Motor Control Circuit for Cordless Power Tool

Reference Guide

RD166-RGUIDE-01

TOSHIBA ELECTRONIC DEVICES & STORAGE CORPORATION

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1. Introduction

This Reference Guide (hereinafter referred to as "this guide") describes the systems and specifications of the brushless DC motor (hereinafter referred to as "BLDC motor") drive circuits, board layout patterns, operating procedures, etc. for use with cordless power tools.

The motor drive circuit in this guide supports two types of operation modes: square wave drive and sine wave drive using the position detection sensor of the motor. The MCU is configured to control the overall operation such as operation mode switching and rotation speed control.

This motor drive circuit uses N-channel power MOSFET TPH1R204PB (V_{DSS}=40 V) with U-MOS IX series for driving each phase of the motor.

To download TPH1R204PB datasheet → Click Here

We have used the most appropriate TPH1R204PB for the specifications of this motor drive circuit, but in addition to this product, we have a wide lineup of low loss, small package MOSFET products using the latest trench technology so that you can select the most appropriate one for your environment and specifications.

In terms of boards, two boards consist of a main board mounting MOSFET and MCUs and an interface board that connects peripheral devices, such as displays, so that the entire tool can be miniaturized in consideration of the size and space restrictions of the enclosure of the power tool.

Design information such as circuit diagram and board pattern data of this circuit is published as a reference design. Please refer to this guide when designing the motor drive circuit.

To download the reference design for motor drive circuits for cordless power tools

→ Click Here

2. Motor Drive Circuit

2.1. Specifications and System Block Diagram

Table2.1 shows the main specifications of the motor drive circuit in this guide, and Fig.2.1 shows a system block diagram.

Table2.1 Main Specifications

Item	Value	Unit
Input voltage	12～24	V
Output power	200	W
Average current	±20	A
Maximum peak current	±60	A
Switching frequency	20	kHz
Driving system	Control with square-wave and sine-wave drive position sensors	

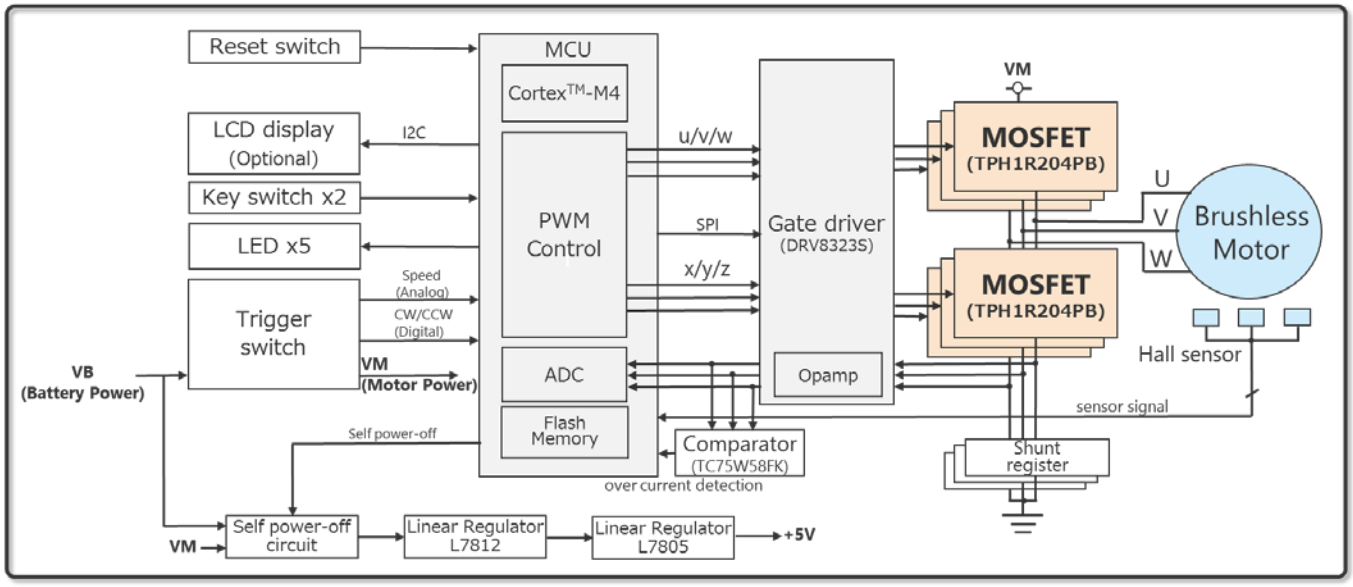


Fig.2.1 System Block Diagram

2.2. Appearance

Fig. 2.2 shows an external photograph of this circuit. It consists of main board and interface board. The black part in the bottom center of the photo is the trigger switch, which is attached to the power tool enclosure by hand so that the trigger part comes out. The strength to squeeze this trigger allows you to control the speed and torque of the motor.

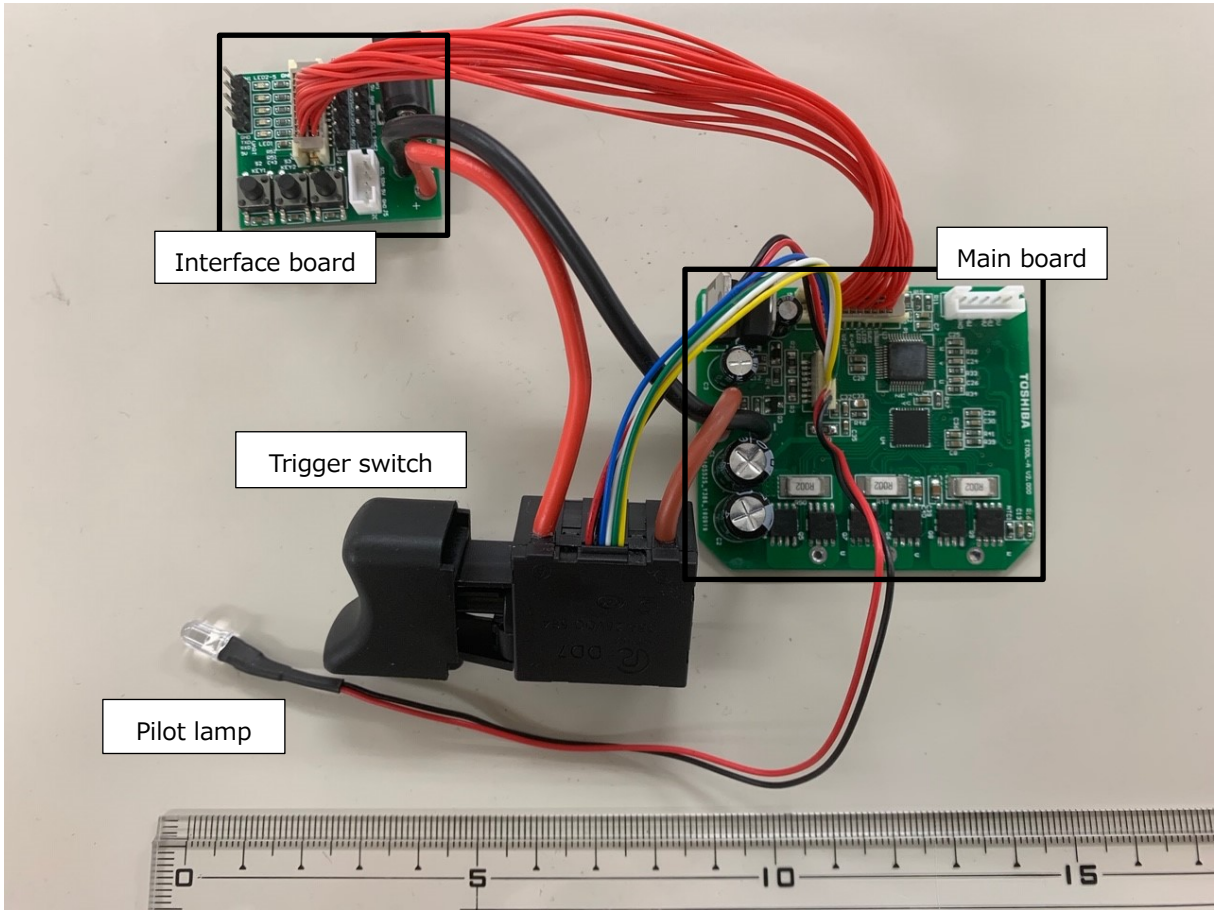


Fig.2.2 Appearance

3. Bill of materials

Table 3.1 to 3.3 show the bill of materials in this motor drive circuit.

Table3.1 Bill of Materials (1 of 3)

Item	Parts	Quantity	Value	Part name	Manufacturer	Description	Package name	Standard Dimensions Mm (inch)
1	C1, C2	2	470 µF			Electrolysis 35V, ±10 %		8×16
2	C3	1	47 µF			Electrolysis 35V, ±10 %		6×11
3	C4, C5, C9 C10, C11, C13, C15, C17, C18, C22, C23, C32, C36, C44	14	100 nF			Ceramic 50V, ±10 %		1.6×0.8 (0603)
4	C6	1	100 µF			Electrolysis 16V, ±10 %		5×11
5	C7, C12, C24, C25, C26, C30	6	10 nF			Ceramic 50V, ±10 %		1.6×0.8 (0603)
6	C8, C27, C28	3	4.7 µF			Ceramic 50V, ±10 %		1.6×0.8 (0603)
7	C14, C16, C29, C34, C35, C43, C45, C46	8	1 µF			Ceramic 50V, ±10 %		1.6×0.8 (0603)
8	C19, C20, C21	3	470 pF			Ceramic 50V, ±10 %		1.6×0.8 (0603)
9	C31	1	10 µF			Ceramic 35V, ±10 %		2.0×1.2 (0805)
10	C33	1	47 nF			Ceramic 50V, ±10 %		1.6×0.8 (0603)
11	C37, C41, C42	3	1 nF			Ceramic 50V, ±10 %		3.2×1.6 (1206)
12	C38, C39, C40	3	100 nF			Ceramic 50V, ±10 %		2.0×1.2 (0805)
13	R1, R5, R6, R7, R8, R24, R25, R26	8	4.7 kΩ			100 mW, ±10 %		1.6×0.8 (0603)
14	R2, R3	2	1 kΩ			125 mW, ±10 %		2.0×1.2 (0805)
15	R4	1	47 kΩ			100 mW, ±10 %		1.6×0.8 (0603)
16	R9, R11, R27, R28, R32, R33, R34	7	0			Jumper		1.6×0.8 (0603)

Table3.2 Bill of Materials (2 of 3)

Item	Parts	Quantity	Value	Part name	Manufacturer	Description	Package Name	Standard Dimensions Mm (inch)
17	R10	1	3.3 Ω			100 mW, ±10 %		1.6×0.8 (0603)
18	R14, R18	2	27 kΩ			100 mW, ±1 %		1.6×0.8 (0603)
19	R15	1	5.1 kΩ			100 mW, ±1 %		1.6×0.8 (0603)
20	R16, R20, R21, R22	4	10 kΩ			100 mW, ±1 %		1.6×0.8 (0603)
21	R17	1	2.7 kΩ			100 mW, ±1 %		1.6×0.8 (0603)
22	R19, R35, R36, R37, R38, R39, R42	7	10 kΩ			100 mW, ±10 %		1.6×0.8 (0603)
23	R23, R43, R44, R45, R47	5	100 Ω			100 mW, ±10 %		1.6×0.8 (0603)
24	R29, R30, R31	3	51 Ω			100 mW, ±10 %		1.6×0.8 (0603)
25	R40	1	3 Ω			250 mW, ±10 %		3.2×1.6 (1206)
26	R41, R51, R52, R53, R54, R55	6	3 kΩ			100 mW, ±10 %		1.6×0.8 (0603)
27	R46	1	5.1 Ω			100 mW, ±10 %		1.6×0.8 (0603)
28	R48, R49, R50	3	2 mΩ			3 W		6.4×3.2 (2512)
29	D1, D2	2	-	CUHS15F40	TOSHIBA	Schottky Barrier Diode	US2H	1.4×2.5
30	D3	1	-	BAS316	TOSHIBA	Switching diode	USC	1.25×2.5
31	Q1	1	-	2SA2056	TOSHIBA	High-speed switching PNP power transistor	TSM	2.8×2.9
32	Q2	1	-	2SC6061	TOSHIBA	High-speed switching NPN power transistor	TSM	2.8×2.9
33	Q3	1	-	TMBT3904	TOSHIBA	For low frequency amplification Transistor	SOT23	2.4×2.9
34	Q4, Q5, Q6, Q7, Q8, Q9	6	-	TPH1R204PB	TOSHIBA	N-ch power MOSFET	SOP Advance	5.0×6.0
35	IC1	1	-	L7812	STM	3-terminal regulator	TO-220	
36	IC2	1	-	L7805	STM	3-terminal regulator	TO-220	
37	U1, U2	2	-	TC75W58FK	TOSHIBA	Comparator	US8	2.0×3.1
38	U3	1	-	-	-	MCU	LQFP48	9.0×9.0
39	U4	1	-	DRV8323S	TI	Three-phase gate driver	WQFN40	6.0×6.0
40	NTC1	1	-	NCP18XV103J03RB	Murata Manufacturing	Thermistor		1.6×0.8 (0603)

Table3.3 Bill of Materials (3 of 3)

Item	Parts	Quantity	Value	Part name	Manufacturer	Description	Package name	Standard Dimensions Mm (inch)
41	J3	1	-	PH2.0-ZZ_5P	Risym	5-pin connector		
42	J4	1	-	1*6P 2.54mm	JICHENG	6-pin connector		
43	J5	1	-	PH2.0-ZZ_5P	Risym	4-pin connector		
44	J6	1	-	DC-005 2.1/2.5	BOTAIXIN	Power jack		
45	CON1, CON2	2	-	1*4P 2.54mm	JICHENG	4-pin connector		
46	P1	1	-	GH-20AB/AWB(A)	MINGYUE	Connector (male)		
47	P2	1	-	GH-20AB/AWB(A)	MINGYUE	Connector (female)		
48	BOOT1	1	-	1*2P 2.54mm	JICHENG	2-pin connector		
49	SW1	1	-	1.25T-8AWB(A)	Hong Yun	Switch		
50	S2, S3, S4	3	-	Microswitch	MUXIN	Switch		6.0×6.0
51	LED1	1	-	0603 Green	ZTSMDLED	LED (green)		
52	LED2, LED3, LED4, LED5	4	-	0603 Red	ZTSMDLED	LED (red)		

4. Board Pattern Drawing

The circuit board example of the motor drive circuit in this guide consists of main board and interface board, taking into consideration the size reduction of the entire tool. For main board, a MOSFET that directly drives each phase of the motor and its gate drivers, microcontroller, and other devices are arranged. For interface board, connectors and various switches are arranged to connect the main board and external devices such as displays.

Fig.4.1 and Fig.4.2 show the layout of the main board top side (component mounting surface) and Fig.4.3 and Fig.4.4 show the bottom side.

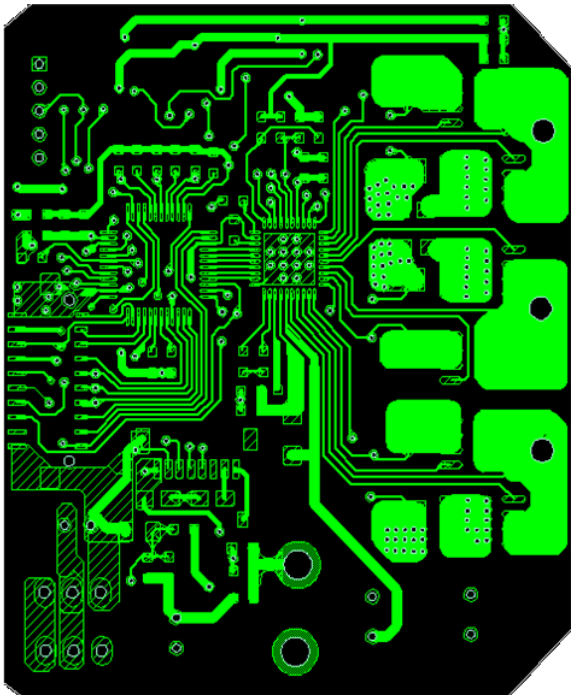


Fig.4.1 Main Board Pattern (Top side)

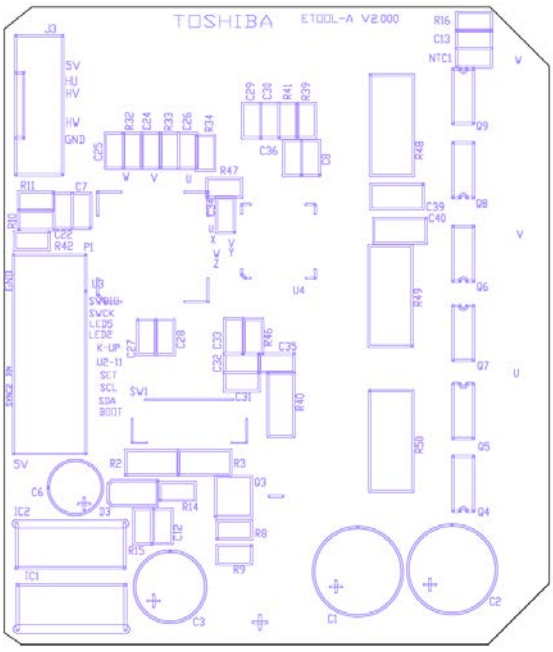


Fig.4.2 Main Board Substrate Silk (Top side)

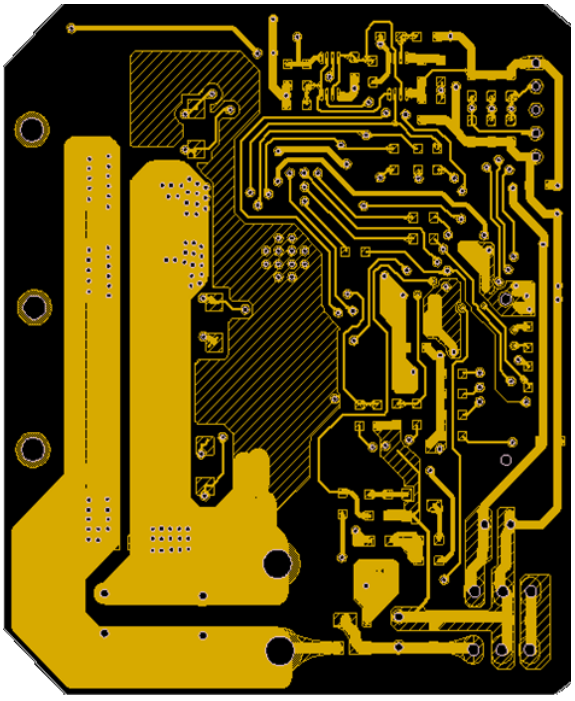
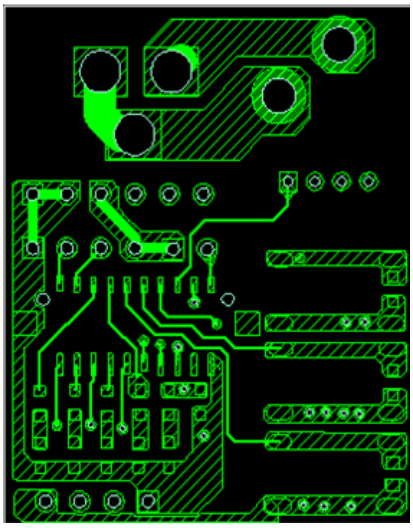


Fig.4.3 Main Board Pattern (Bottom side)

Fig.4.4 Main Board Substrate Silk (Bottom side)

Fig.4.5 shows the top side layout of the interface board, and Fig.4.6 shows the bottom side. Note that there is no silk layer on the back of the interface board.



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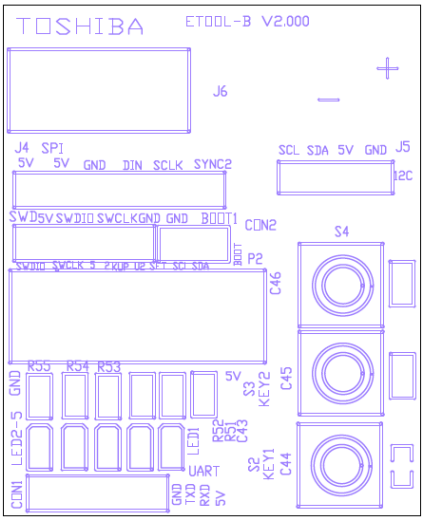

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Fig.4.5 Interface Board Pattern and Substrate Silk (Top side)

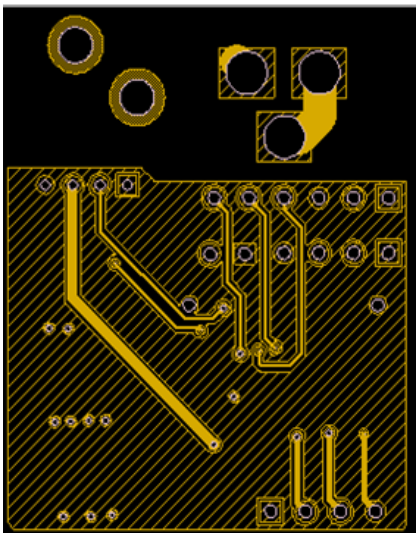

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Fig.4.6 Interface Board Pattern (Bottom side)

5. Operation Procedure

Fig.5.1 and Fig.5.2 show the layout of the main board and interface board components.

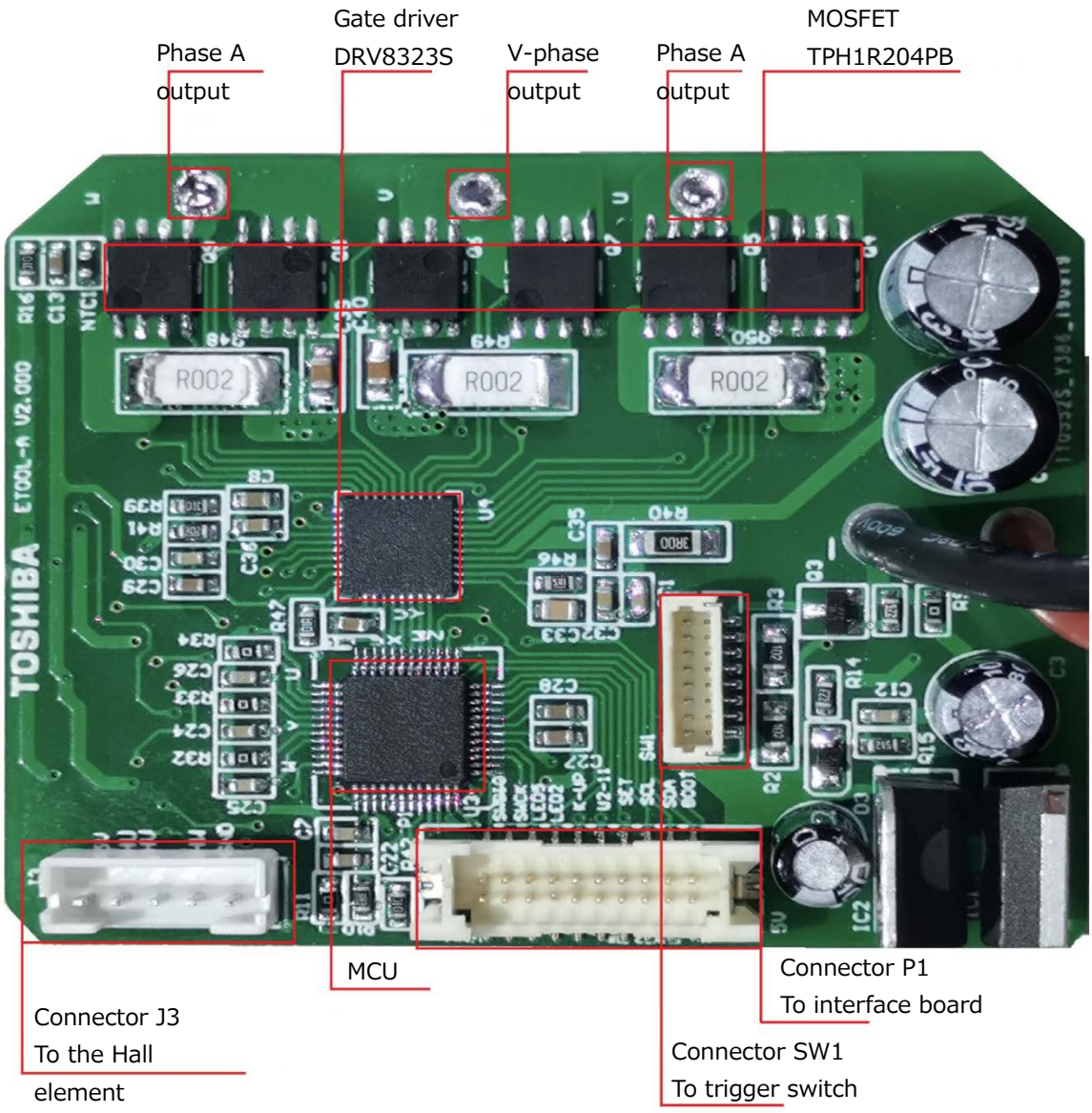

Fig.5.1 Layout of the Main Board

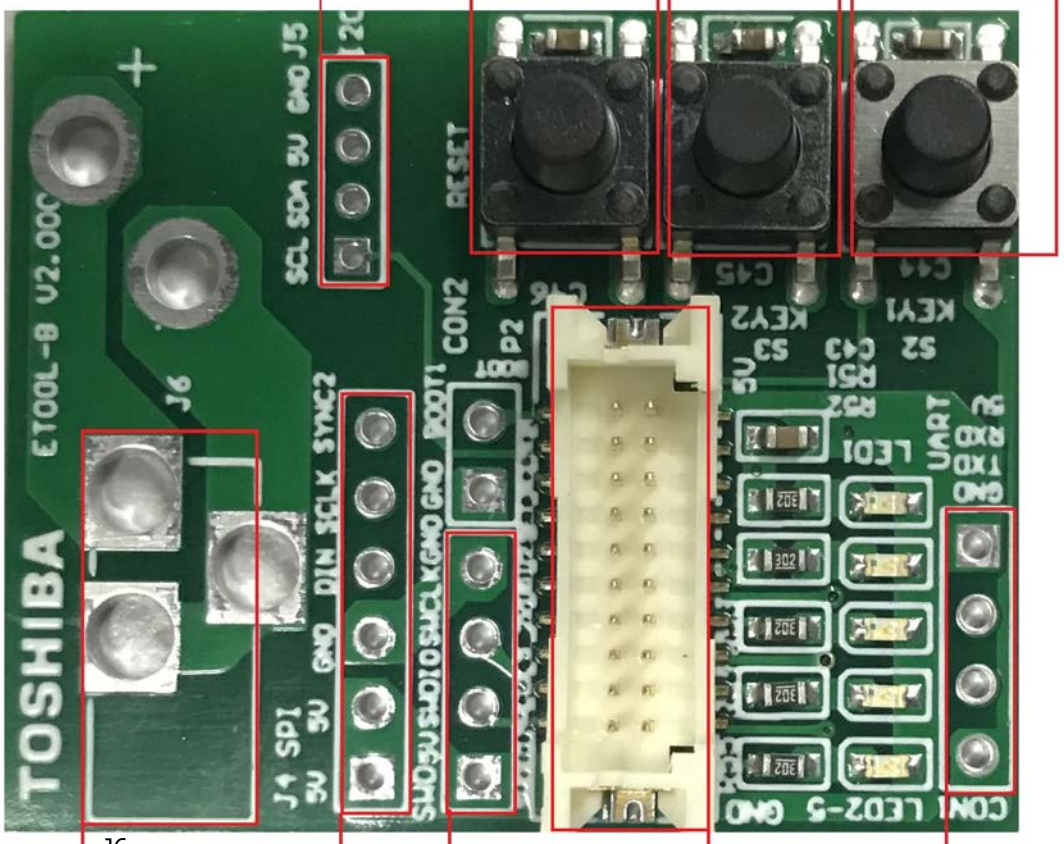

Fig.5.2 Layout of Interface Board

Table5.1 shows the detail of components on the main board and the interface board.

Table5.1 Detail of Components

Element number	Description
J3	Connector for Hall sensor
J4	DAC connector SPI interface can be connected to external DAC module for debugging purposes
J5	I2C interface connected to the display (LCD module)
J6	DC inputs, connectors to PC adapters, etc.
CON1	Connector for connecting to UART such as firmware update
CON2	JTAG/SW connector
KEY1	Display switching of display speed information and error information
KEY2	Short push (<2S): Motor speed control, default values are low speed, HIGH/LOW switching Press and hold (≧2S): Driver mode switch.
KEY3	Reset switches
SW1	Connecting to E-Tool Switches
LED1	Power-on status LED. Indicates that 5V power is supplied to the board.
LED2	Error status LED. Indicates error information.
LED3~LED5	Voltage display LED: VDC_LOW or higher, LED5 ON, otherwise OFF VDC_MID or higher, LED3 OFF, otherwise ON VDC_HIGH or higher, LED3~LED5 is on

E-tool switch connected to the connector SW1 uses a trigger switch to control the operation of the tool. The operation procedure is as follows.

1. Place the power supply (battery, etc.) in place.
2. Set the rotation direction with the trigger switch.
3. Set the motor speed control mode and the motor speed control mode (square wave/sine wave) of the motor using KEY2.
   (2. And 3. The order may be reversed.)
4. Press the trigger switch to start motor rotation.
5. Adjust the force to press the trigger switch so that the desired rotation speed is achieved. The rotation speed is displayed on the display.
6. Release the trigger switch completely to stop the motor.

6. Operation Waveform

6.1. Trip Points

This section shows the operation waveforms of the square wave drive and sine wave drive of this circuit. The waveforms introduced are the gate-source voltage waveforms ($V_{gs(UL)}$, $V_{gs(VL)}$, $V_{gs(WL)}$) for each phase low-side MOSFET, the U phase high-side MOSFET drain-source voltage waveforms ($V_{ds(UH)}$), and the U phase output current waveforms ($I_{OUT(U)}$).

Fig.6.1 shows the locations of the voltages and currents shown in the block diagram.

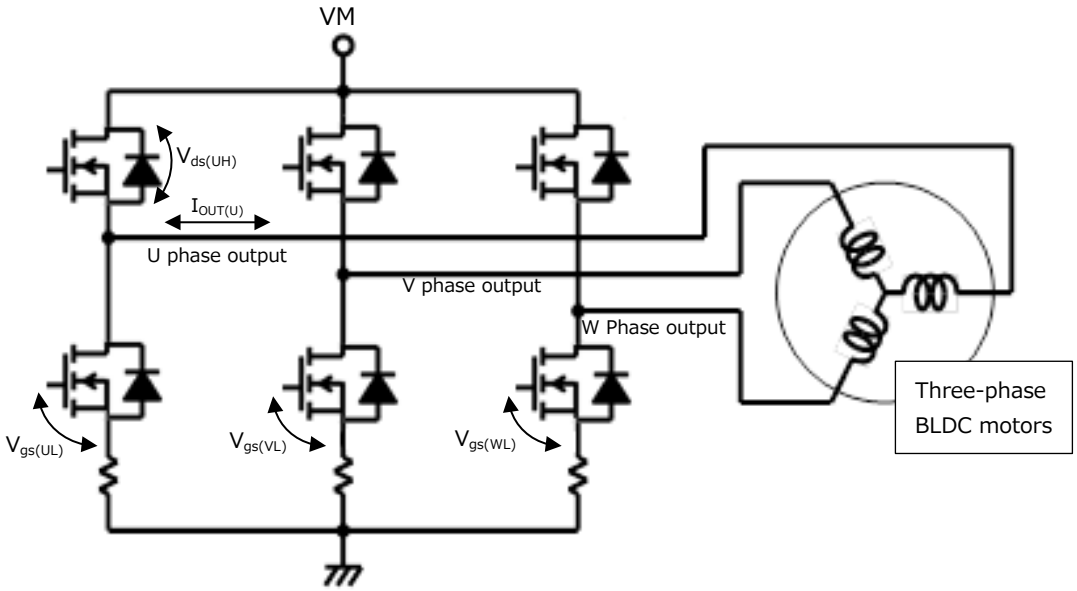

Fig.6.1 Trip Point for Operation Waveforms

Section 6.2 shows the waveform when driving a square wave, and section 6.3 shows the waveform when driving a sine wave. In Fig. 6.1, the resistor connected to the source of each phase low side MOSFET is the motor current sensing resistor.

6.2. Square Wave Drive Mode

Fig.6.2 and Fig.6.3 show the waveforms of each part when the motor rotate with square wave drive mode.

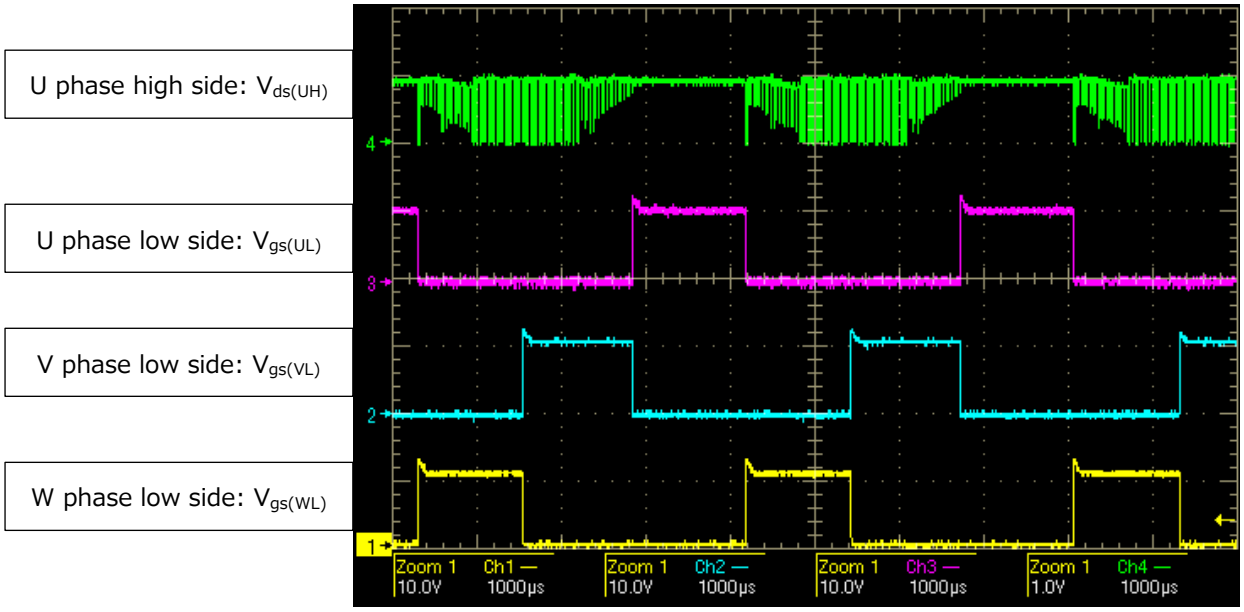

Fig.6.2 Square Wave Drive Mode Operation Waveforms (1)

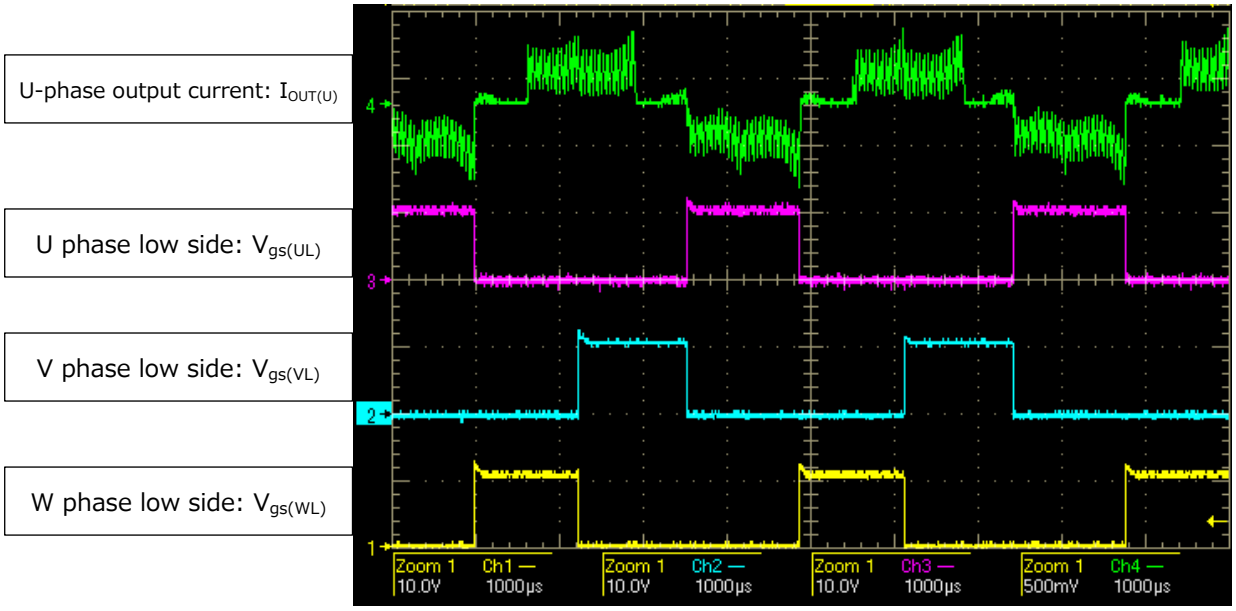

Fig.6.3 Square Wave Drive Mode Operation Waveforms (2)

6.3. Sine Wave Drive Mode

Fig.6.4 and Fig.6.5 show the waveforms of each part when the motor rotates with sine wave drive mode.

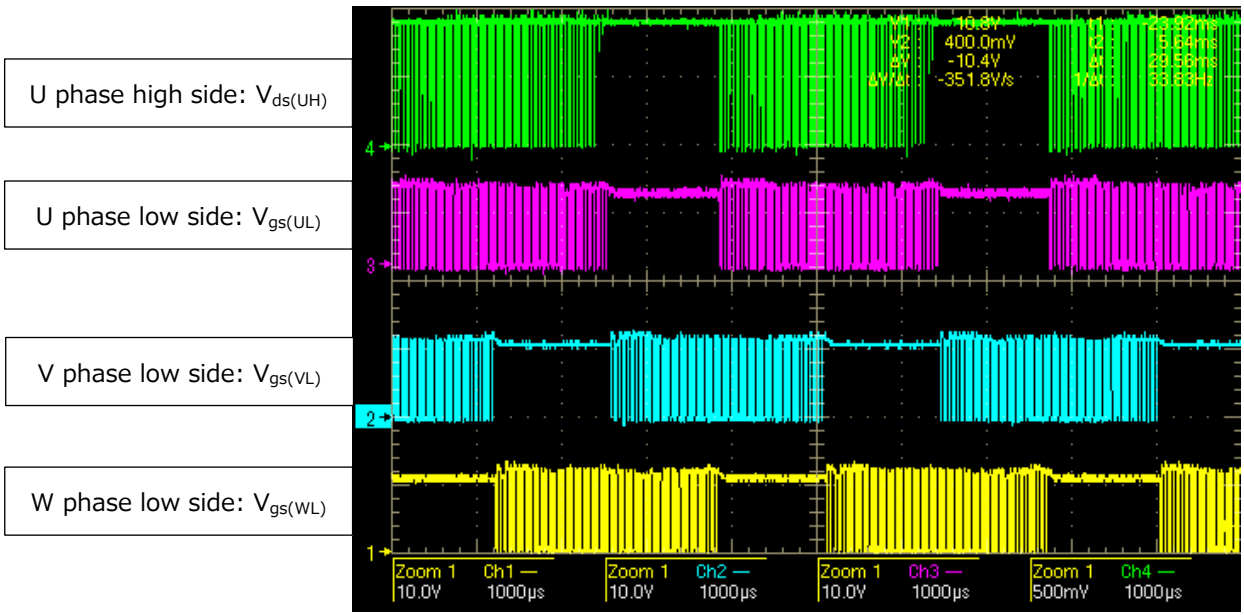

Fig.6.4 Sine Wave Drive Mode Operation Waveforms (1)

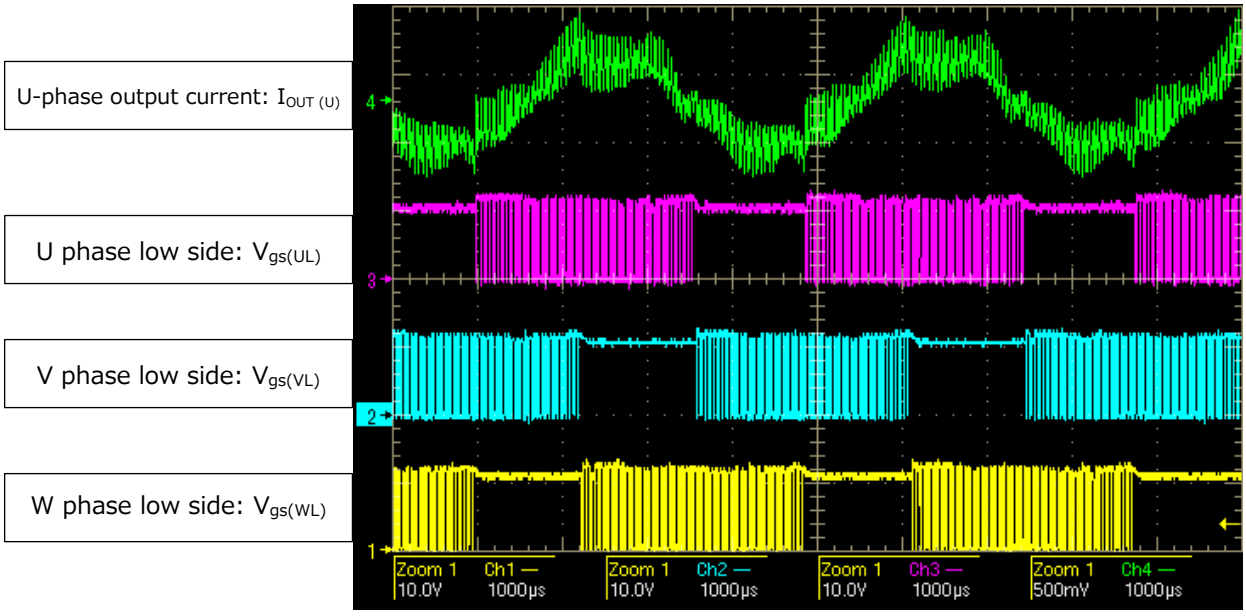

Fig.6.5 Sine Wave Drive Mode Operation Waveforms (2)

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