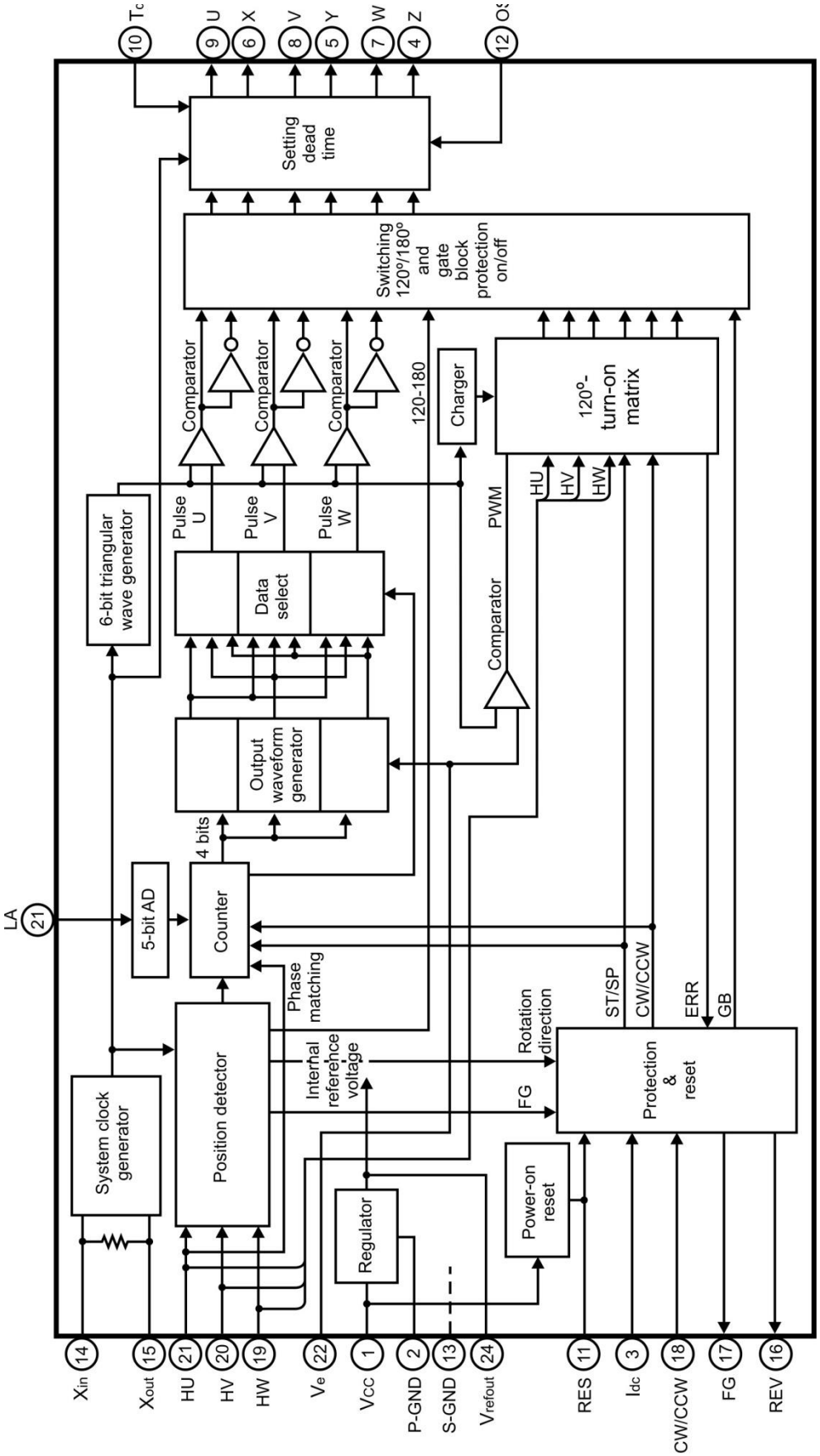
PACKAGE INFORMATION

SSOP24-P-300-1.00



Weight: 0.33 g (typ.)

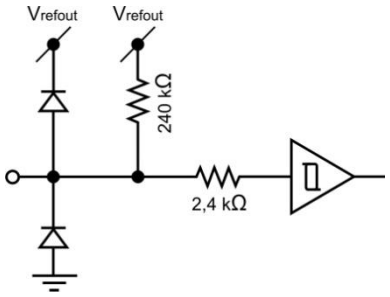
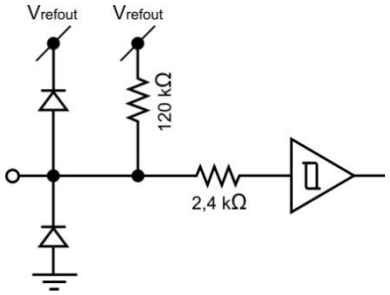
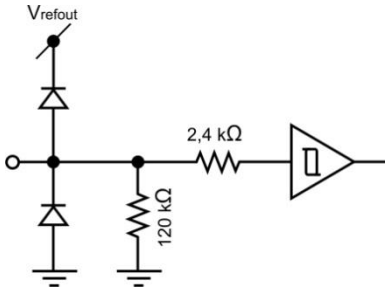
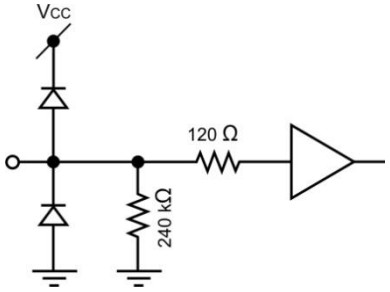
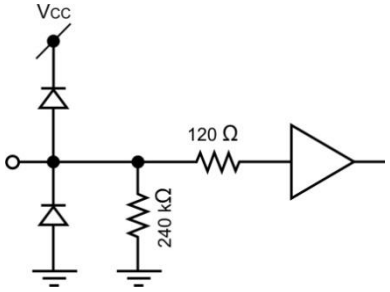
BLOCK DIAGRAM

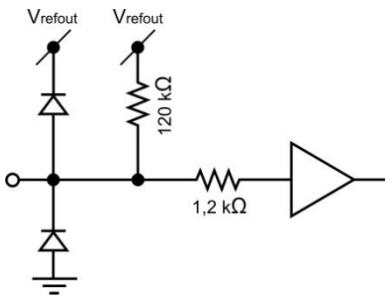
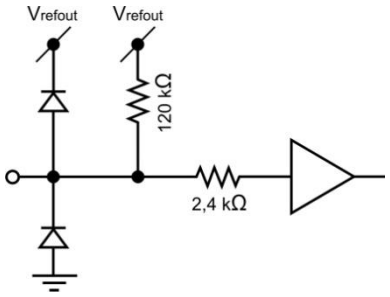
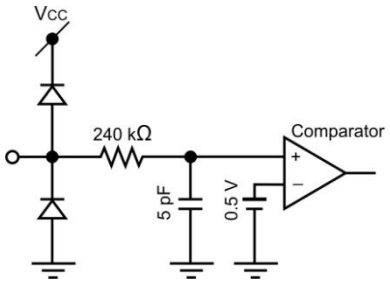
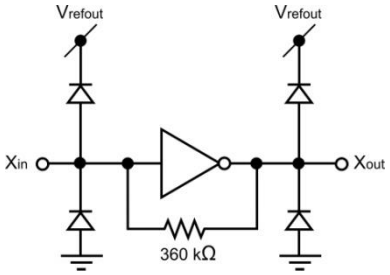
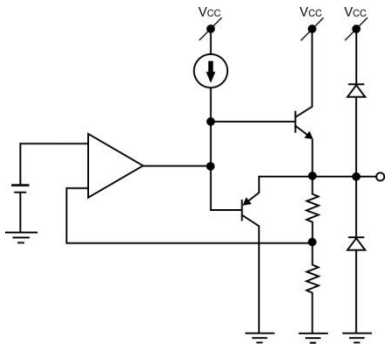


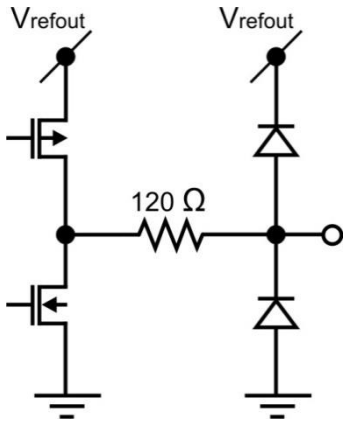
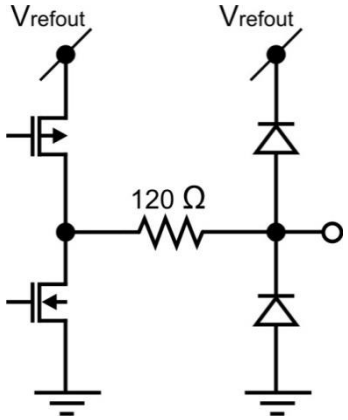
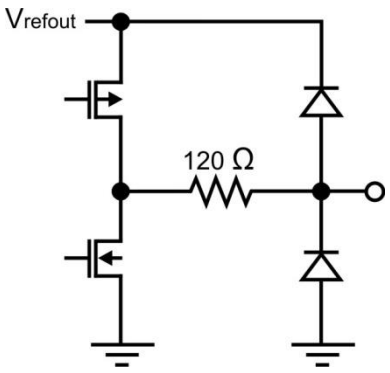
PIN LIST AND DESCRIPTIONS

Pin	Name	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
03	Idc	Inputs overcurrent-protection-signal	Inputs DC link current. Reference voltage: 0.5 V With built-in filter (≈ 1 μs)
14	Xin	Inputs clock signal	With built-in feedback resistor
15	Xout	Outputs clock signal	
24	Vrefout	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.
09	U	Outputs turn-on signal	Select active high or active low using the output logic select pin.
08	V	Outputs turn-on signal	
07	W	Outputs turn-on signal	
06	X	Outputs turn-on signal	
05	Y	Outputs turn-on signal	
04	Z	Outputs turn-on signal	
01	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
02	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: Vrefout - 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: Vrefout - 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: Vrefout - 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%)	Ve	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 Vrefout or higher is clipped to Vrefout	

Setting dead time input pin L: 3.8 µs H or Open: 2.6 µs	Td	Digital L: 0.8 V (max) H: Vrefout - 1 V (min)	
Output logic select signal input pin L: Active low H: Active high	OS	Digital L: 0.8 V (max) H: Vrefout - 1 V (min)	
Overcurrent protection signal input pin	Idc	Analog Gate block protected at 0.5 V or higher (released at carrier cycle)	
Clock signal input pin	Xin	Operating range 2 MHz to 8 MHz (crystal oscillation)	
Clock signal output pin	Xout		
Reference voltage signal output pin	Vrefout	5 ± 0.5 V (max 30 mA)	

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: Vrefout - 0.78 V (min)	

ABSOLUTE MAXIMUM RATINGS* (T_A = 25ºC)

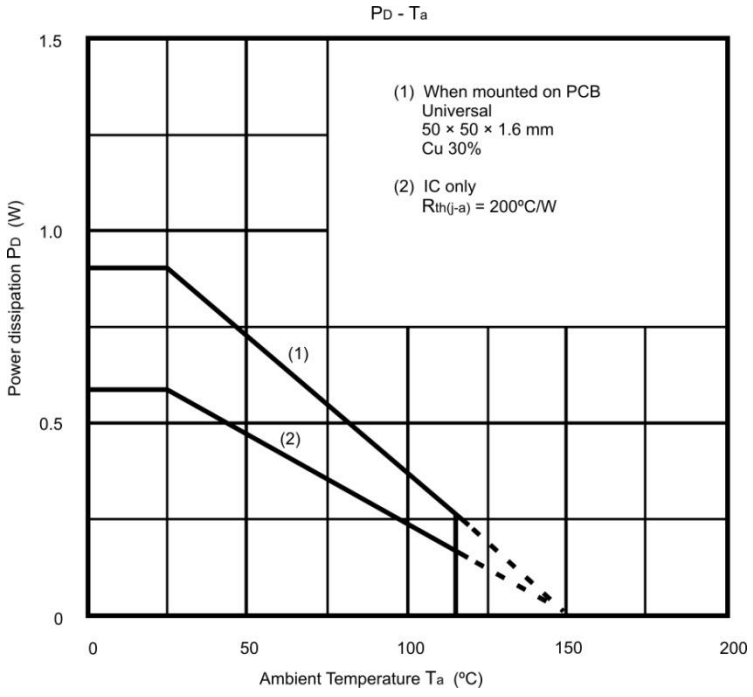
Symbol	Parameter	Min	Max	Unit
V_{CC}	Supply voltage	-	12	V
Vin $_{(1)}$ (Note 1)	Input voltage	-0.3	V_{CC}	V
Vin $_{(2)}$ (Note 2)		-0.3	5.5	
I_{OUT}	Turn-on signal output current	-	2	mA
P_D (Note 3)	Power Dissipation	-	0.9	W
Topr (Note 4)	Operating temperature	-30	+115	°C
Tstg	Storage temperature	-50	+150	°C

Note:
1) Vin $_{(1)}$ pin: Ve, LA
2) Vin $_{(2)}$ pin: HU, HV, HW, CW/CCW, RES, OS, Idc, Td
3) When mounted on PCB (universal 50 × 50 × 1.6 mm, Cu 30%)
4) Operating temperature range is determined by the P_D - T_A characteristic.

**Stresses beyond those listed under "Absolute Maximum Ratings" may cause permanent damage to the device. These are stress ratings only and functional operation of the device at these or any other conditions beyond those indicated in the operational sections of the specifications are not implied. Exposure to absolute maximum rating conditions for extended periods may affect device reliability.*

RECOMMENDED OPERATING CONDITIONS (T_A = 25ºC)

Symbol	Parameter	Min	Typ	Max	Unit
V_{CC}	Supply voltage	6	7	10	V
Xin	Crystal oscillation frequency	2	4	8	MHz

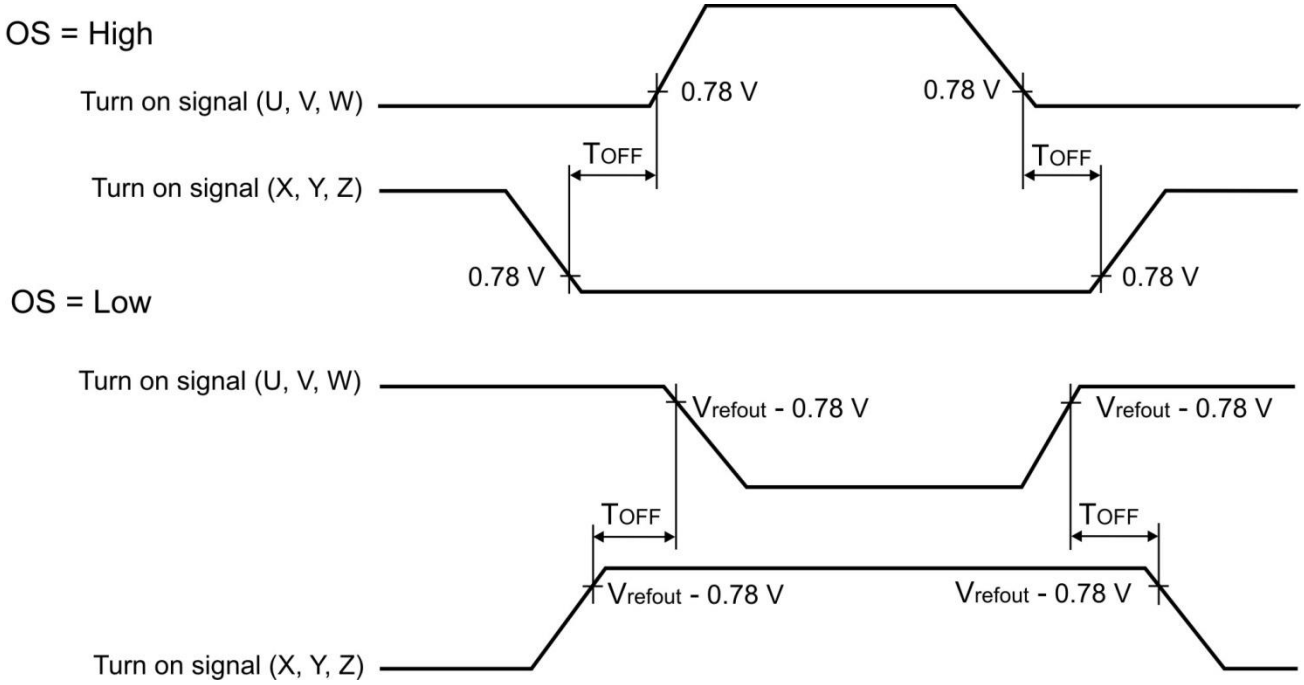


ELECTRICAL CHARACTERISTICS

T_A = 25ºC, V_{CC} = 15V, unless otherwise specified.

Description	Symbol	Condition	Min	Typ	Max	Unit
Supply current	I_{CC}	Vrefout = open	-	3	6	mA
Input current	Iin (1)	Vin = 5V Ve, LA	-	20	40	µA
	Iin (2)-1	Vin = 0V HU, HV, HW	-40	-20	-	
	Iin (2)-2	Vin = 0V CW/CCW, OS, Td	-80	-40	-	
	Iin (2)-3	Vin =5V RES	-	40	80	
Input voltage	Vin High	HU, HV, HW, CW/CCW, RES, OS, Td,	Vrefout -1	-	Vrefout	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	Vrefout -0.78	Vrefout -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	Vrefout -1.0	Vrefout -0.5	-	
	$V_{REV(L)}$	I_{OUT} = -1 mA REV	-	0.5	1.0	
	$V_{FG(H)}$	I_{OUT} = 1 mA FG	Vrefout -1.0	Vrefout -0.5	-	
	$V_{FG(L)}$	I_{OUT} = -1 mA FG	-	0.5	1.0	
	Vrefout	I_{OUT} = -30 mA Vrefout	4.5	5.0	5.5	
Output leakage current	$I_{L(H)}$	V_{OUT} = 0V U, V, W, X, Y, Z	-	0	10	µA
	$I_{L(L)}$	V_{OUT} = 3.5V U, V, W, X, Y, Z	-	0	10	
Output off-time by upper/lower transistor (Note 5)	$T_{OFF(H)}$	Td = High or open, Xin = 4.19MHz, I_{OUT} = ± 2 mA, OS = High/Low	2.2	2.6	-	µs
	$T_{OFF(L)}$	Td = Low, Xin = 4.19 MHz, I_{OUT} = ± 2 mA, OS = High/Low	3.0	3.8	-	
Overcurrent detection	Vdc	Idc	0.46	0.5	0.54	V
Lead angle correction	$T_{LA(0)}$	L_A = 0V or Open, Hall IN = 100Hz	-	0	-	º
	$T_{LA(2,5)}$	L_A = 2.5 V, Hall IN = 100Hz	27.5	32	34.5	
	$T_{LA(5)}$	L_A = 5 V, Hall IN = 100Hz	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	3.7	4.0	4.3	

Note 5: T_{OFF}


OS = High
Turn on signal (U, V, W)
0.78 V
0.78 V
TOFF
TOFF
Turn on signal (X, Y, Z)
0.78 V
0.78 V
OS = Low
Turn on signal (U, V, W)
Vrefout - 0.78 V
Vrefout - 0.78 V
TOFF
TOFF
Vrefout - 0.78 V
Vrefout - 0.78 V
Turn on signal (X, Y, Z)

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).

5 Hz ~: When driven by sine-wave PWM (180° turn-on).

Approximately 5 Hz @ fosc = 4MHz, $f = fosc/(2^{12} \times 32 \times 6)$.

2. Function to stabilize bootstrap voltage.

(1) When voltage instruction is input at Ve ≤ 0.2 V:
Turns on the lower transistor at regular (carrier) cycle. (On duty is approx. 8%).

(2) When voltage instruction is input at Ve > 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 Ve ≤ 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.

T_d Pin	Internal Counter	T_{OFF}
High or Open	11/fosc	2.6 µs
Low	16/fosc	3.8 µs

T_{OFF} values above are obtained when fosc = 4.19 MHz.

fosc = 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 on analog input 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 = fosc/252 (Hz) fosc = 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 Idc).
   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.)

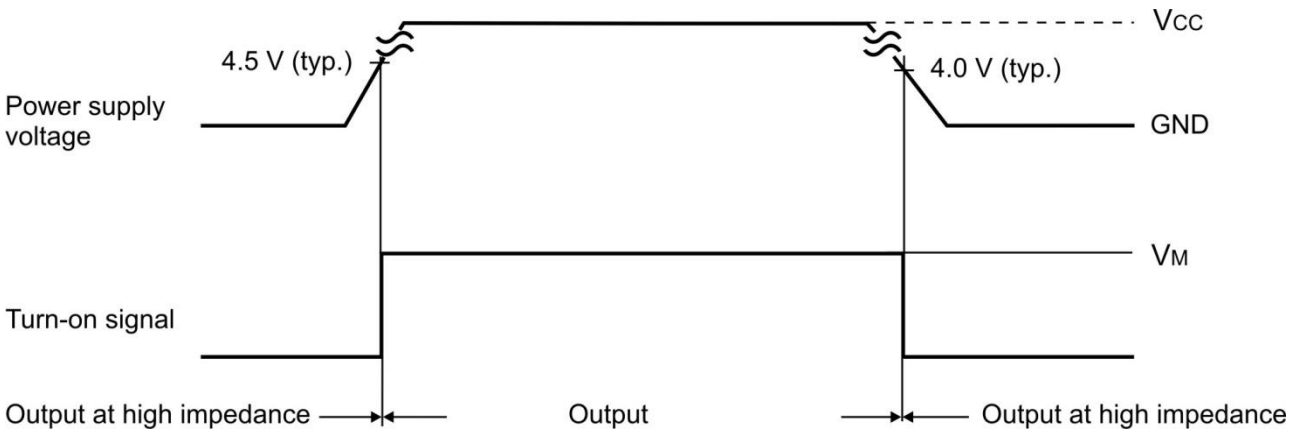
3. Internal protection

♦ Positional signal abnormality protection

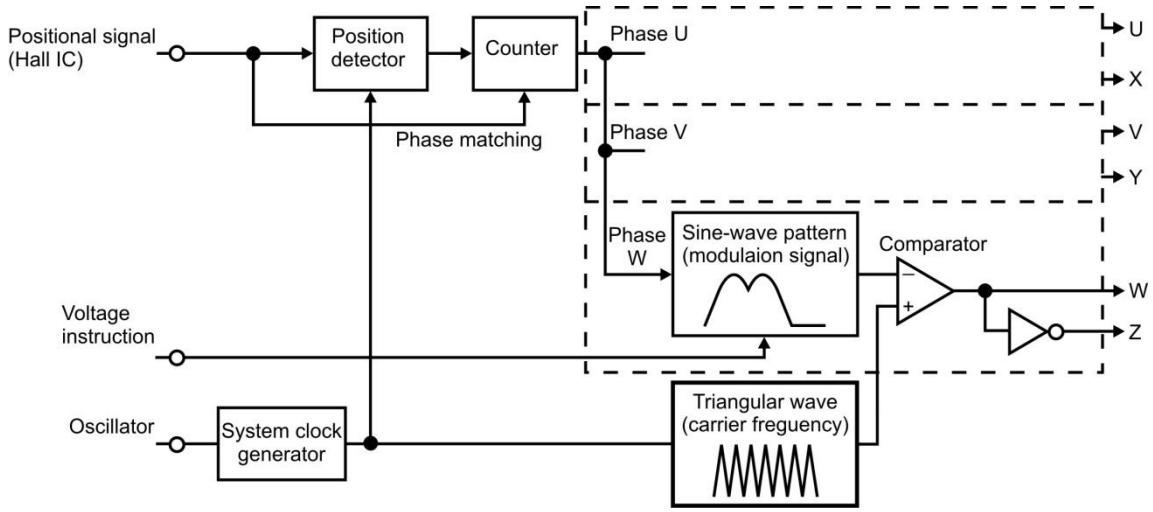
When the positional signal is HHH or LLL, turns off the output; otherwise, restarts the output.

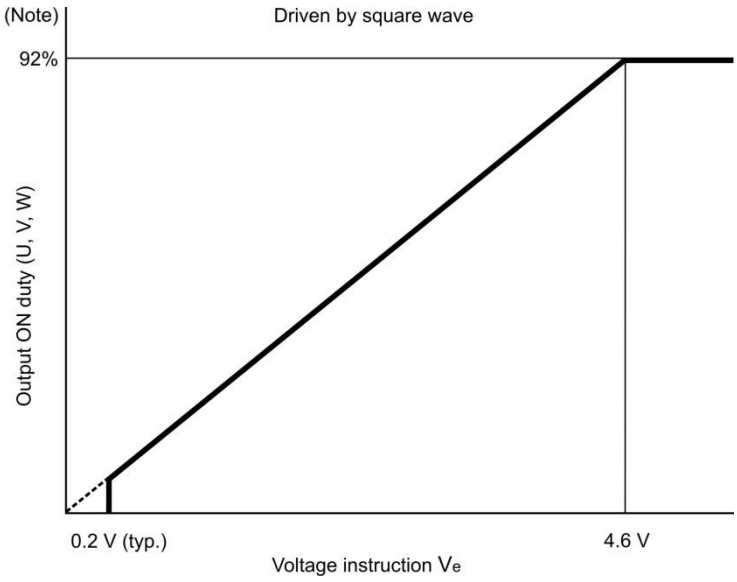
♦ Low power supply voltage protection (V_{CC} monitor)

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.

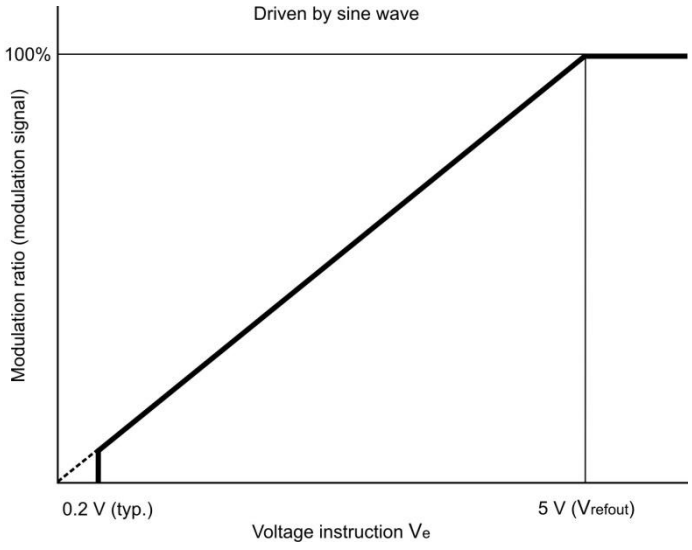


OPERATION FLOW





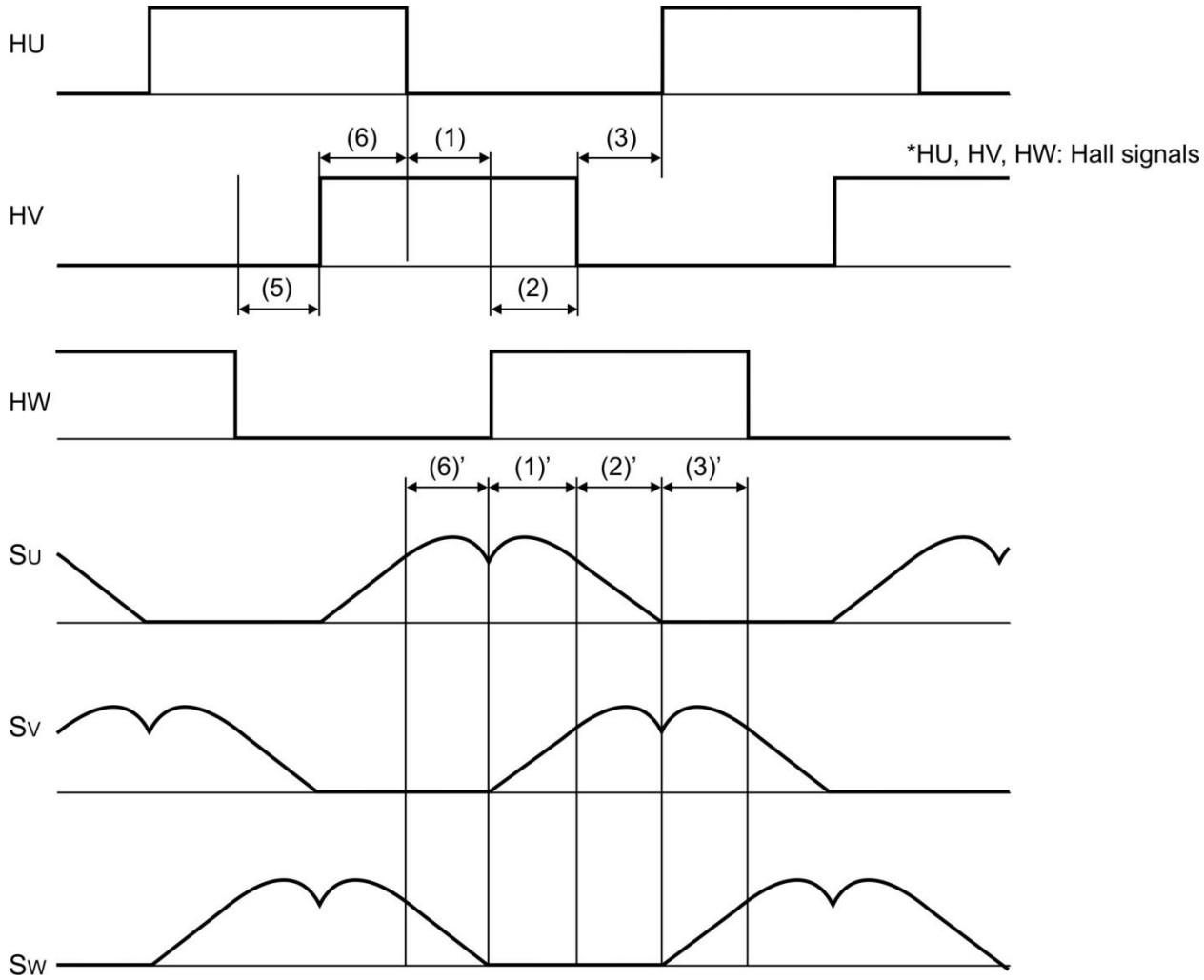
Note: Output ON time is decreased by the dead time (carrier frequency × 92% - Td × 2)



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.

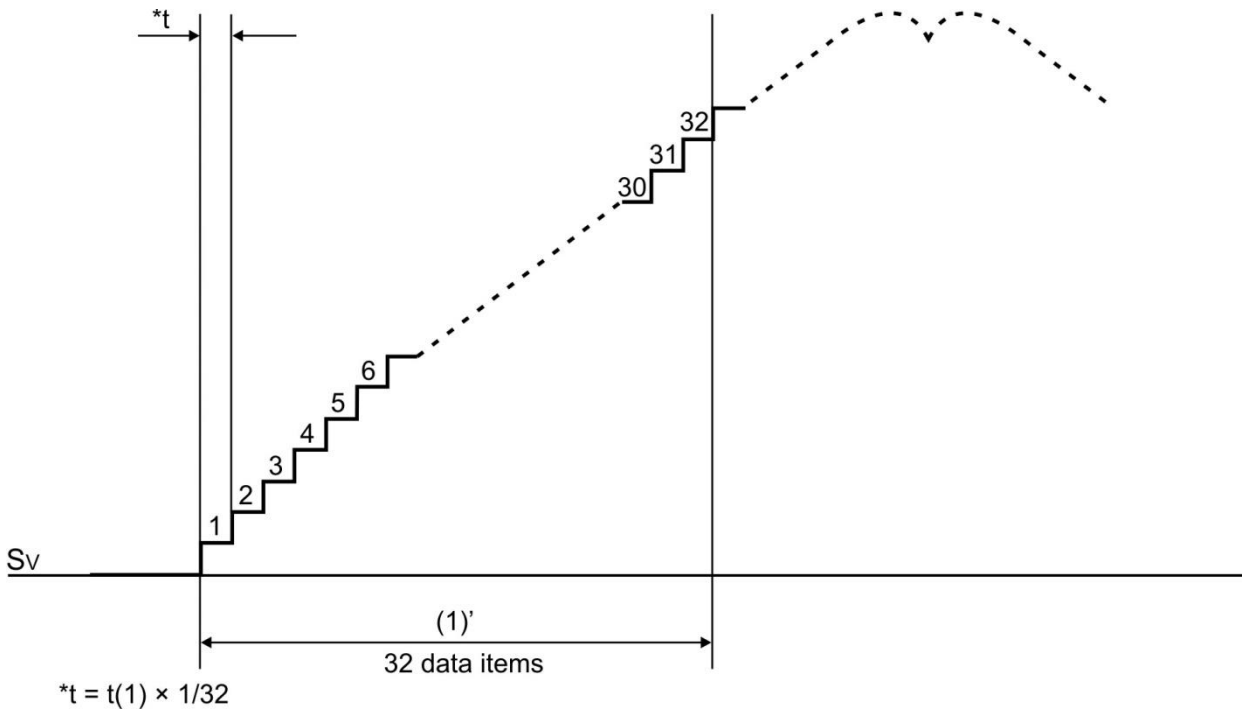
The time (electrical degrees: 60°) from the rising (or falling) edges of the three Hall signals to the next falling (or rising) edges are counted. The counted time is used as the data for the next 60° phase of the modulation waveform.

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: ↑.

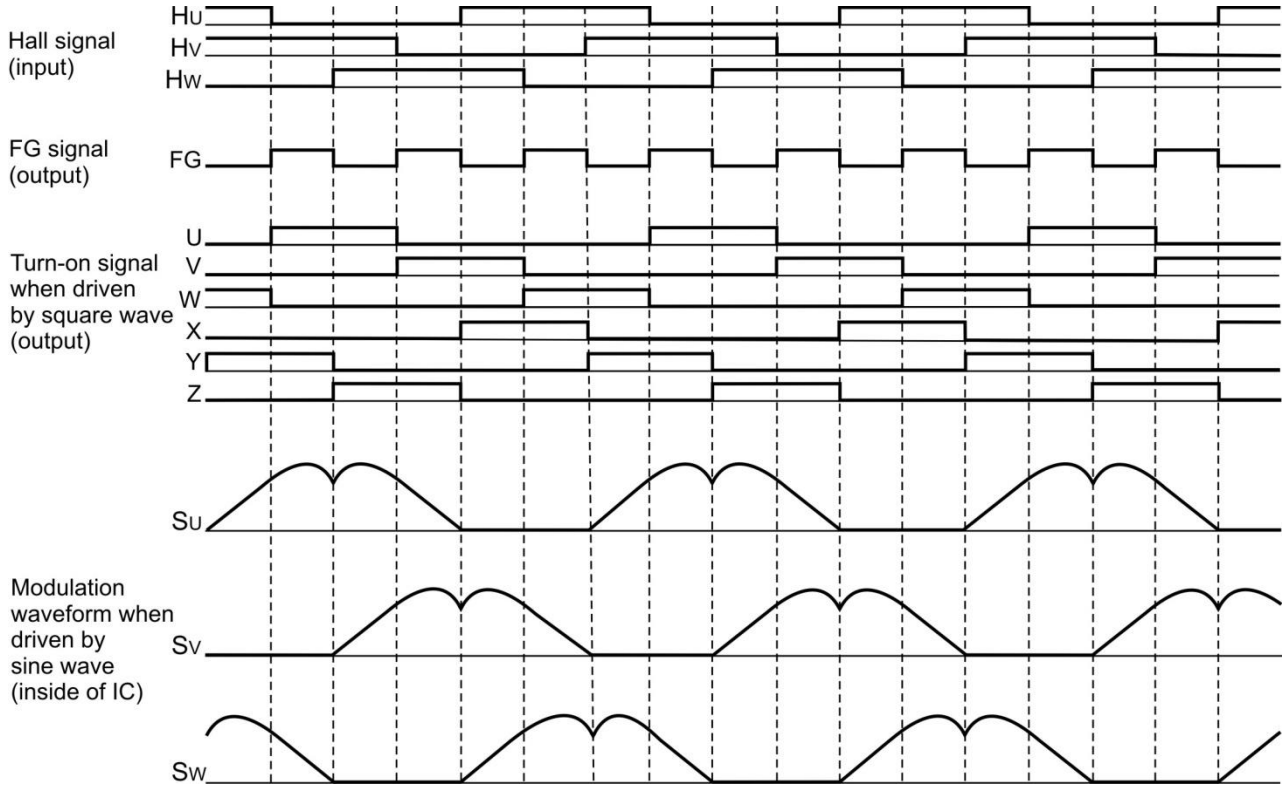
If the next edge does not occur after the 32 data items end, the next 32 data items move forward by the same time width until the next edge occurs.



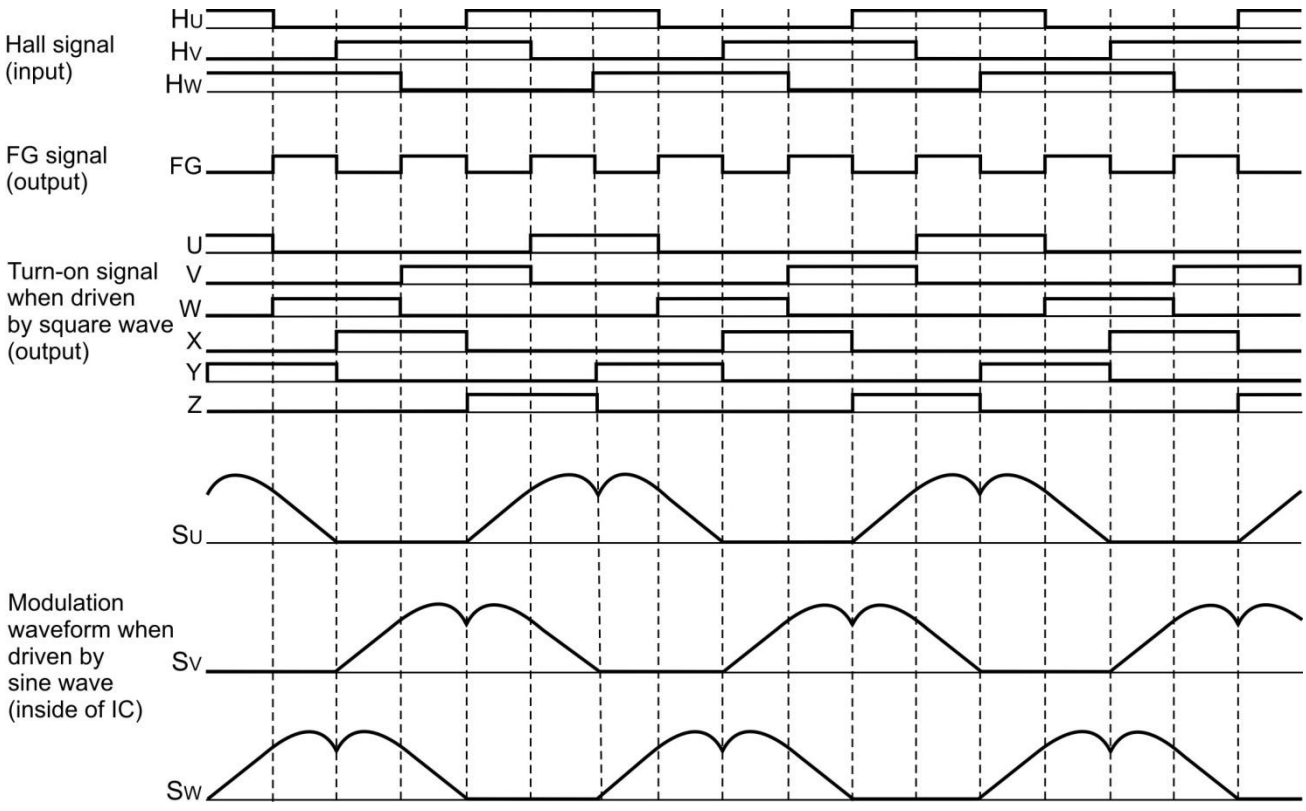
The modulation wave is brought into phase with every zero-cross point of the Hall signal.

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

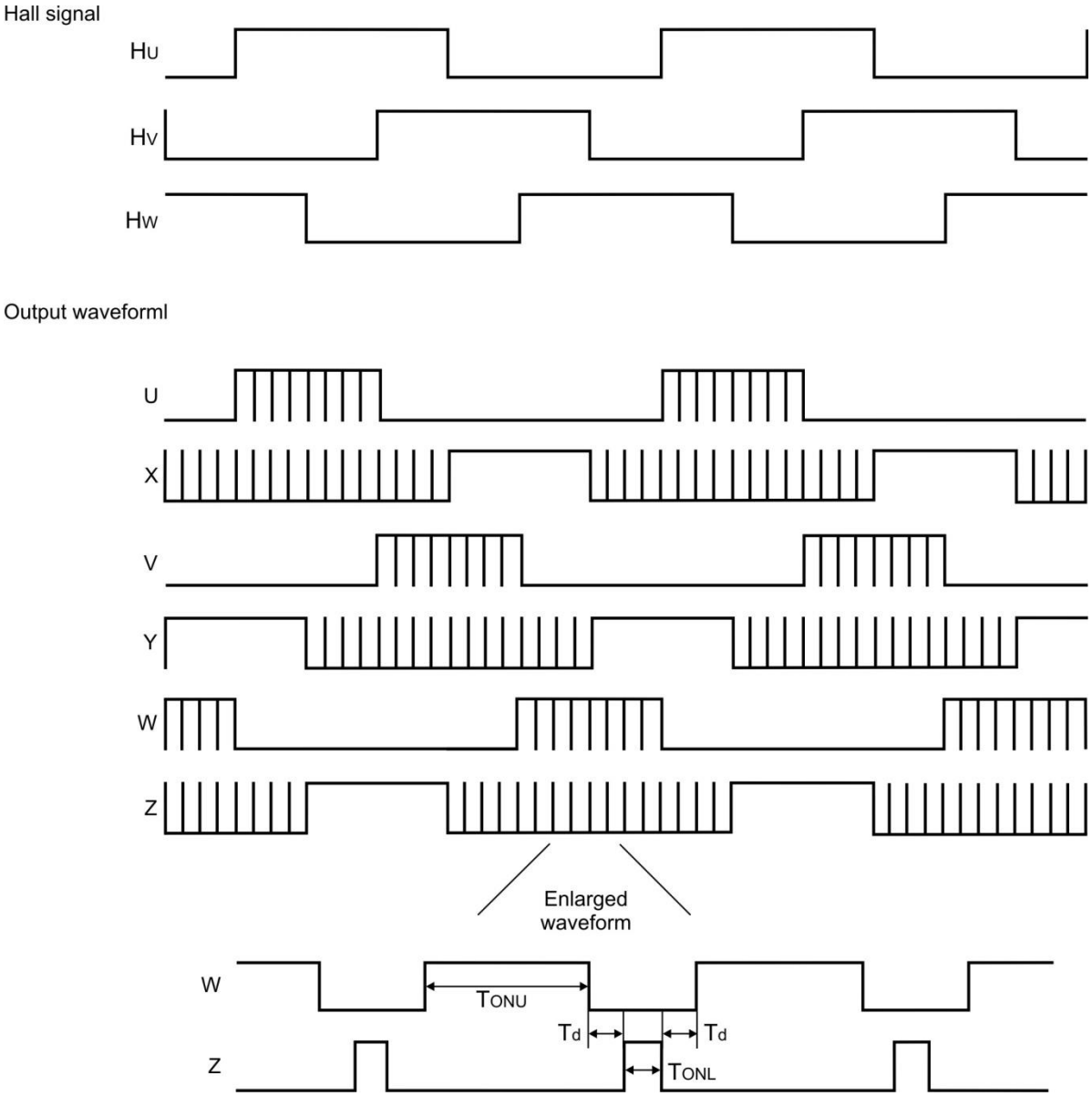


Forward



Reverse

OPERATION 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. (Td varies with input Ve)

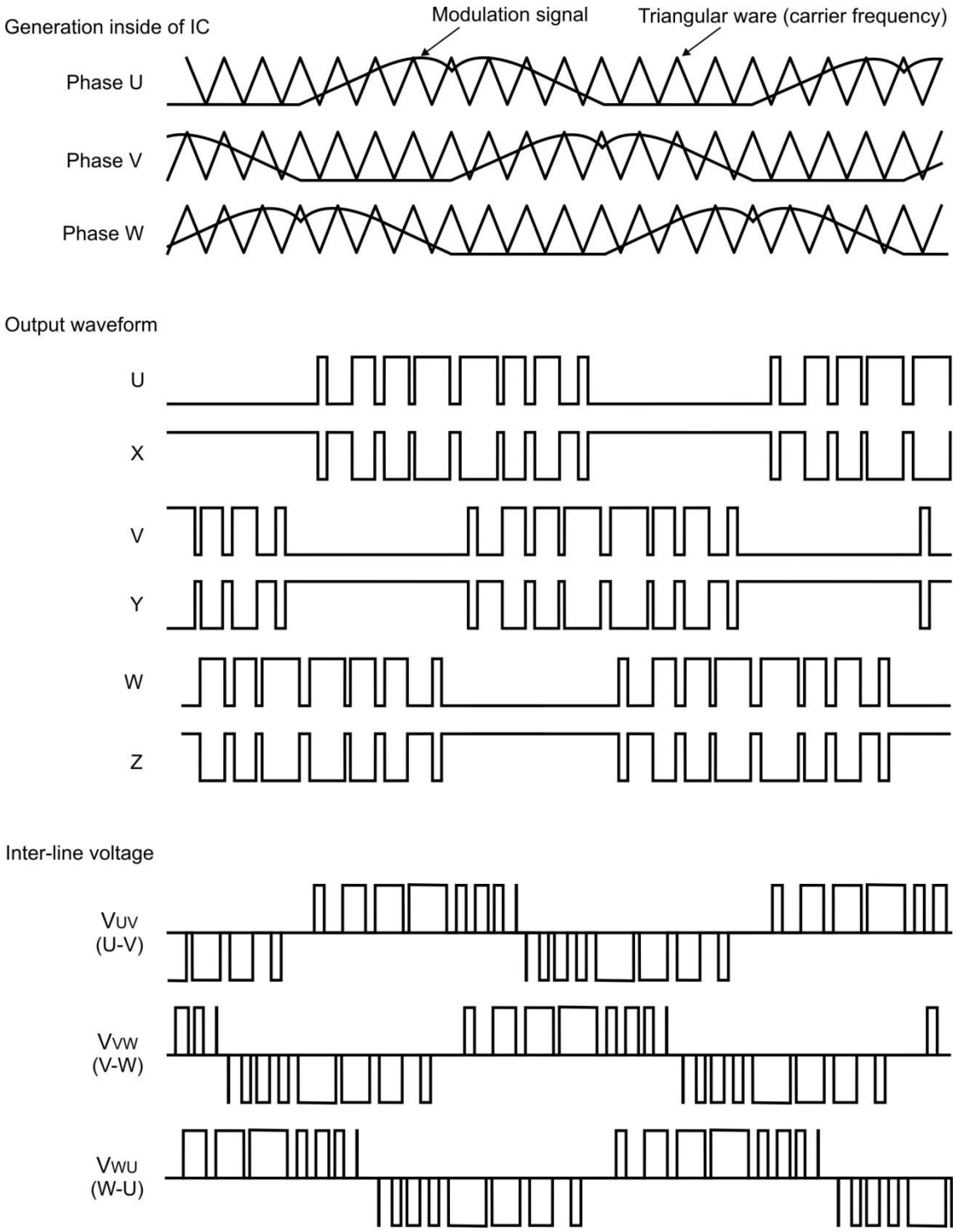
Carrier cycle = fosc/252 (Hz) Dead time: Td = 16/fosc (s) (In more than Ve = 4.6 V)

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

When the motor is driven by a square wave, acceleration/deceleration is determined by voltage Ve. The motor accelerates/decelerates according to the On duty of T_{ONU} (see the diagram of output On duty on page 13).

Note: At startup, the motor is driven by a square wave when the Hall signals are 5 Hz or lower (fosc = 4 MHz) and the motor is rotating in the reverse direction as the IK6501 controls it (REV = High).

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

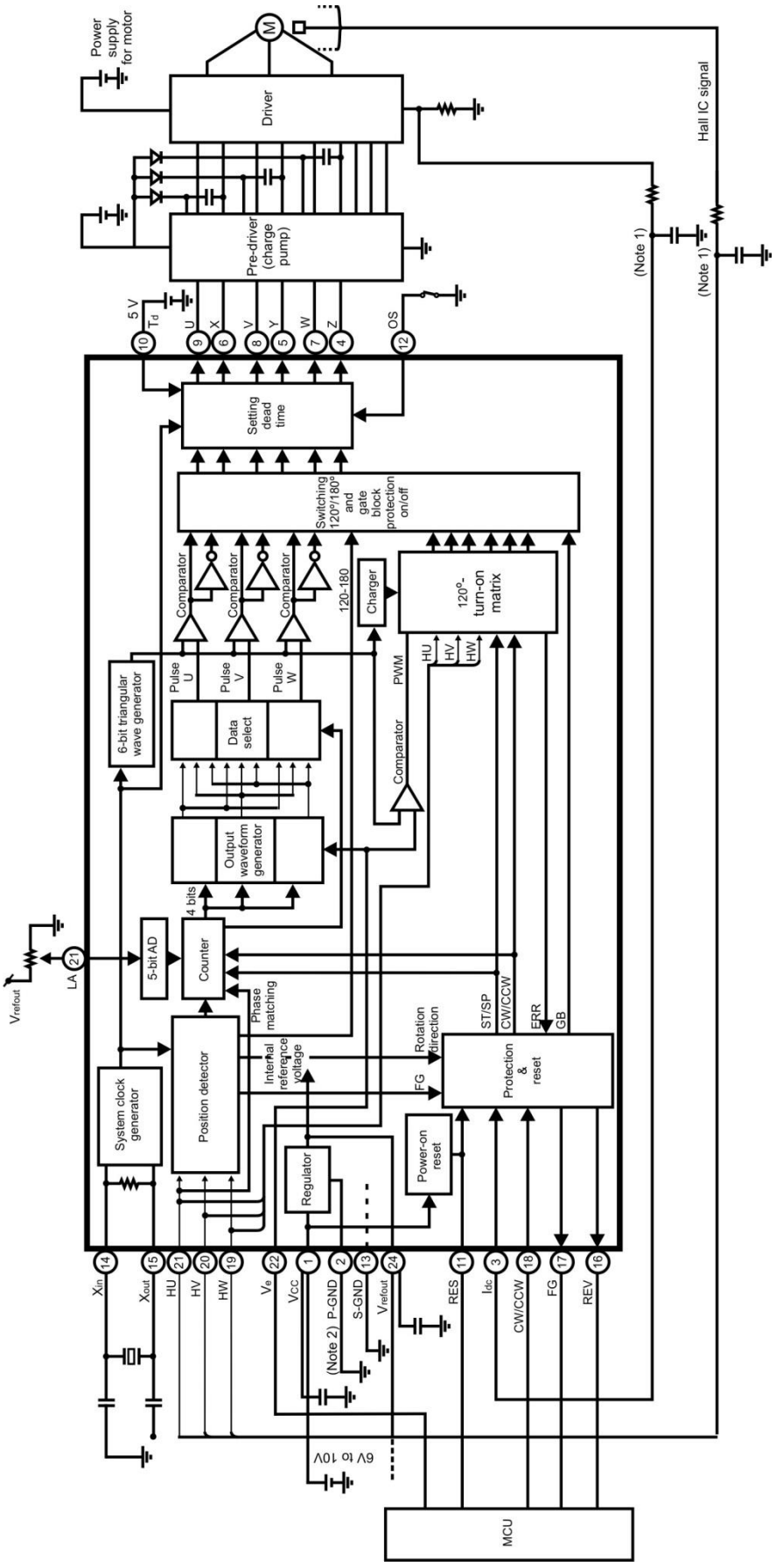


When the motor is driven by a sine wave, the motor is accelerated/decelerated according to the On duty of T_{ONU} when the amplitude of the modulation symbol changes by voltage Ve (see the diagram of output On duty on page 13).

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 (fosc = 4 MHz) and the motor is rotating in the same direction as the IK6501 controls it (REV = Low).

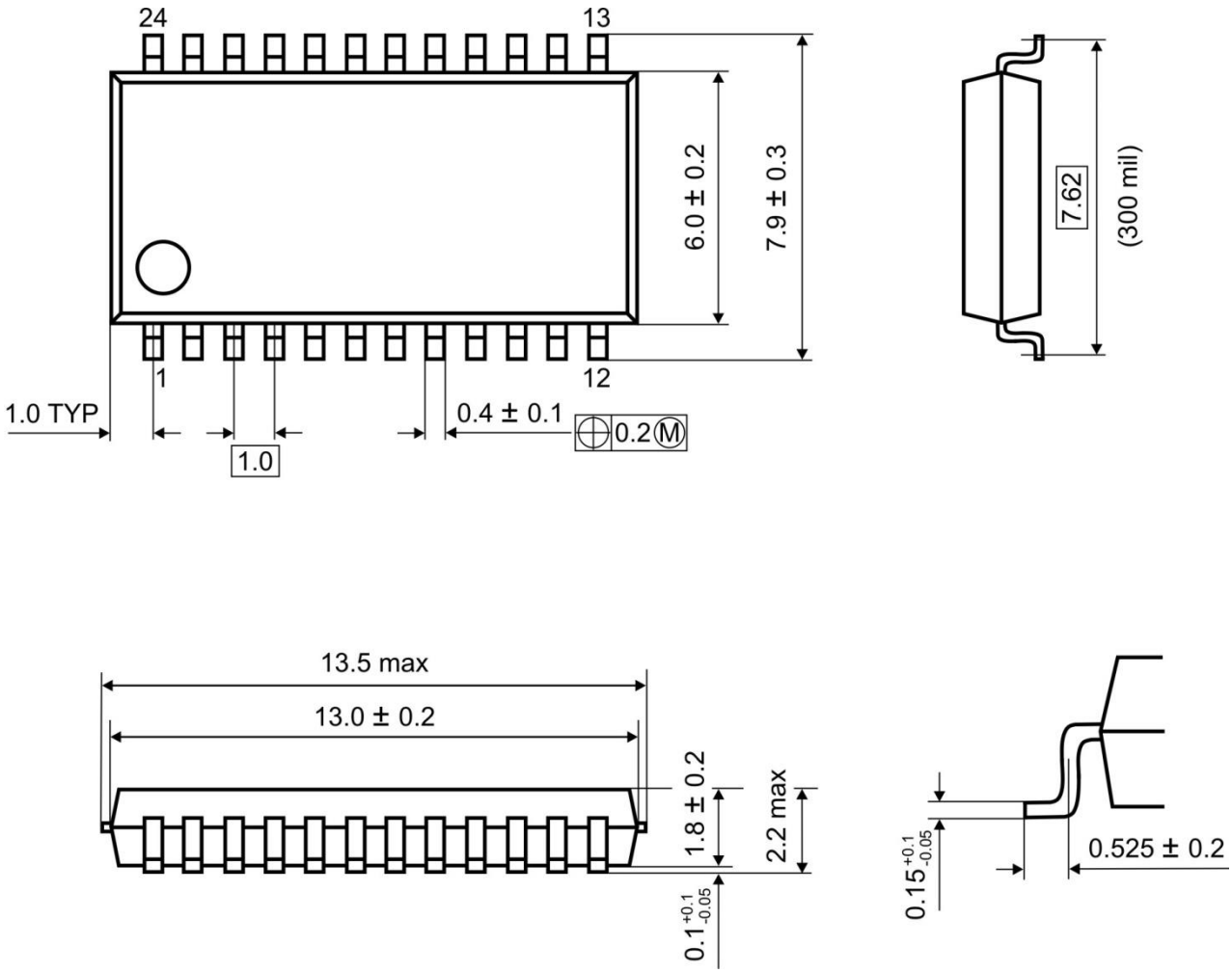
Example of Application Circuit



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. Peripheral parts may also be damaged 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 INFORMATION

SSOP24-P-300-1.00 Unit: mm



Weight: 0.33 g (typ)