3-Phase Bridge Drive Circuit for Automotive and Industrial BLDC Motors

Reference Guide

RD176-RGUIDE-01

TOSHIBA ELECTRONIC DEVICES & STORAGE CORPORATION

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1. Overview

A motor is a generic name of machine designed to convert electric energy into mechanical energy. When an electric current flows through a motor's coil, magnetic fields are produced. The rotor of the motor spins as magnets in the rotor are attracted and repelled by the magnetic fields. The direction of motor rotation can be changed by controlling the direction of the electric current.

In line with the low power consumption requirement of home appliances and increasing vehicle electrification, the importance of motors is growing dramatically. There are various kinds of motors. For example, brushed direct-current (DC) motors are commonly used in automotive applications, toy trains and so on. Nowadays, brushed DC motors are the most widely used due to their excellent controllability, high efficiency, ease of size reduction, and low price. Stepping motors, which are also in widespread use, are characterized by their high accuracy. For example, industrial precision machines require high positioning accuracy, which is enabled by stepping motors. In addition, stepping motors ensure repeatability of movement. The stepping motors found in air-conditioner louvers also feature long service life and quiet operation.

Brushed DC motors use brushes to send electric currents to coils. A motor's rotor has several coils, and a commutator is attached on the motor shaft. The commutator is a rotating electrical switch that reverses the current direction in the rotor coils periodically. The commutator is connected to the coils rotating inside magnetic fields. As a coil rotates, it makes contact with one brush on the power supply side. At this point, the commutator reverses the direction of current through the coil. The commutation sequence is controlled to produce an even torque.

In contrast, BLDC motors do not use any brush (i.e., mechanical contactor) or commutator to change the current direction. Instead, BLDC motors rely on sensors and electronic circuits (collectively called a "driver"). Current commutation using an electronic motor driver was enabled by the progress of semiconductor devices. Being similar in the principle of operation, brushed and BLDC motors have almost the same current-to-torque and voltage-to-rpm relationships. However, as the structure of BLDC motors is similar to that of alternating-current (AC) motors, BLDC motors provide the combined advantages of both DC and AC motors. BLDC motors are small, provide high output power, generate no internal spark or noise due to brushes, have a long service life being free from mechanical wear, and exhibit low energy loss. Therefore, BLDC motors are widely used for various applications including computers and home appliances.

TPD7212F/FN is a power MOSFET gate driver for a 3-phase full-bridge circuit with a charge pump method. The built-in charge pump circuit for the high side drive makes it easy to configure a 3-phase full-bridge circuit. In addition, when combined with an external discrete N-channel MOSFET, the 3-phase brushless motor drive circuit can be easily configured with a large current.

In addition to basic operation using TPD7212F/FN for gate drive of MOSFET for automotive and industrial 3-phase inverters, this guide describes applications of gate drive of protection MOSFET such as power supply reverse connection protection, current detection method, and output cutoff function using 1-output high-side N-channel power MOSFET gate driver TPD7104AF for safety assurance and abnormal operation protection for automotive applications.

We would be pleased to refer to this guide as a help in designing a 3-phase BLDC motor drive circuit using our power MOSFET.

Refer to the datasheet for TPD7212F/FN and TPD7104AF functions and detailed information.

Download TPD7212F data sheet from here → Click Here

Download the new TPD7212FN data sheet here → Click Here

Download TPD7104AF data sheet from here → Click Here

Note) Regarding TPD7212F/FN, the F and FN types have the same function but different package. Therefore, the TPD7212F will be described below as a representative.

1.1 Target Application

- For automotive use: EPS, pump control, slide doors, etc.
- For industrial use: server fans, fans for home appliances, etc.

Circuit example

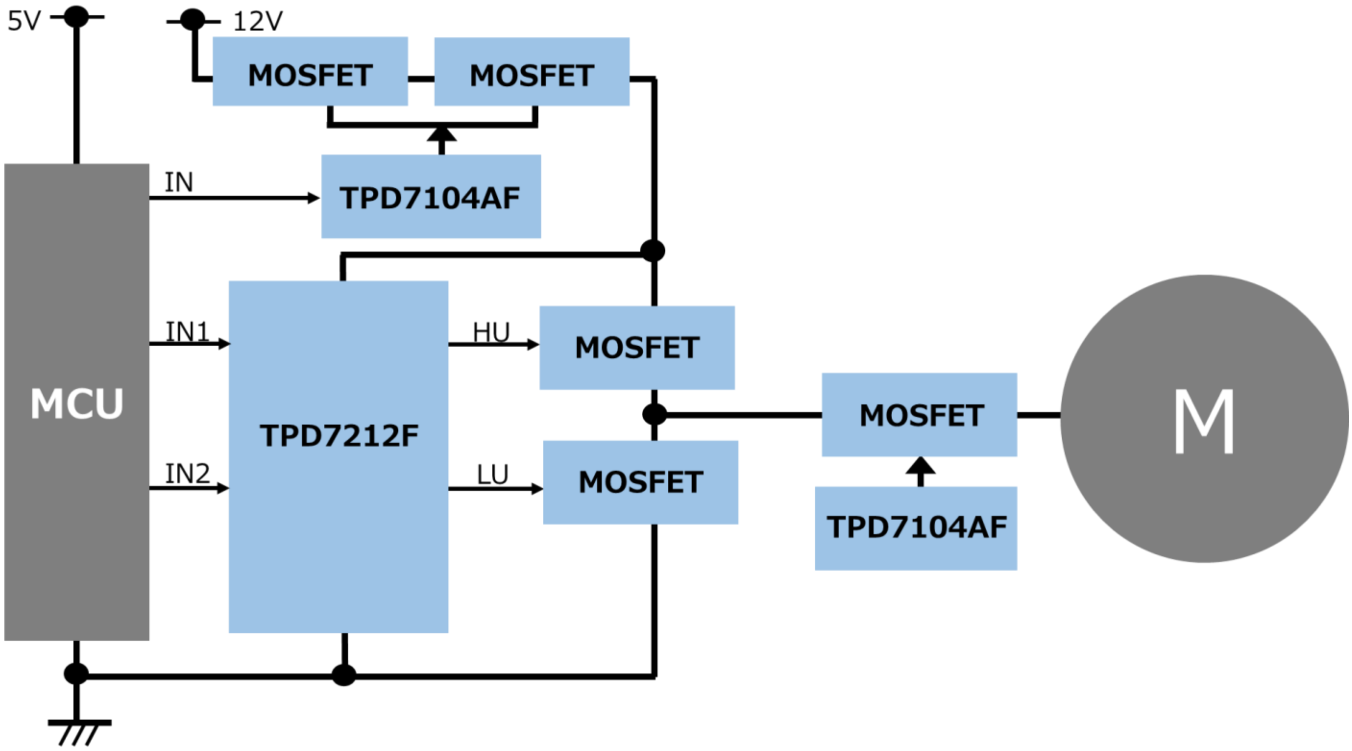


Fig. 1.1 3-phase BLDC Motor Drive Applications (U-phase)

※ Although Fig. 1.1 shows the U-phase as an example, the V-phase and W-phase are the same.

1.2 Basic Operation of 3-phase BLDC Motors

As a basic operation of the 3-phase BLDC motors, the application notes describe how to apply 120° square-wave commutation. Please refer to it.

For application note on brushless motor 120° square-wave commutation method, click here.

→ Click Here

2. Application Circuit Block Diagram

Fig. 2.1 is a block diagram of 3-phase BLDC motor-driven applied circuitry. The functions (1) to (5) in the block diagram are described in detail in Chapter 4, "Applied Circuit Design Guide," and should be checked together.

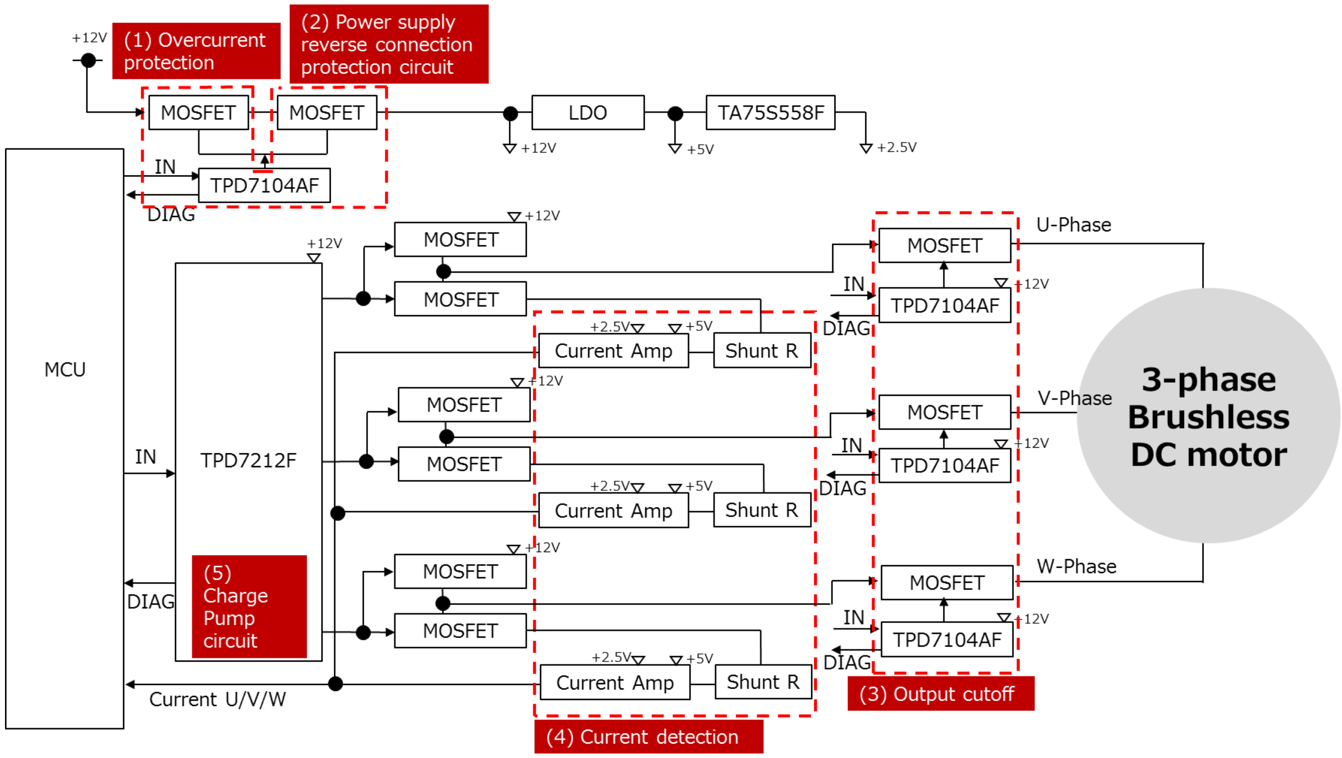


Fig. 2.1 Block Diagram of 3-Phase BLDC Motor-Driven Applied Circuit

The N-channel MOSFET is TPW1R104PB (V_{DS}=40 V, $R_{DS(ON)}$=1.14 mΩ (max)). A TPD7212F is for the gate drive of MOSFET for the 3-phase inverter. The gate driver of the output cutoff MOSFET is TPD7104AF to protect the power supply in the event of an error (1) overcurrent protection, (2) power supply reverse connection protection, and interruption of each phase current (3). PWM control signals, power supply, and phase current on/off control must be received from the MCU and other controller ICs. In addition, the (4) current detection using an op-amp and the diagnostic output of the gate driver are output to the controller IC. And also, TPD7212F drives an N-channel MOSFET on the high side, which requires a boost to bias the gate. (5) By adopting a charge pump circuit, 100% on-duty control is possible.

(1) Overcurrent protection → 4.1 Overcurrent protection function
(2) Power supply reverse connection protection → 4.2 Power supply reverse connection protection function
(3) Output cutoff → 4.3 Output cutoff Function
(4) Current detection → 4.4 Current detection method
(5) Charge pump circuit → 4.5 Design of the charge pump circuit

In addition to the above, in Chapter 5, simulations of various protection functions using TPD7212F are presented.

The complete schematic of the 3-phase BLDC motor drive is published in (RD176-SCHEMATIC-01), so please refer to it.

The overall schematic of the 3-phase BLDC motor drive from here → Click Here

TPW1R104PB data sheet from here → Click Here

More information on MOSFET devices from here → Click Here

3. Bill of Materials

Table 3.1 is the bill of materials for the general schematic of the 3-phase BLDC motor drive.

Table 3.1 Bill of Materials for 3-phase BLDC Motor-Driven Applied Circuits

No.	Ref.	Q'ty	Value	Part Number	Manufacturer	Description	Package Name	Standard Dimensions in mm (inches)
1	IC1、IC7、IC9	3	-	INA199A1DCKR	TEXAS INSTRUMNTS	Current-Shunt Monitor	SC70	1.45 x 1.85
2	IC2	1	-	TA75S558F	TOSHIBA	Opamp	SMV	2.8 x 2.9
3	IC3	1	-	NJW4107U2-05A-T1	JRC	LDO	SOT-89	4.5 x 4.5
4	IC4,IC6,IC8,IC10	4	-	TPD7104AF	TOSHIBA	IPD	PS-8	2.9 x 2.8
5	IC5	1	-	TPD7212F	TOSHIBA	IPD	WQFN32	5.0 x 5.0
6	Q1	1	-	SSM3K17FU	TOSHIBA	MOSFET	USM	2.0 x 2.1
7	Q2,Q3,Q4,Q5,Q6,Q7,Q8,Q9,Q10,Q11,Q12	11	-	TPW1R104PB	TOSHIBA	MOSFET	DSOP	5.0 x 6.0
8	D1、D2、D4,D5,D10,D11,D12,D13,D14,D15,D16,D17,D18,D19,D20,D21,D22,D23,D24	19	-	CRZ16	TOSHIBA	Zener diode	S-FLAT	1.6 x 3.5
9	D3、D6	2	-	CMZ27	TOSHIBA	Zener diode	M-FLAT	2.4 x 4.7
10	D7、D8、D9	3	-	CRH01	TOSHIBA	Diode	S-FLAT	1.6 x 3.5
11	R1,R2,R3,R8,R9,R10,R11,R15,R26,R27,R36,R37,R46,R47	14	10K			Carbon ±5%	1608	1.6 x 0.8 (0603)
12	R4,R6,R28,R38,R48	5	200K			Carbon ±5%	1608	1.6 x 0.8 (0603)
13	R5,R29,R39,R49	4	1K			Carbon ±5%	1608	1.6 x 0.8 (0603)
14	R12,R13,R14,R17,R18,R19	6	10			Carbon ±5%	1608	1.6 x 0.8 (0603)
15	R16,R20,R23,R24,R33,R34,R43,R44	8	10			Carbon ±1%	3216	3.2 x 1.6 (1206)
16	R21,R22,R31,R32,R41,R42	6	22			Carbon ±5%	1608	1.6 x 0.8 (0603)
18	R25,R35,R45	3	1m	PSEDTE2L00F	KOA	Current detecting resistor,5W ±1%	6464	6.4 x 6.4
19	R51,R52,R53	3	1K			Carbon ±1%	1608	1.6 x 0.8 (0603)
20	C1,C8	2	330uF			Aluminum、50V,±20%	–	DIP
21	C2,C14,C17,C20,C22,C24,C26	7	100nF			Ceramic,50V,±10%	1608	1.6 x 0.8 (0603)
22	C3,C4,C6,C10,C11	5	2.2uF			Ceramic,50V,±20%	1608	1.6 x 0.8 (0603)
23	C5,C27	2	4.7uF			Ceramic,50V,±10%	3216	3.2 x 1.6 (1206)
24	C7,C9,C12,C15,C18,C21,C23,C25	8	1nF			Ceramic,50V,±10%	1608	1.6 x 0.8 (0603)
25	C13,C16,C19	3	100uF			Aluminum、50V,±20%	-	DIP

4. Applied Circuit Design Guide

This chapter describes the five key blocks of "Overcurrent protection", "Power supply reverse connection protection function", "Output cutoff", "Current Detection" and "Charge Pump Circuit" in Chapter 4.1 to 4.5.

4.1 Overcurrent Protection Function

Overcurrent protection is a function that cuts off the power supply path when an overcurrent occurs due to a load short circuit or inverter error. Fig. 4.1 shows the overcurrent protection circuit.

* Fig. 4.1 shows a circuit configuration that detects the current externally (Fig. 4.4 Current detection method) and shuts off the current (turns off the MOSFET) by a signal from the MCU.

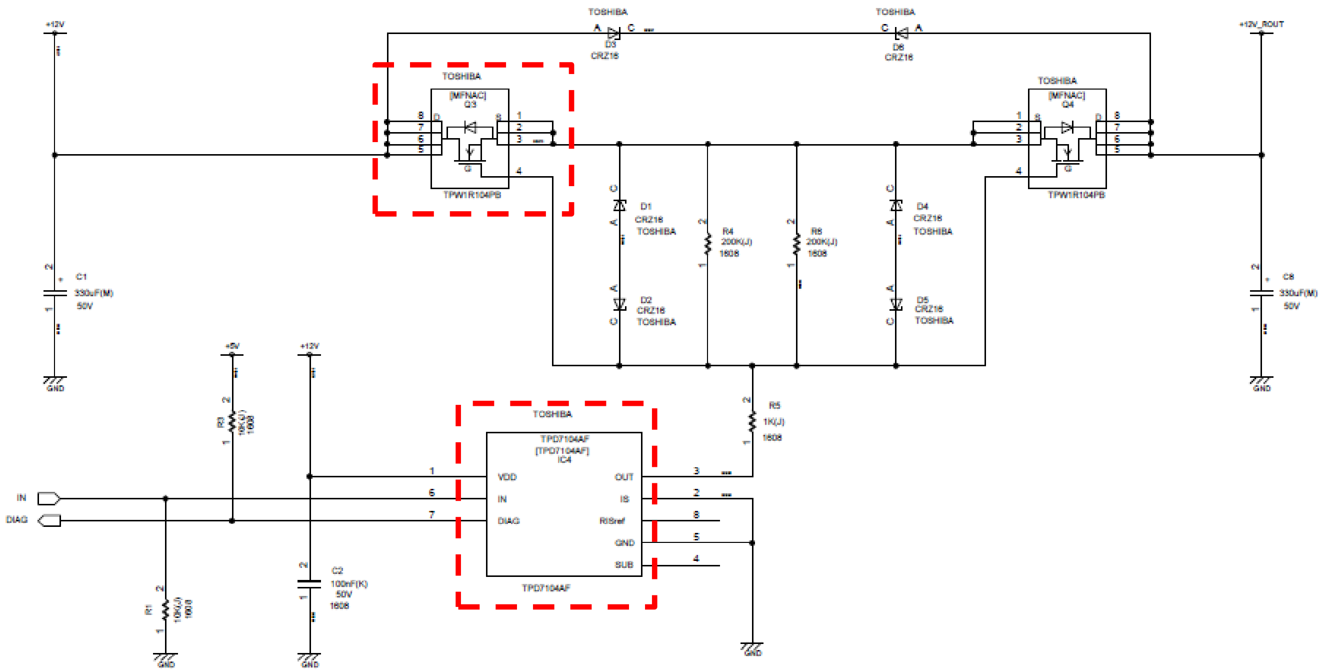


Fig. 4.1 Overcurrent Protection Circuit

Of the two MOSFET arranged in series in Fig. 4.1, Q_3 MOSFET is to shut off the overcurrent. In this circuit, the overcurrent protection function is realized by using IC4 (TPD7104AF). Refer to Reference Design (RD016-RGUIDE-01) for overcurrent protection function using TPD7104AF.

→ TPD7104AF reference design from here Click Here

4.1.1 Simulation Verification

The overcurrent protection function is effective for IC protection when a load is short-circuited. Table 4.1 shows the simulation conditions and procedures, and Fig. 4.2 shows the simulation circuit. Since MOSFET incorporates a parasitic diode called a body diode, the source pins such as M14 and M15 in Fig. 4.2 are connected together to shut off the current generated in both directions. Current interruption controls the VIN pin of TPD7104AF.

Table 4.1 Simulation Conditions and Procedures

1	VBB0	12 V
2	V_DIAG	5 V
3	U2	Outputs 120° square-wave conduction pattern
4	M11、M12、M13	Conducting state
5	Start of simulation	
6	U7_VIN	L-state for 10 ms to 20 ms (M14, M15 off)

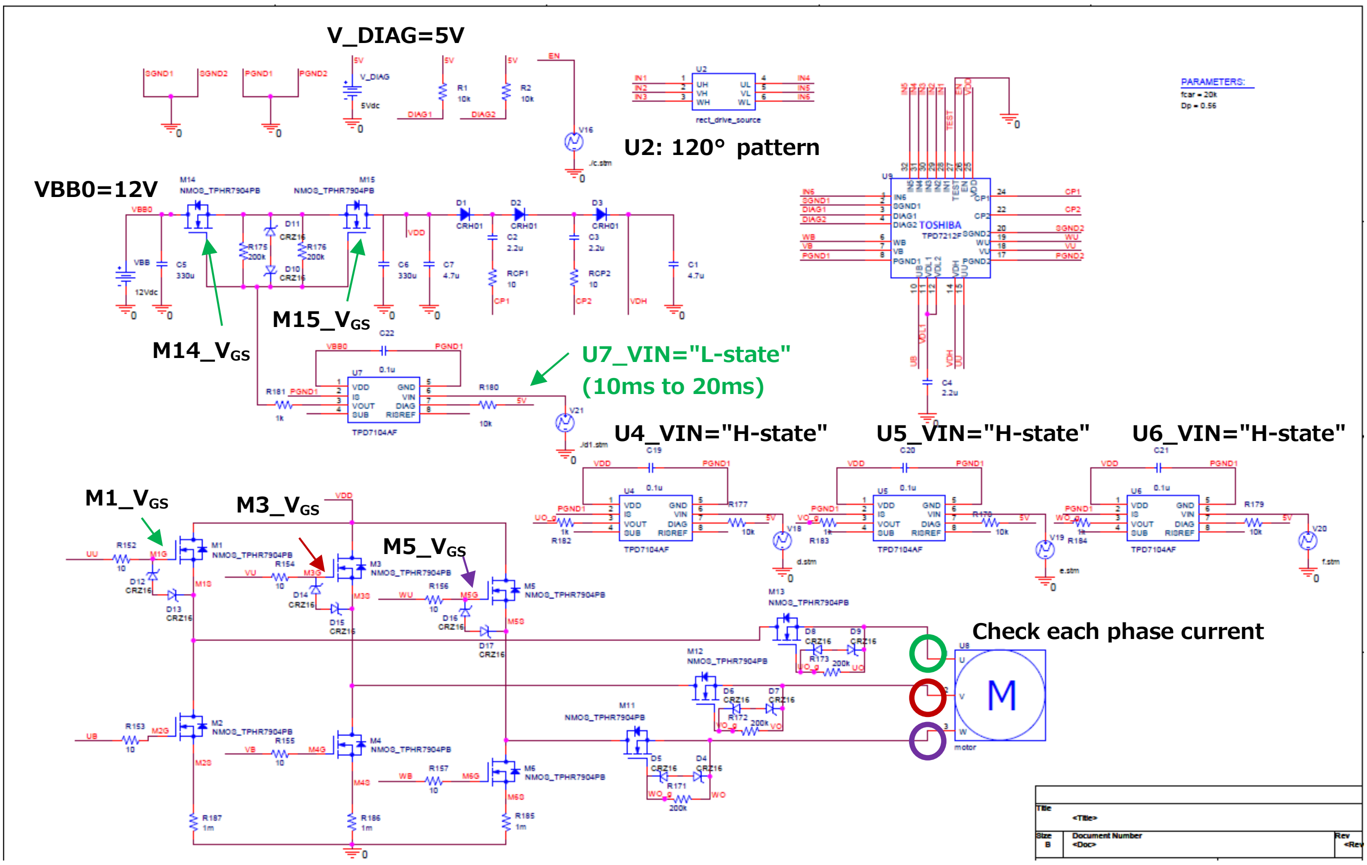


Fig. 4.2 Overcurrent Protection Simulation Circuit

Fig. 4.3 shows the simulation waveform when the power line is cut off. During normal operation, the U7 VIN pin is set to the L-state and MOSFET M14 and M15 are turned off during the period from 10 ms to 20 ms. Consequently, no power is supplied from VBB0 and the phase currents of the motors are interrupted. Power from VBB0 was stopped, but the power supply pin VDD of TPD7212F is maintained at about 5 V, and the ICs continue to operate. This is because the induced voltage is generated by the rotation of the motor, and the voltage is applied to the VDD pin of TPD7212F through the body diode of MOSFET of the inverter section.

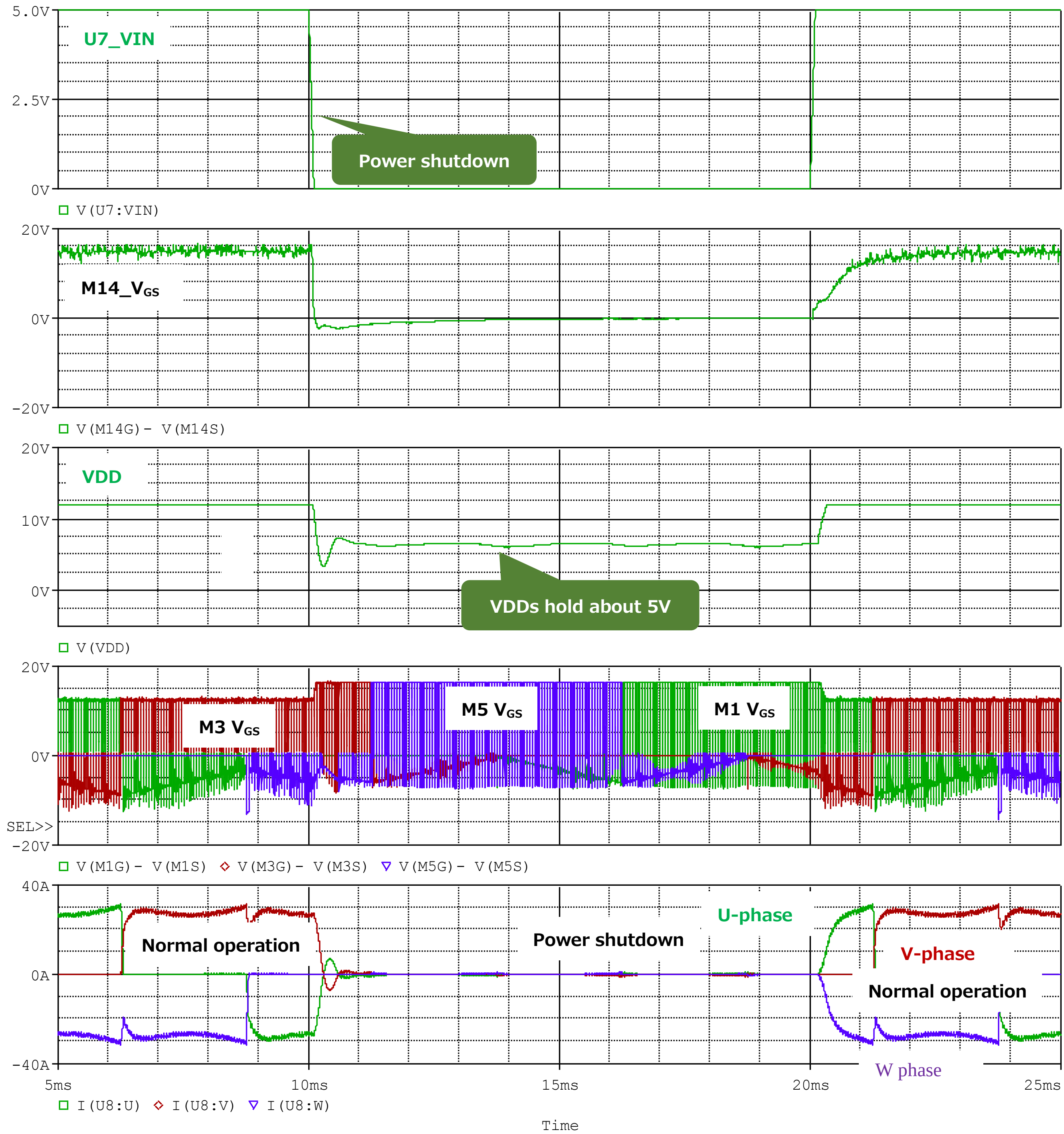


Fig. 4.3 Simulation Waveform for Overcurrent Protection

4.2 Power Supply Reverse Connection Protection Function

Power supply reverse connection protection is a function that suppresses current to prevent damage to the control unit if the battery is accidentally connected in reverse. Fig. 4.4 shows the power supply reverse connection protection circuit. Of the two MOSFET arranged in series in Fig. 4.4, Q4 is MOSFET for protecting the power supply from reverse connection. Q4 must be kept off reliably when the power supply is reversed. IC4 (TPD7104AF) enables the power supply reverse-connection protection function by opening the SUB pin.

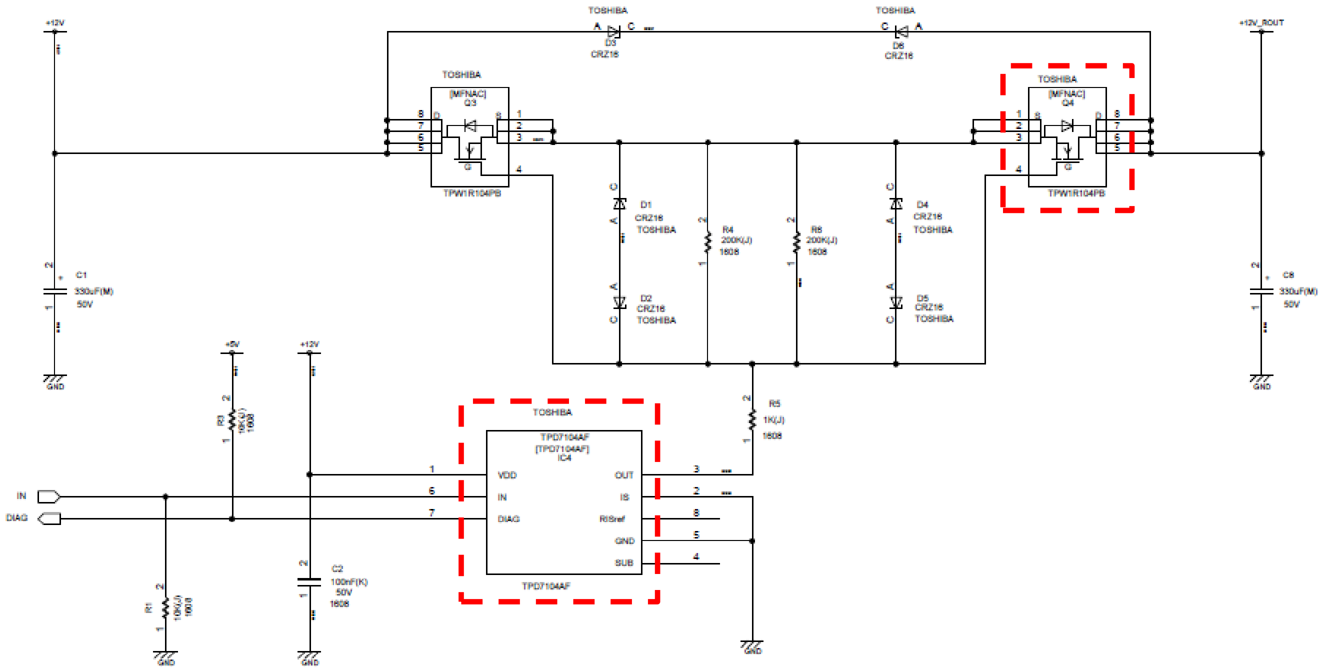


Fig. 4.4 Power Supply Reverse Connection Protection Circuit

4.2.1 Simulation Verification

Table 4.2 shows the simulation conditions and procedures, and Fig. 4.5 shows the simulation circuit. The power supply is reversed by setting VBB0 pin to-12 V. M15 V_{GS} and drain current are monitored. Fig. 4.6 shows the simulation waveform. It can be seen that the drain current M15_I_D is suppressed to several tens of μA and the inverse current is suppressed.

Table 4.2 Simulation Conditions and Procedures

1	VBB0	-12 V
2	U2	Outputs 120° conduction pattern

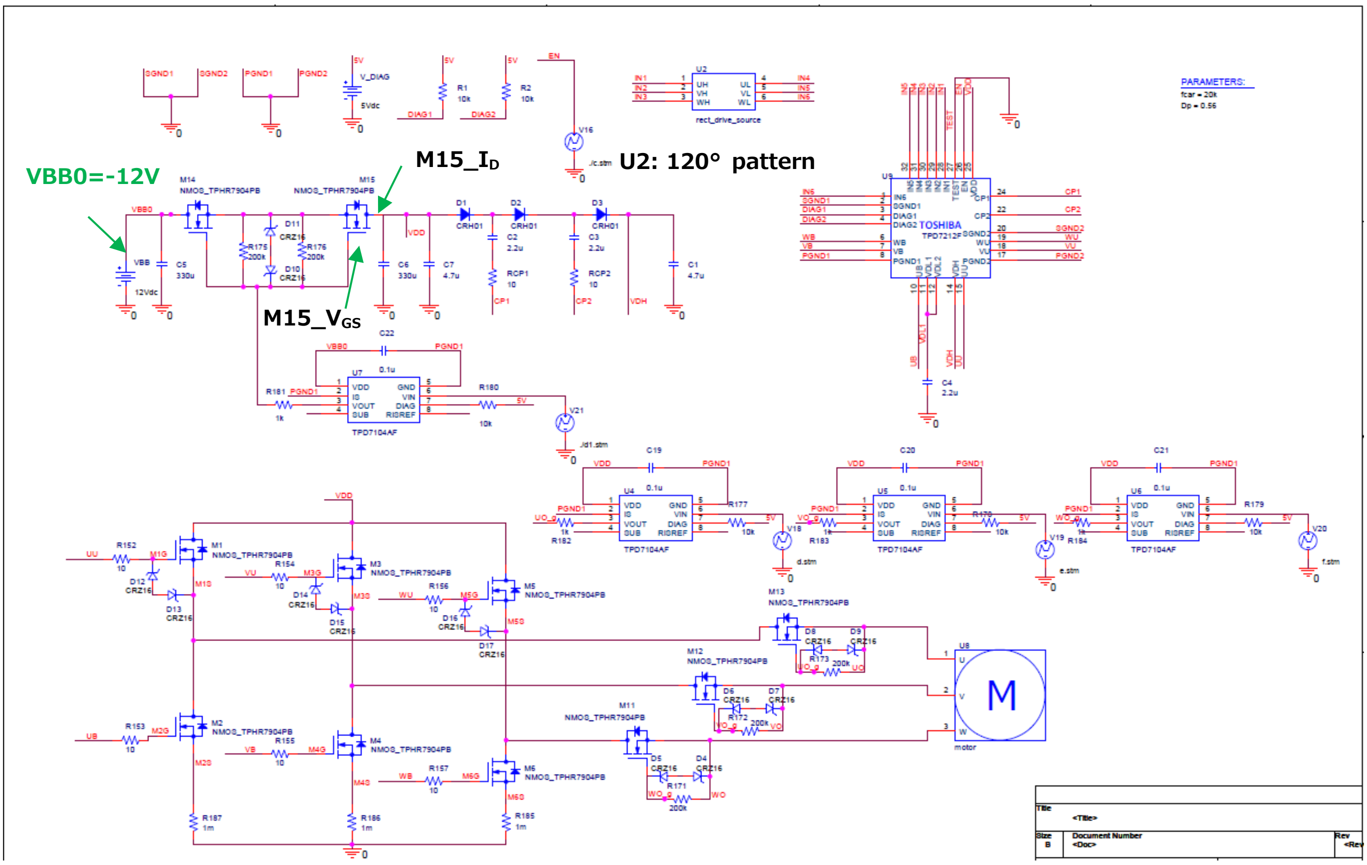


Fig. 4.5 Power Supply Reverse Connection Protection Simulation Circuit

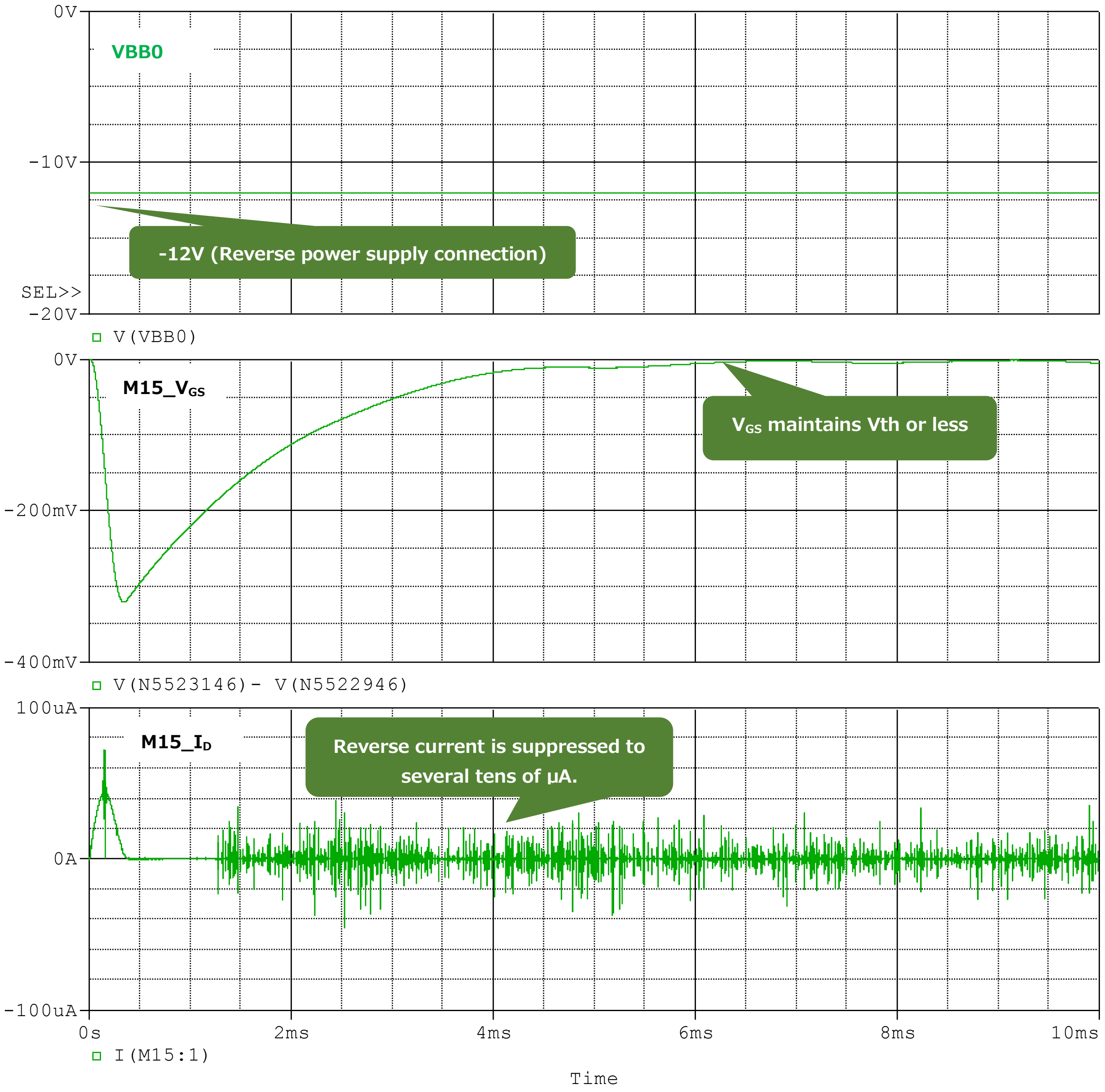


Fig. 4.6 Power Supply Reverse Connection Protection Simulation Waveform

4.3 Output Cutoff Function

In this circuit, the output cutoff function is realized by using IC6 (TPD7104AF). By inputting the signal from the controller to the IN of TPD7104AF as shown in Fig. 4.7, the output can be controlled by MOSFET connected to the OUT. If an error is detected on the controller, output cutoff control can be performed.

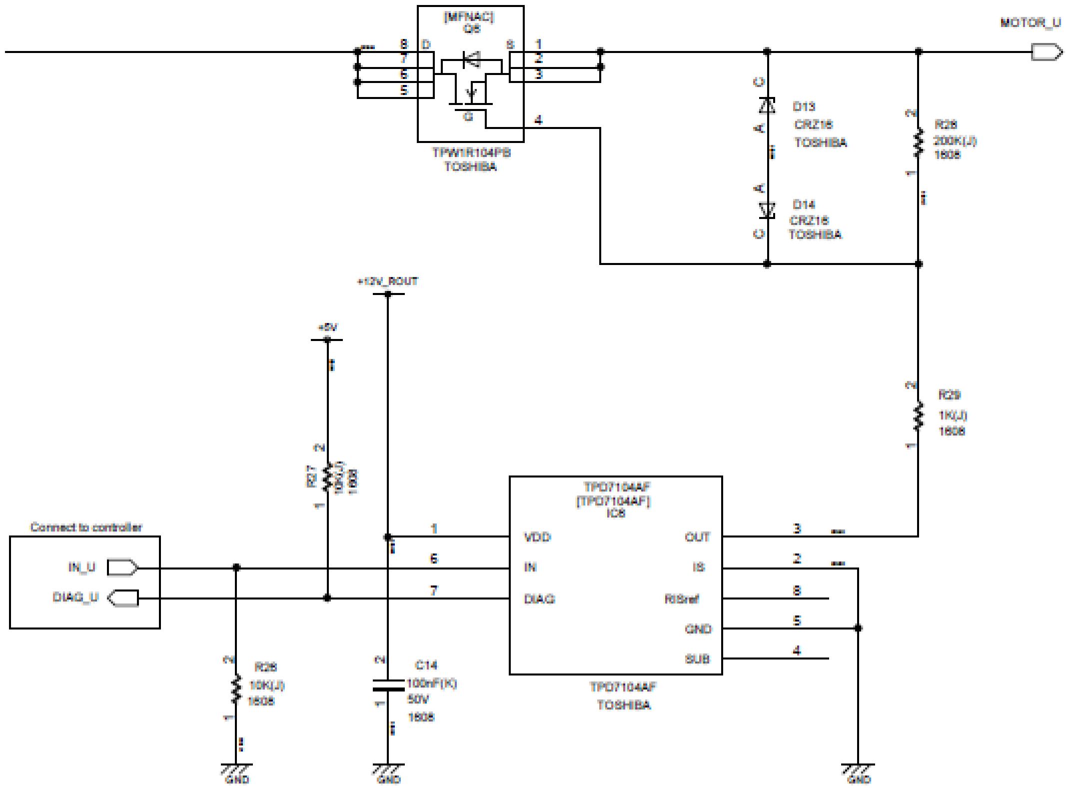


Fig. 4.7 Output Cutoff Circuit (U-phase)

※ Fig. 4.7 shows the U-phase as an example, but the V-phase and W-phase are the same.

4.3.1 Simulation Verification

The output cutoff function stops the output current of each phase of the motor. Table 4.3 shows the simulation conditions and procedures, and Fig. 4.8 shows the simulation circuit. Motor control for automotive electric power steering requires a function to disconnect the current path of each phase in order to avoid locking due to abnormal operation of the motor. Reproduce this behavior in a simulation. MOSFET and gate driver IC TPD7104AF are used to conduct and shut off the phase current of the 3-phase DC motor. To interrupt the phase current when an abnormal operation such as an overcurrent occurs, control the VIN pin of TPD7104AF.

Table 4.3 Simulation Conditions and Procedures

1	VBB0	12 V
2	V_DIAG	5 V
3	U7	H-state (on state)
4	U2	Outputs 120° conduction pattern
5	Start of simulation	
6	U5_VIN	L-state for 9 ms to 11 ms (M12 off)
7	U6_VIN	L-state for 14 ms to 16 ms (M11 off)
8	U4_VIN	L-state for 19 ms to 22 ms (M13 off)

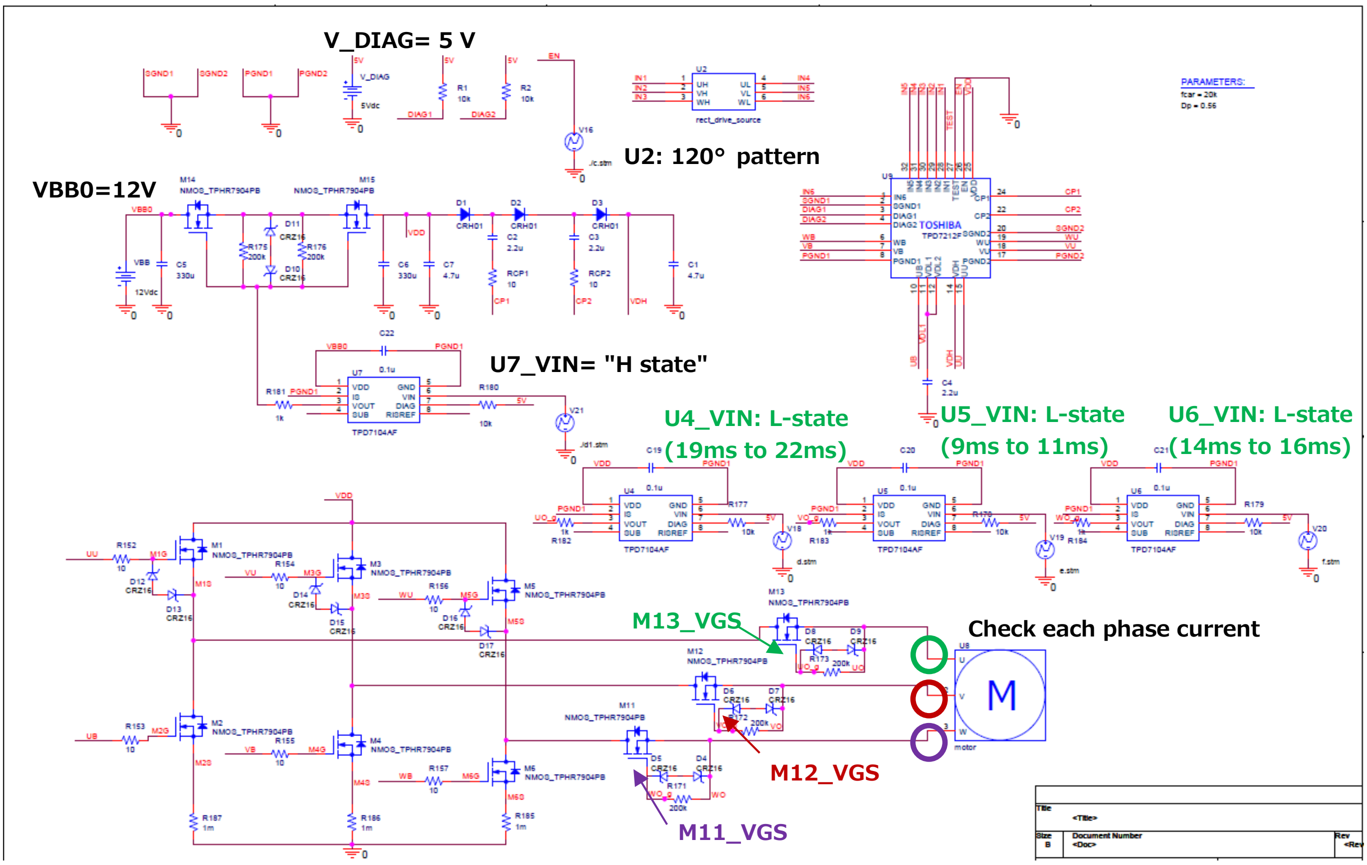


Fig. 4.8 Output cutoff Simulation Circuit

Fig. 4.9 shows the simulation waveform when the phase current is interrupted. The current of each phase is interrupted asynchronously during normal operation. It can be confirmed that the motor current is stopped by shutting off MOSFET (M11, M12, M13) connected to each phase. V_{GS} of MOSFET (M11, M12, M13) when each phase is energized is approximately 16 V. This means that it is clamped with a Zener diode CRZ16.

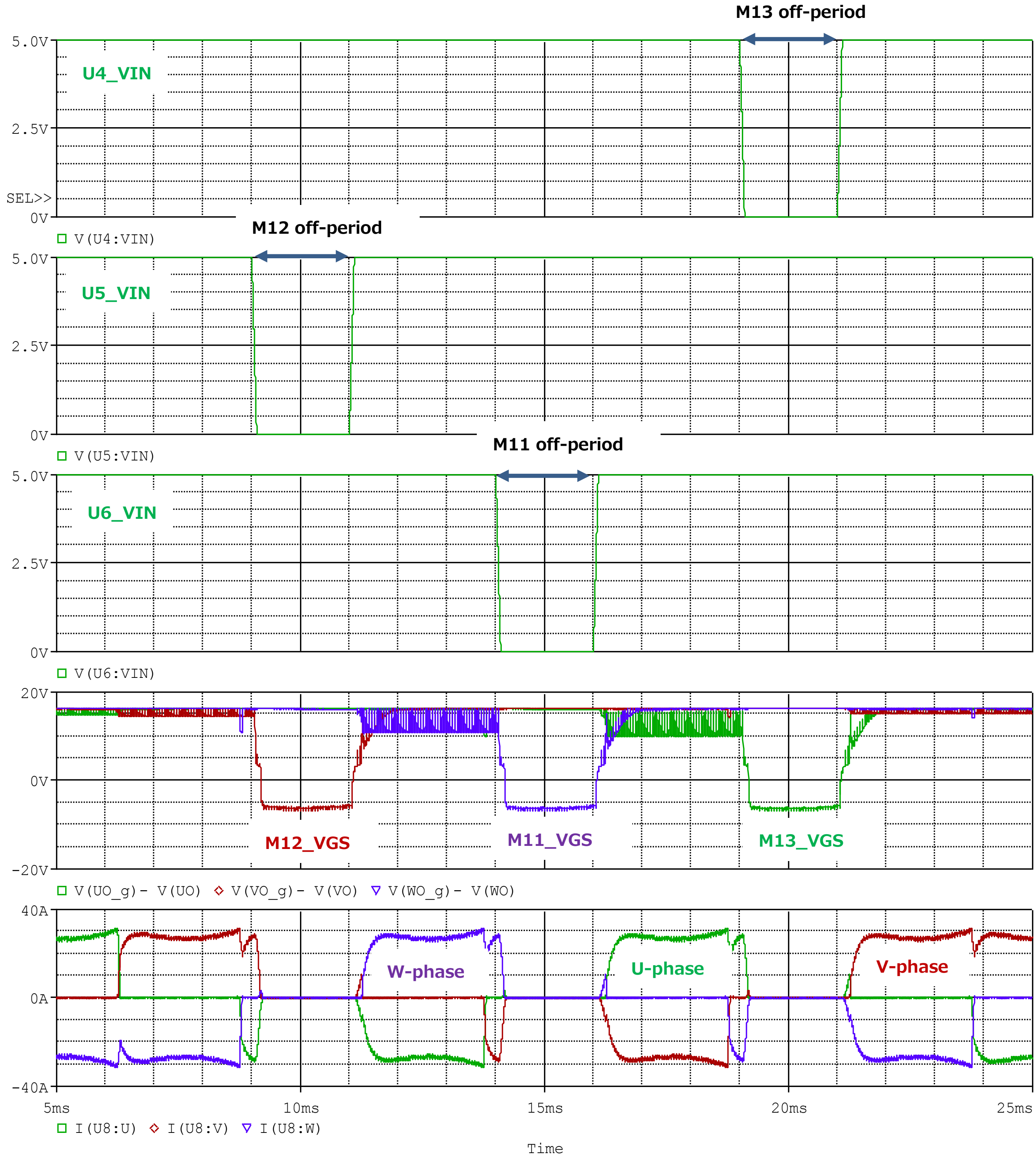


Fig. 4.9 Output cutoff Simulation Waveform

4.4 Current Detection Method (3-shunt current detection method)

Fig. 4.10 shows the current detection circuit for abnormal current detection. The U-phase current is detected by the voltages generated across the current detecting resistor (R25) located between the low-side MOSFET of the U-phase and GND.

In systems that support high currents, such as motor drivers, current sensing resistors generally use low-resistance current sensing resistors to minimize loss at the resistors. As a result, the signal generated by the current sensing resistor is very small (several tens of millivolts), making it difficult for the MCU to directly measure the signal. Therefore, the signal is amplified by an amplifier (IC1) and inputted to the MCU. In addition, since the current flowing through the 3-phase brushless motor is bidirectional, both positive and negative voltages are generated in the current detection resistor.

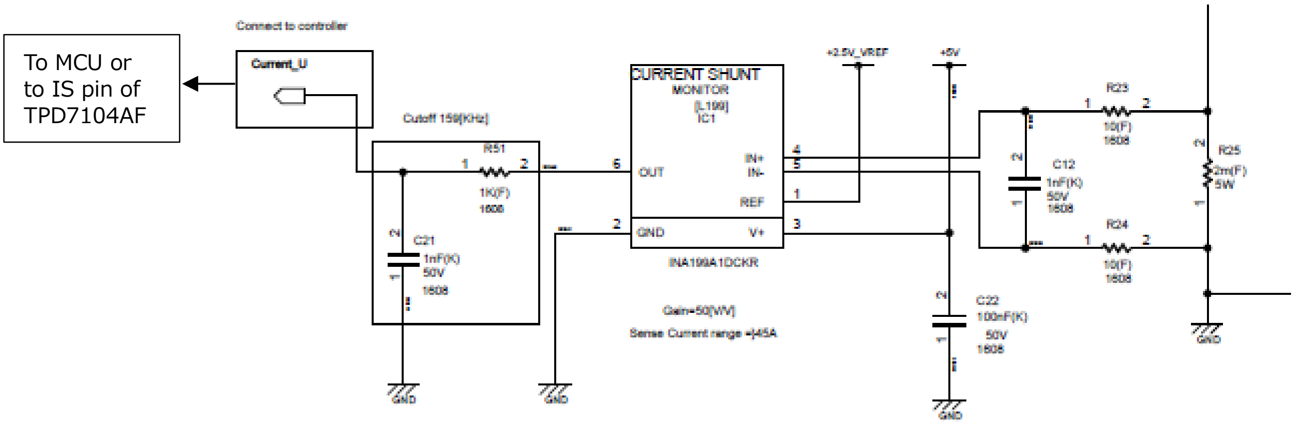


Fig. 4.10 Current detection circuit (U-phase)

※ Fig. 4.10 shows the U-phase as an example, but the V-phase and W-phase are the same.

Since the input signal to the MCU requires a positive voltage, an amplifier that can offset the output is used. For bi-directional current applications such as the drive circuit of a 3-phase brushless motor, offset the amplifier output so that the MCU can detect bi-directional current. When detecting a current with the same level in both directions, set the offset voltage to the center value of the input range of the ADC circuit on the MCU side. In this circuit, 2.5 V is applied to the offset pin (REF-pin) of IC1, assuming an input range of 5 V for the ADC of the MCU. Thus, when the load current is zero, the output of the amplifier circuit is 2.5 V of the offset voltage applied to the REF pin, and the ADC output range of the MCU is ±2.5 V with 2.5 V as the center value. The output of the amplifier circuit increases above VREF for a positive differential signal and decreases below VREF for a negative differential signal.

The following section describes the gain of the amplifier. In this circuit, the maximum detection current of the motor is set to ±45 A, allowing ±50 A to be measured at the full ADC range of the MCU, including the margin. Since the current detection resistance is 1 mΩ, a voltage of ±50 mV is generated at the maximum.

These considerations result in a gain of 2.5 V/50 mV = 50 V/V, so an amplifier with a gain of 50 V/V is used. Fig. 4.11 shows the relationship between the current flowing through the current detection resistor and the amplifier output voltage. Fig. 4.12 shows the 3-phase current waveform in the time axis and Fig. 4.13 shows a schematic diagram of the output waveform of the operational amplifier. Select a current detection resistor, amplifier, amplifier gain, or peripheral circuit according to the application requirements.

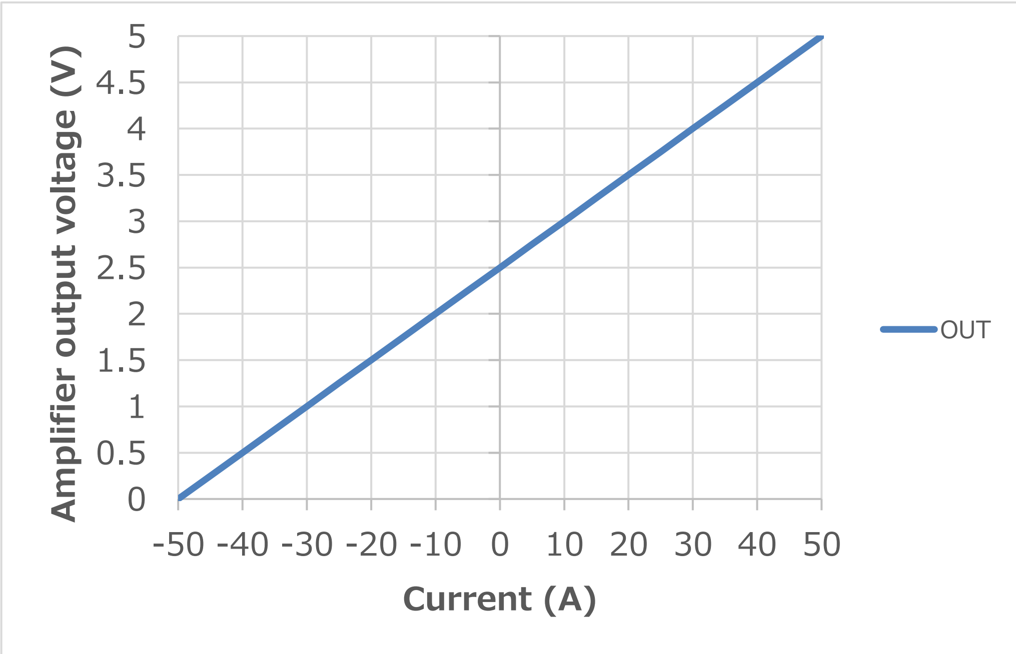


Fig. 4.11 Relationship between Current and Amplifier Output Voltage

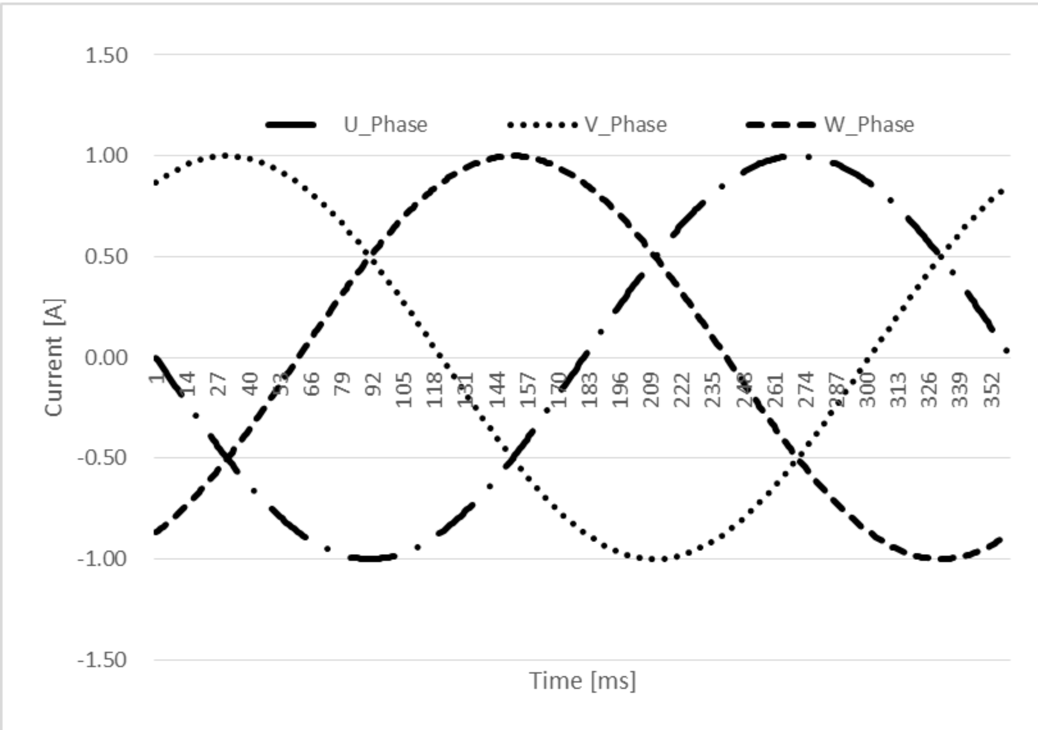


Fig. 4.12 3-phase Current Waveform Schematic Diagram

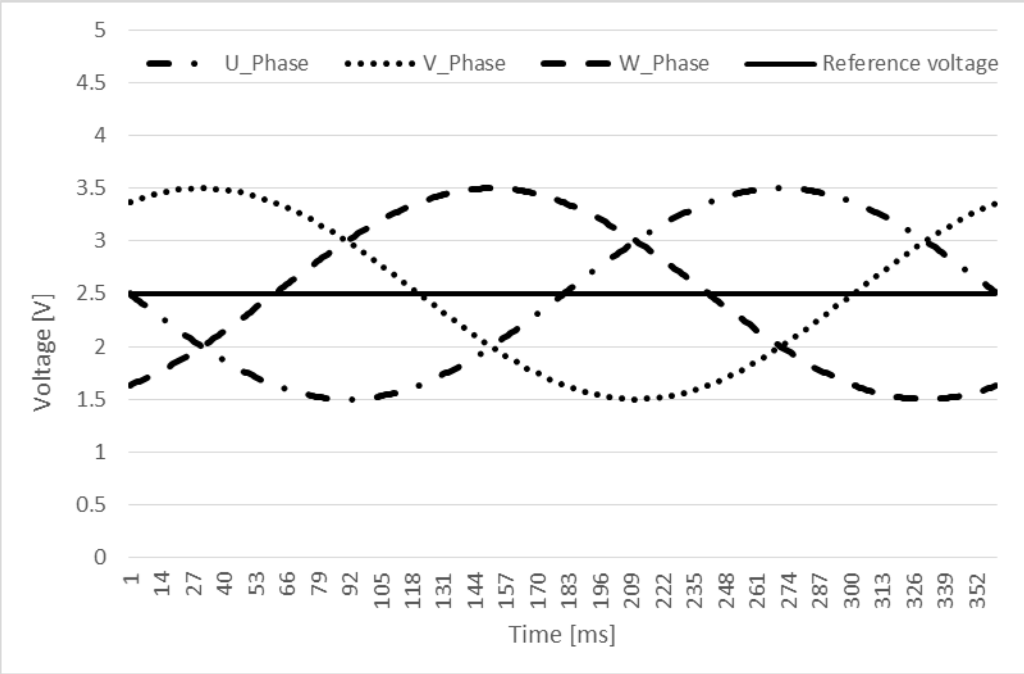


Fig. 4.13 Operational Amplifier Output Waveform Schematic Diagram

Note that the current detection signal has a small level and is susceptible to noise, so careful attention must be paid to the layout. The Kelvin connection shown in Fig. 4.14 is recommended.

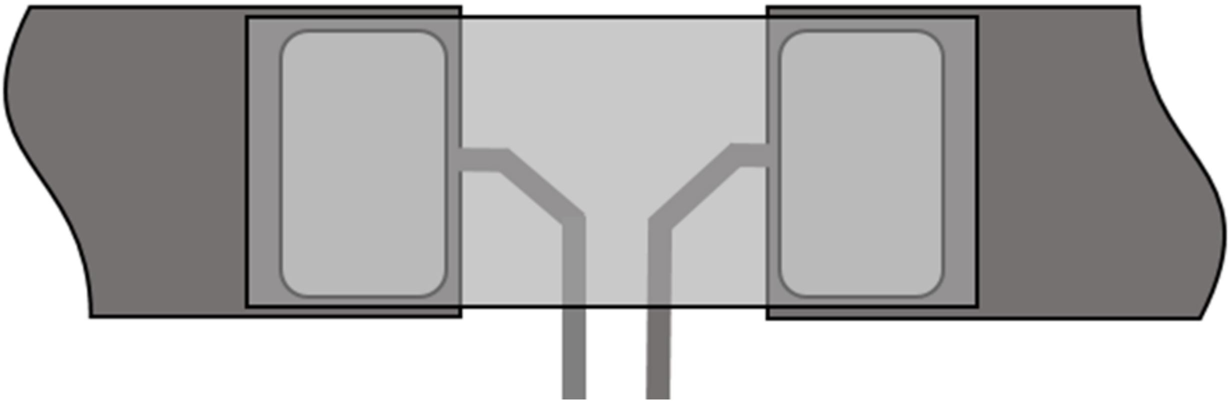


Fig. 4.14 Kelvin connection

4.5 Design of the Charge Pump Circuit

Fig. 4.15 shows the peripheral circuitry required to use TPD7212F charge pump circuitry.

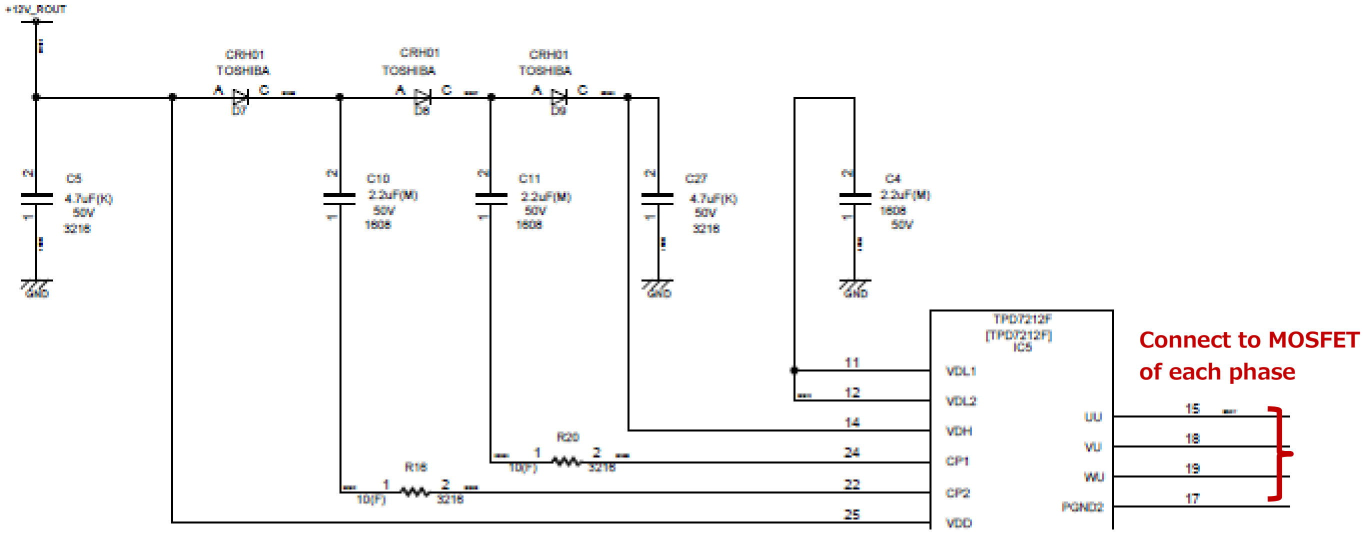


Fig. 4.15 Charge Pump Circuit

Commonly used as non-isolated high-side gate drivers are the bootstrap method or the charge pump method. The bootstrap method requires periodic recharging of the bootstrapped capacitor, so operation close to 100 % duty is not possible. Therefore, the bootstrap method cannot be used for systems requiring high-duty operation, such as systems with low input voltages and high loads.

TPD7212F employs a charge pump system capable of 100% duty operation, so it can also be used for systems requiring high duty.

The currents required for the charge pump circuit can be obtained from the driving MOSFET, VDD pin voltage of TPD7212F, power supply voltage, and drive frequency. Table 4.4. shows conditoins of this circuit.

Table 4.4 Required Conditions for Charge Pump Circuit

MOSFET	TPW1R104PB
VDD-pin voltage of TPD7212F	12 V
Power supply voltage	12 V
Drive Frequency (F_{SW})	20 kHz

The dynamic input/output characteristics of MOSFET (TPW1R104PB) shown in Fig. 4.16 calculate the amount of gate-input charges required to drive MOSFET 1 piece.

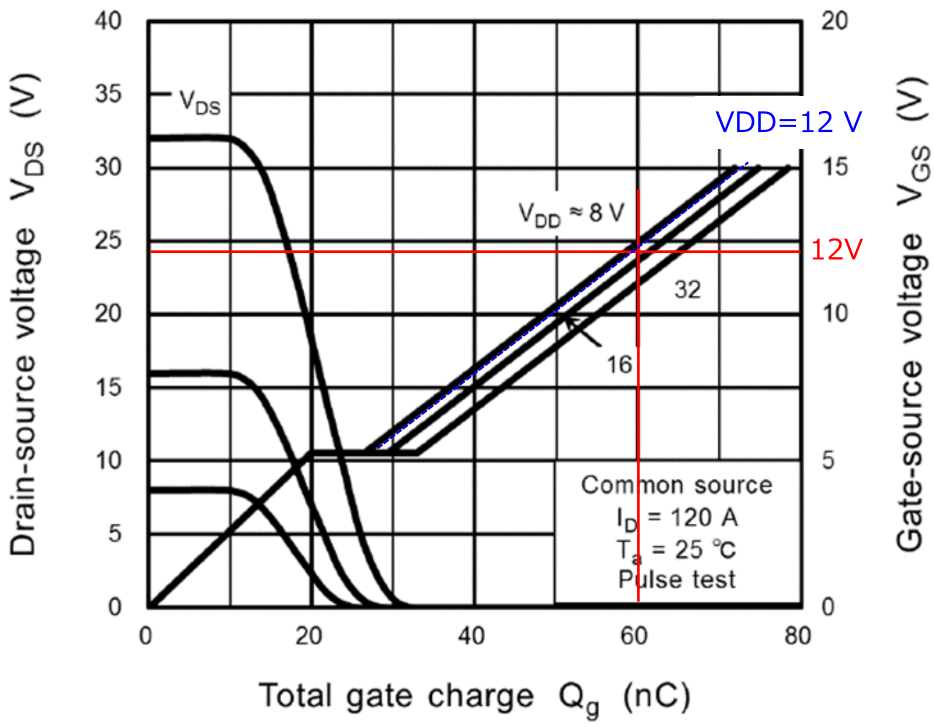


Fig. 4.16 TPW1R104PB Dynamic Input/Output Characteristics

As for the high-side MOSFET, VDD is the system power supply voltage (12 V) and V_{GS} is the gate drive voltage 12 V, the gate input charge is approximately 60 nC from the graph. In this circuit, the high-side MOSFET is driven at a drive frequency (F_{sw}) =20 kHz, so the output current of the charge pump circuit is calculated as follows.

$$I_{average} = Q_g \times F_{SW} = 60\ (nC) \times 20\ (kHz) = 1.2\ (mA)$$

TPD7212F also supplies low-side driver power by stepping down with an internal regulator from the charge pump. The number of channels that turn on per PWM 1cycle varies depending on the energization method. However, the 120° square-wave commutation method uses two channels, so the output current is approximately 2.4 (mA). Also, considering the effects of pull-down resistors and internal impedance of the IC, the capacitance value is estimated in the simulation environment described in the next section. If the external diode is also changed, it is recommended that the device model be changed for simulation.

4.5.1 Simulation Verification

In this section, the output characteristics of the charge pump circuit are verified by simulation.

Table 4.5 shows the simulation conditions and procedures, and Fig. 4.12 shows the simulation circuit.

Table 4.5 Simulation Conditions and Procedures

1	VBB0	12 V
2	V_DIAG	5 V
3	V15	0 V
4	I1	1m to 300mA (1ms span.)
5	C2,C3	0.1μF to 2.2μF

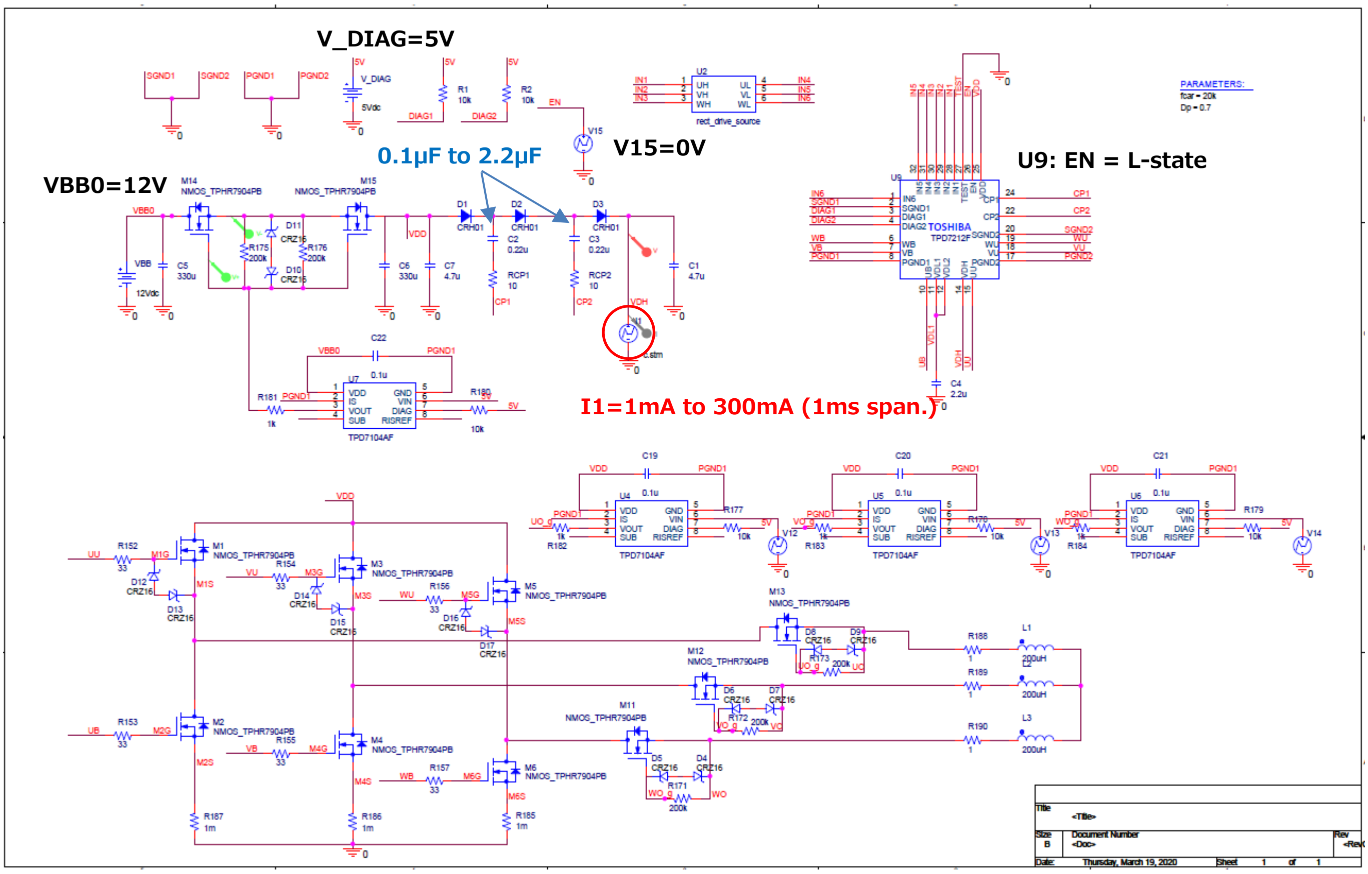


Fig. 4.17 Example of Charge Pump Output Characteristics Simulation Circuit

Fig. 4.17 shows an example of a simulation circuit for checking the charge pump output characteristics. Check that the boosted VDH pin voltage does not drop with respect to the load current caused by the external MOSFET calculated in the previous section. By setting V15 to 0V, the output of U9 is stopped, and only the charge pump circuit is operated. Connect the constant current source I1 and set so that the load current increases every 1ms. Since the charge pump includes an oscillation circuit, DC analysis cannot be performed. Therefore, the above simulation confirms the output characteristics in transient analysis. Fig. 4.18 shows the simulation results. Depending on the characteristics of MOSFET, generally a V_{GS} of at least 10V is required. Therefore, the region where the VDH pin voltage is 22V or less becomes an unstable region where the bias is applied. This result also shows that the output characteristics change depending on the charge pump capacities C2 and C3. It is possible to estimate the capacity value that can be selected from this result. However, environmental temperatures, power supply voltage conditions, and characteristics of peripheral components such as diodes will also be affected, so please check the actual measurement in the end. In this circuit, 2.2μF is selected in consideration of sufficient margin for design.

In addition, caution must be exercised with respect to the withstand voltage of the capacitor because a voltage of 12 V higher than the input voltage is normally applied to the capacitor of the charge pump circuit of TPD7212F. In this circuit, the voltage at the VDH pin is boosted to 24 V with respect to the input voltage of 12 V, so a 50 V withstand voltage product is selected.

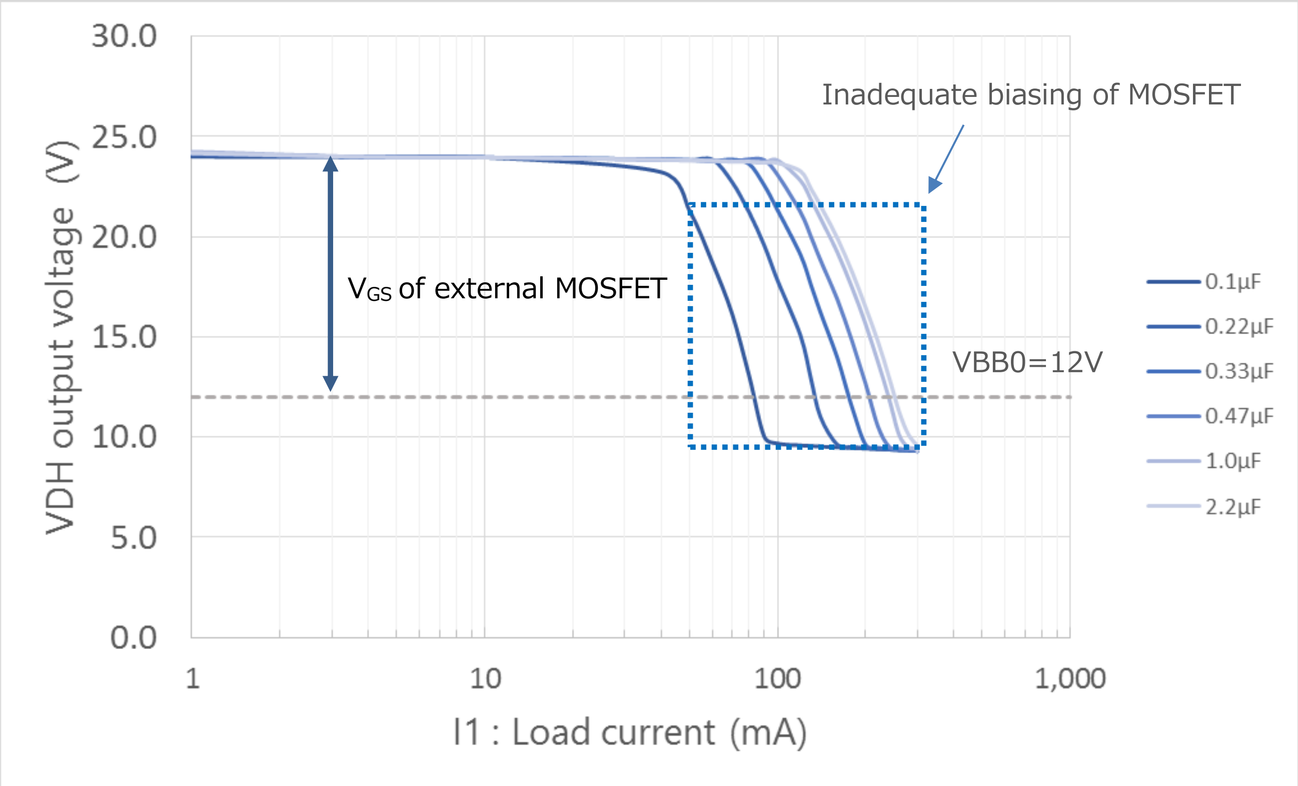


Fig. 4.18 Simulation Results of Charge Pump Output Characteristics

4.6 Surge Protection Function

In this circuit, the Zener diodes D3 and D6 (CMZ27) shown in Fig. 4.1 are inserted to provide a protection function for clamping when surge voltages of 27 V (Typ.) or more are generated, such as road dump surges for vehicles. The clamping voltage must not exceed the withstand voltage of MOSFET and gate driver ICs.

Download CMZ27 data sheet from here → Click Here

In Section 5, the protection functions of TPD7212F are simulated and verified.

5. Simulation (TPD7212F protection functions)

In this chapter, various protection functions built in the TPD7212F are confirmed by simulation.

Actual Simulation circuit (RD176-SPICE-01) is here, → Click Here

5.1 Output-Voltage Monitoring Function

Output-voltage monitoring is a protection function built into TPD7212F. Table 5.1 shows the simulation conditions and procedures, and Fig. 5.1 shows the simulation circuit. This function monitors that the output pins operate normally and that biasing is properly applied to the gate pins of MOSFETs constituting the inverter. Using output pins UU and UB as examples, forcibly reproduce a short to power and a short to ground, and confirm that the protection function is working by simulation.

Table 5.1 Simulation Conditions and Procedures

1	VBB0	12 V
2	V_DIAG	5 V
3	U2	Outputs 120° conduction pattern
4	VIN @ U4～U7	H-state
5	Start of simulation	
6	UU - VDD	Short period from 30 ms to 31 ms
7	EN	Reset at 32 ms
8	UU - GND	Short period between 34 ms and 35 ms
9	EN	Reset at 36 ms
10	UB - VDD	Short period between 38 ms and 39 ms
11	EN	Reset at 40 ms
12	UB - GND	Short period between 42 ms and 43 ms
13	EN	Reset at 44 ms

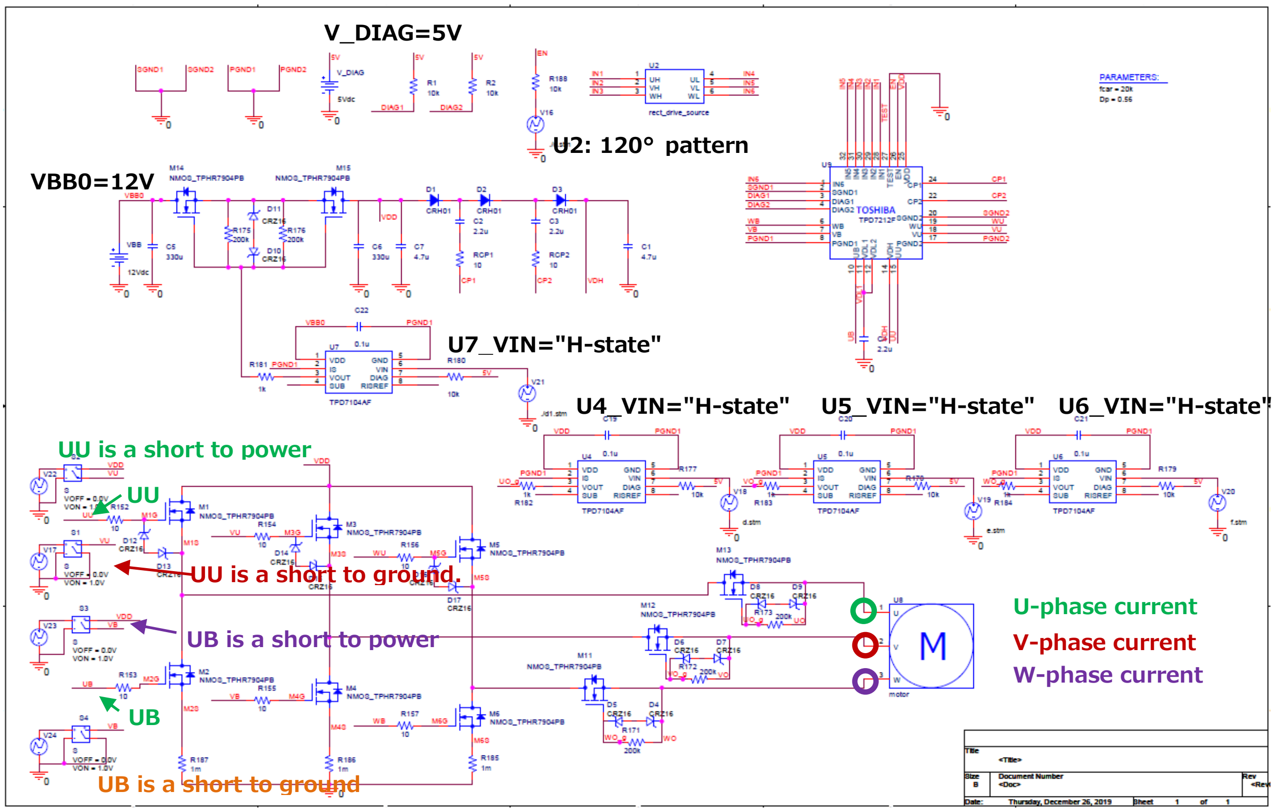


Fig. 5.1 Simulation Circuit

Fig. 5.2 shows the simulation waveform. It can be seen that the UU pin and VDD are short-circuited when the UU is a short to power state. Since the UU pin is in the L-state due to the IC internal resistance (5 kΩ), no output current is generated. Since all six output pins are in the L-state due to the internal resistor of the IC, all MOSFET of the inverter are turned off. Therefore, you can see that each phase current of the motor is stopped. Since the latch-off state is selected, the EN pin is used to perform a reset. When the latch is released at the EN pin, the IC returns to normal operation. In the operating conditions when UU is a short to ground, UB is a short to power, and UB is a short to ground all outputs are cut off, and reset is performed at the EN pin similarly.

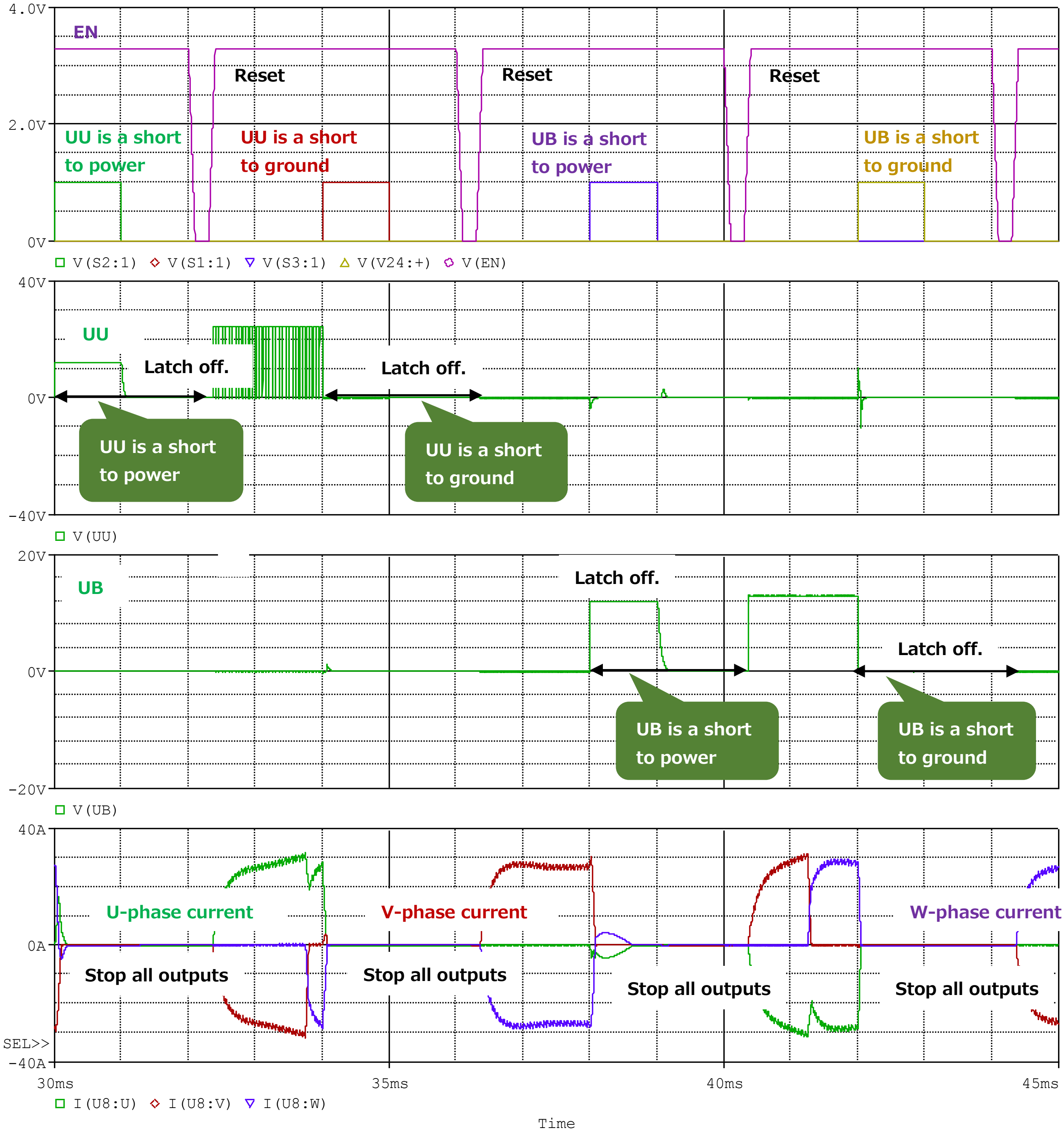


Fig. 5.2 Simulation Results for Output Voltage Error

5.2 VDH pin Output Undervoltage Detection

The VDH pin is a boost voltage source output from the charge pump circuit. Table 5.2 shows the simulation conditions and procedures, and Fig. 5.3 shows the simulation circuit. Used as a power supply for the driver circuit. TPD7212F has a built-in function to detect low-voltage on the VDH pin. If the VDH pin voltage drops due to an increase in the output current load or an abnormal operation such as a short to ground, an error is judged, and "H" is output from the diagnostic output DIAG2.

Table 5.2 Simulation Conditions and Procedures

1	VBB0	12 V
2	V_DIAG	5 V
3	U2	Outputs 120° conduction pattern
4	VIN @ U4～U7	H-state (continuity state)
5	Start of simulation	
6	VDH	Varies from 24 V to 16 V
7	VDL	12 V

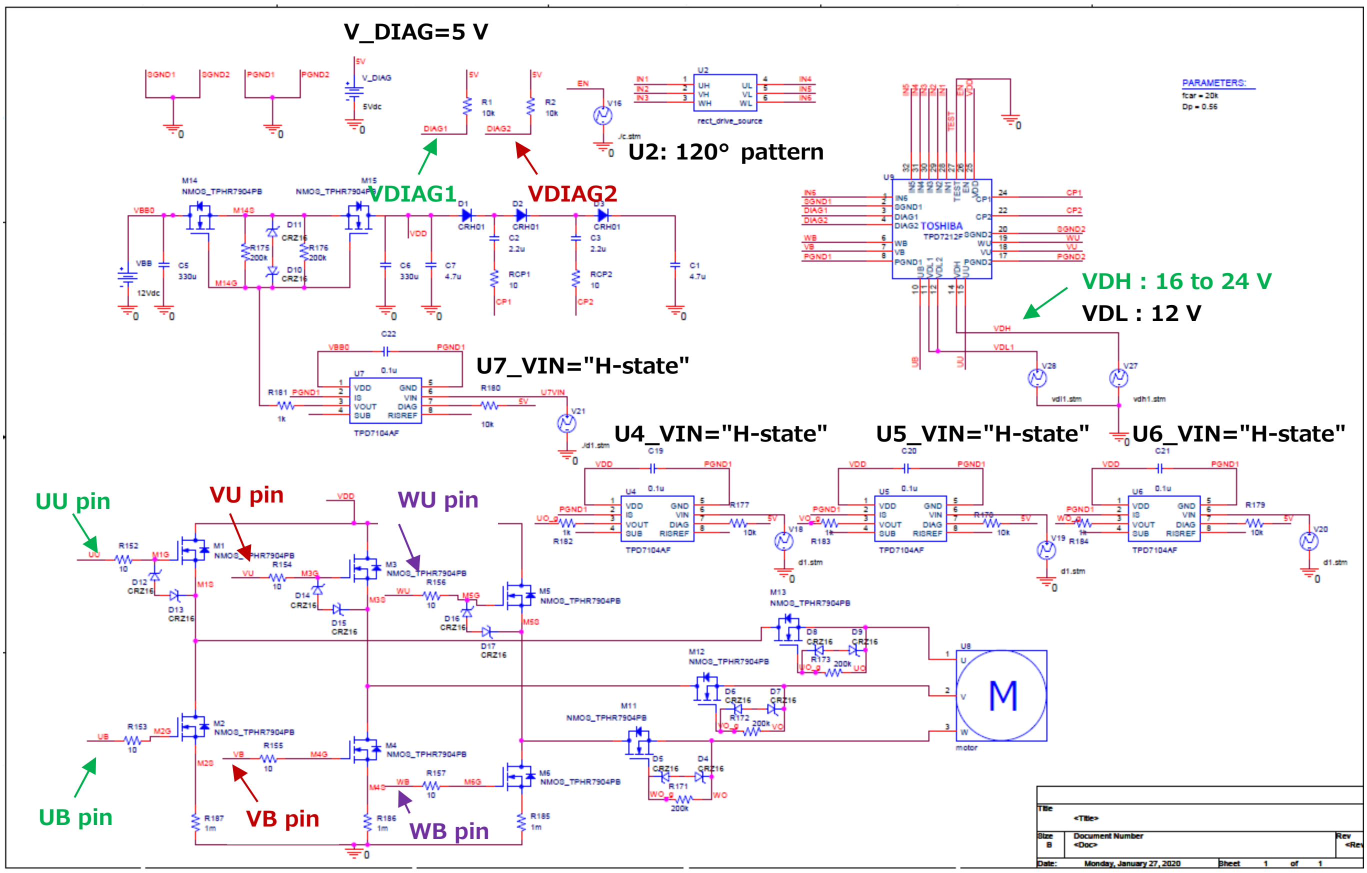


Fig. 5.3 Simulation Circuit

Fig. 5.4 shows the simulation waveform. By forcibly lowering the VDH pin to approximately 16 V, a VDH pin voltage drop is detected and it can be confirmed that VDIAG2 has transitioned to the H-state. In addition, when the voltage is increased from 16 V to 24 V, it can be confirmed that VDIAG2 has transitioned to the L-state indicating the normaL-state.

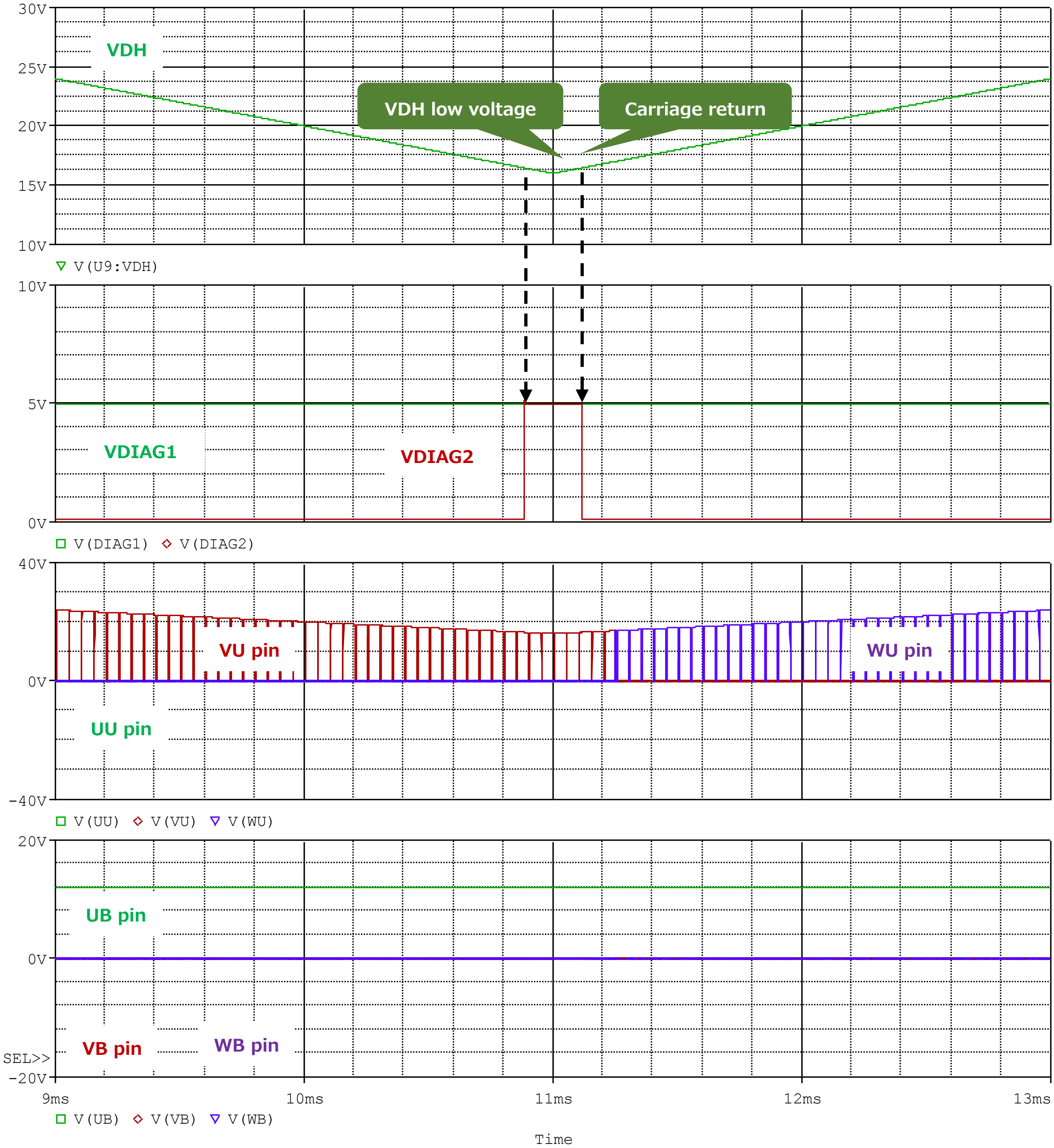


Fig. 5.4 Resulting of Simulated VDH pin Output Low Voltage

5.3 VDL pin Output Overvoltage Detection

The VDL pin outputs the voltage of the internal power supply of the low-side driver (UB, VB, WB). Table 5.3 shows the simulation conditions and procedures, and Fig. 5.5 shows the simulation circuit.

If the VDL pin voltage rises due to an external factor, an overvoltage can be applied to the gate-source voltage of the MOSFET in the inverter section. TPD7212F has a built-in function to determine the overvoltage of the VDL pin and to stop the low-side output.

Table 5.3 Simulation Conditions and Procedures

1	VBB0	12 V
2	V_DIAG	5 V
3	U2	Outputs 120° conduction pattern
4	VIN @ U4～U7	H-state (continuity state)
5	Start of simulation	
6	VDH	24 V
7	VDL	Varies from 4 V to 20 V

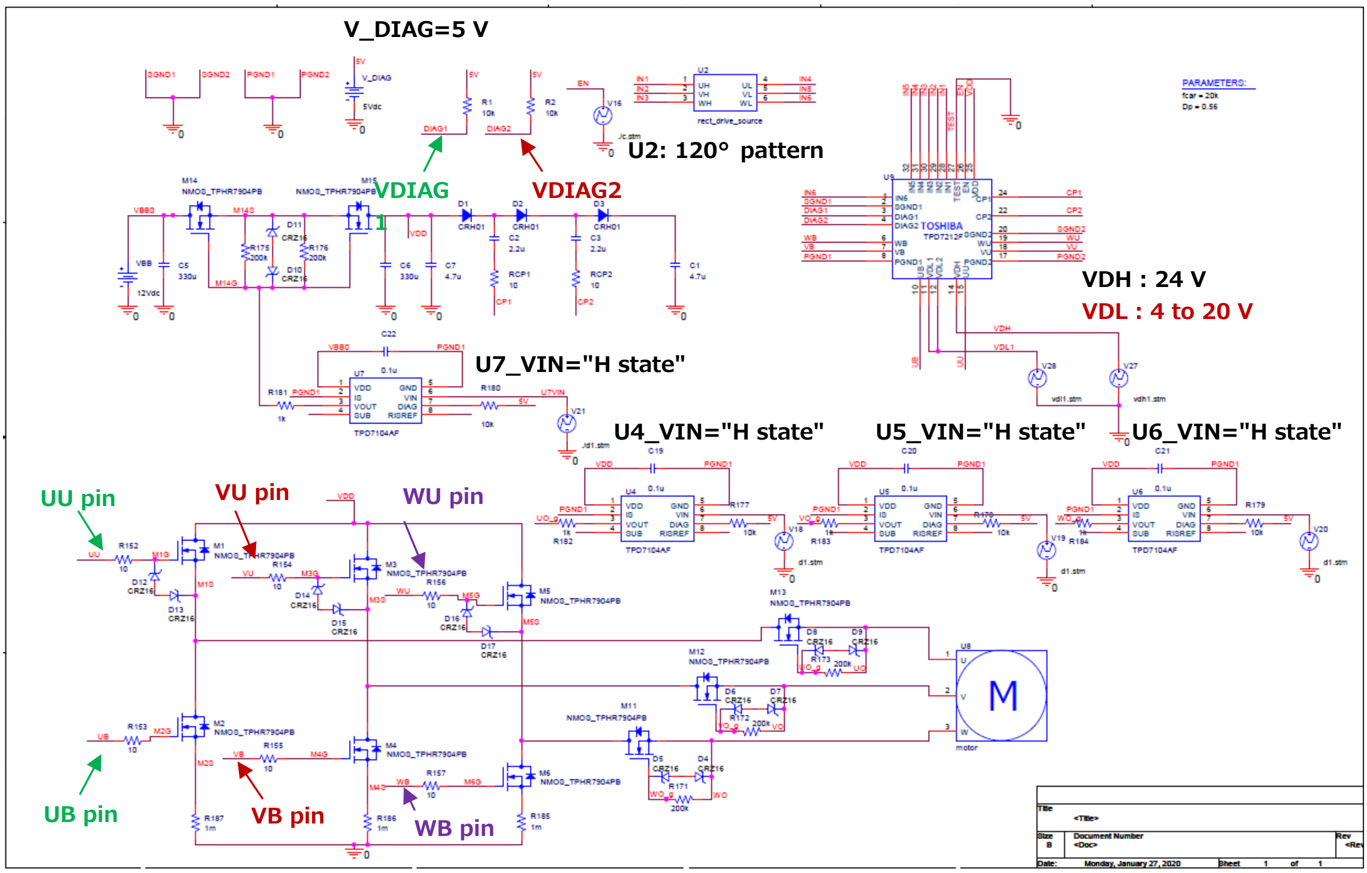


Fig. 5.5 Simulation Circuit

Fig. 5.6 shows the simulation waveform. When the VDL pin becomes overvoltage, VDIAG2 becomes H state and it can be seen that the output pin is stopped. When the voltage recovers normally, the diagnostic output VDIAG2 is in the L-state.

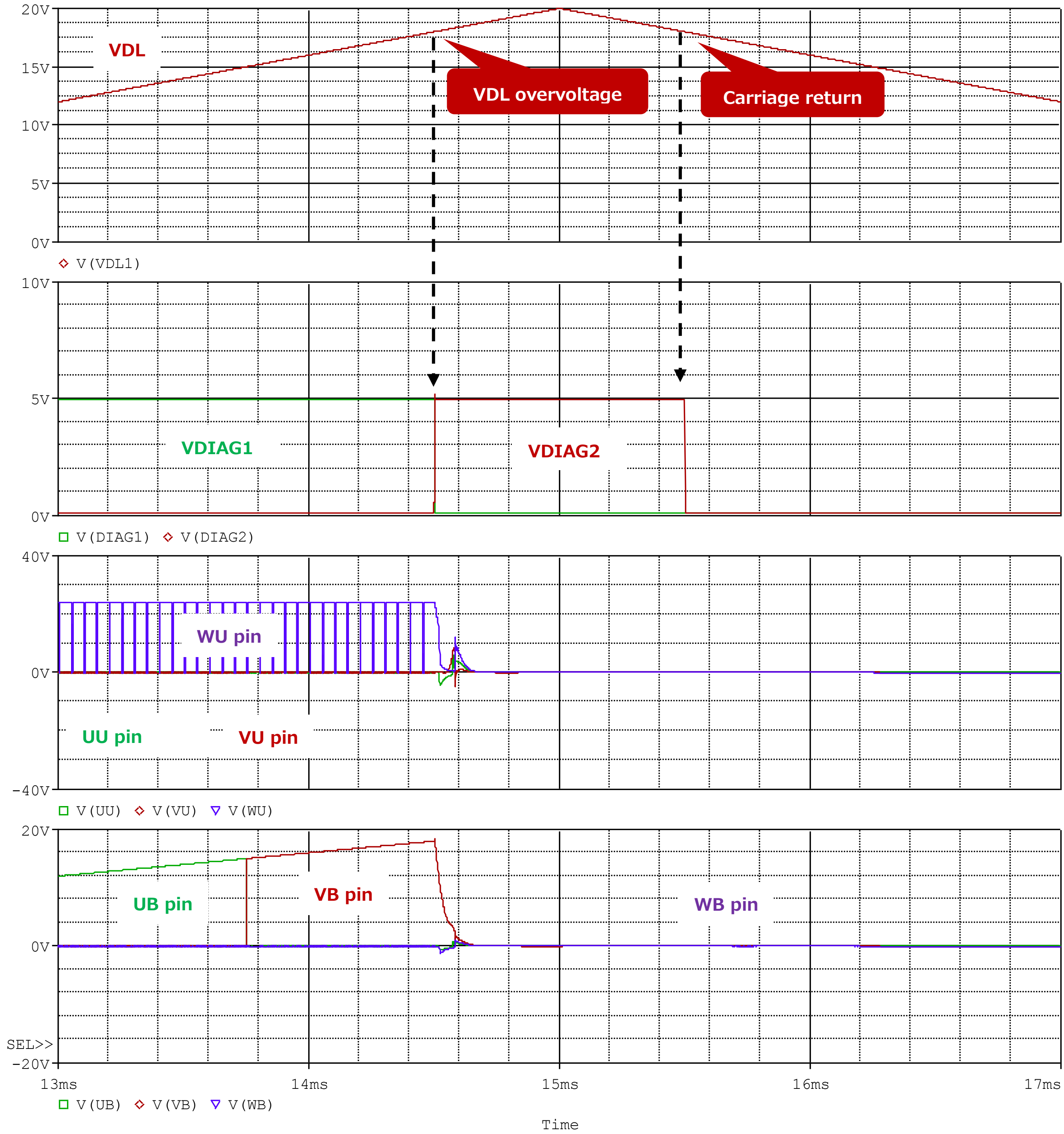


Fig. 5.6 Simulation Results for VDL Pin Overvoltage

5.4 VDL pin Undervoltage Detection

The VDL pin outputs the voltage of the internal power supply of the low-side driver (UB, VB, WB). Table 5.4 shows the simulation conditions and procedures, and Fig. 5.7 shows the simulation circuit.

TPD7212F has a built-in low-voltage detection function to detect underdriving of MOSFET when the voltage of the VDL pin drops. When the VDL pin becomes undervoltage, the diagnostic output VDIAG2 is in the H-state. The output pin continues operation without stopping. When the VDL pin voltage returns to normal, VDIAG2 transitions to the L-state.

Table 5.4 Simulation Conditions and Procedures

1	VBB0	12 V
2	V_DIAG	5 V
3	U2	Outputs 120° conduction pattern
4	VIN @ U4～U7	H-state (continuity state)
5	Start of simulation	
6	VDH	24 V
7	VDL	Varies from 12 V to 4 V

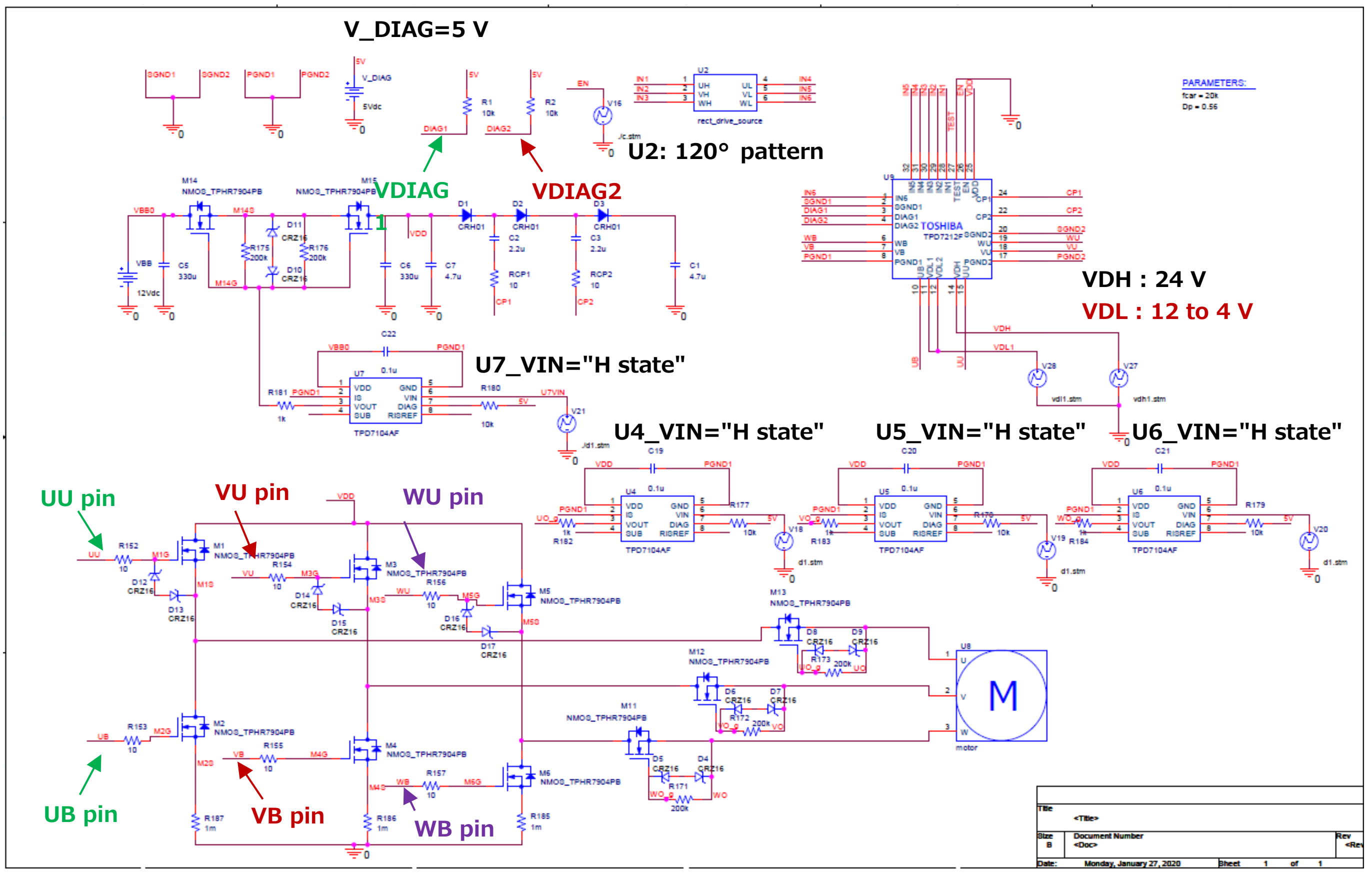


Fig. 5.7 Simulation Circuit

Fig. 5.8 shows the simulation waveform. When VDL becomes undervoltage, VDIAG2 enters the H-state. However, the output pin does not stop and operation continues. When the VDL pin voltage recovers normally, the diagnostic output VDIAG2 is in the L-state.

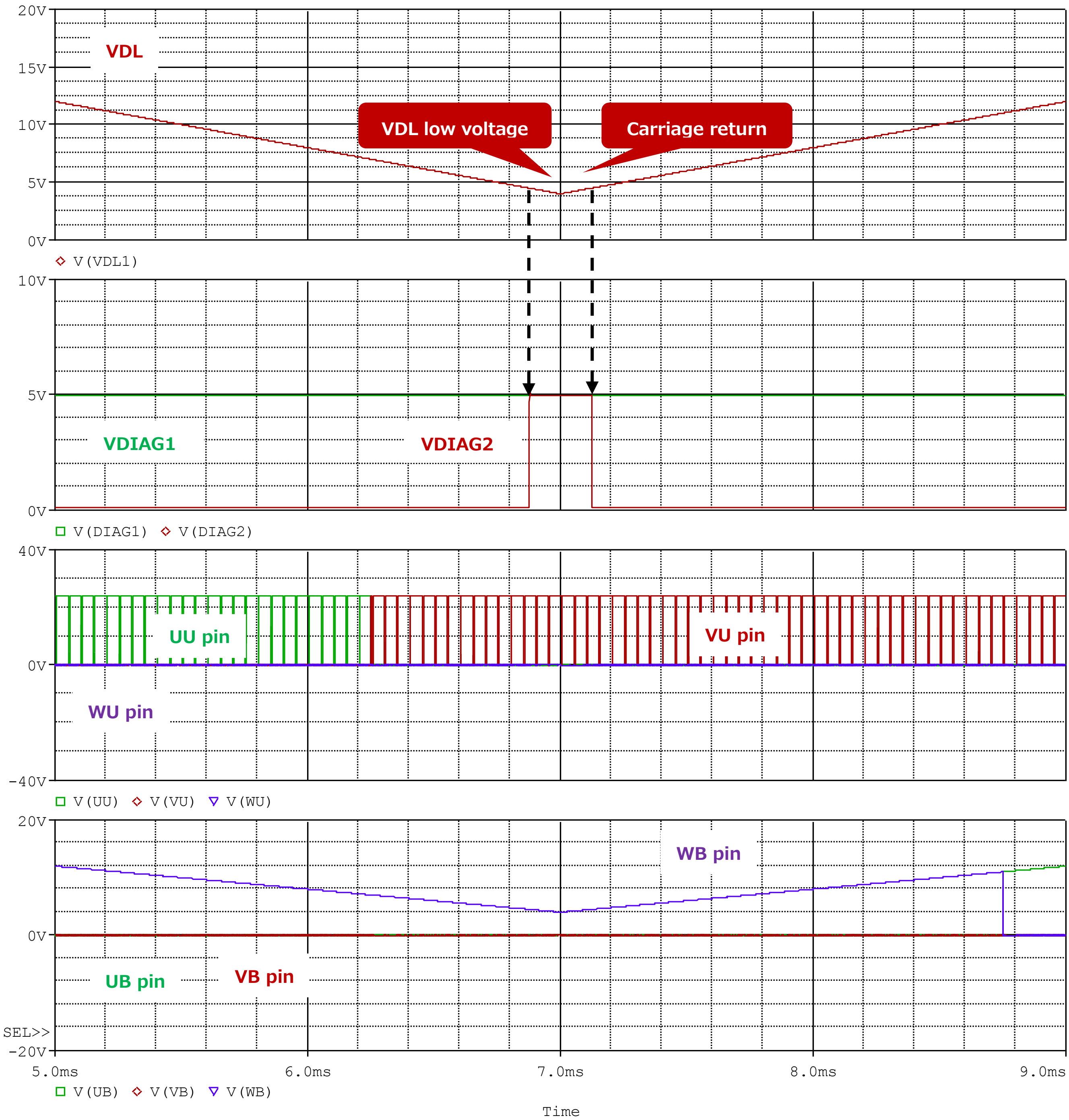


Fig. 5.8 Simulation Results for VDL Pin Undervoltage

6. Product Overview

6.1 TPD7212F/FN

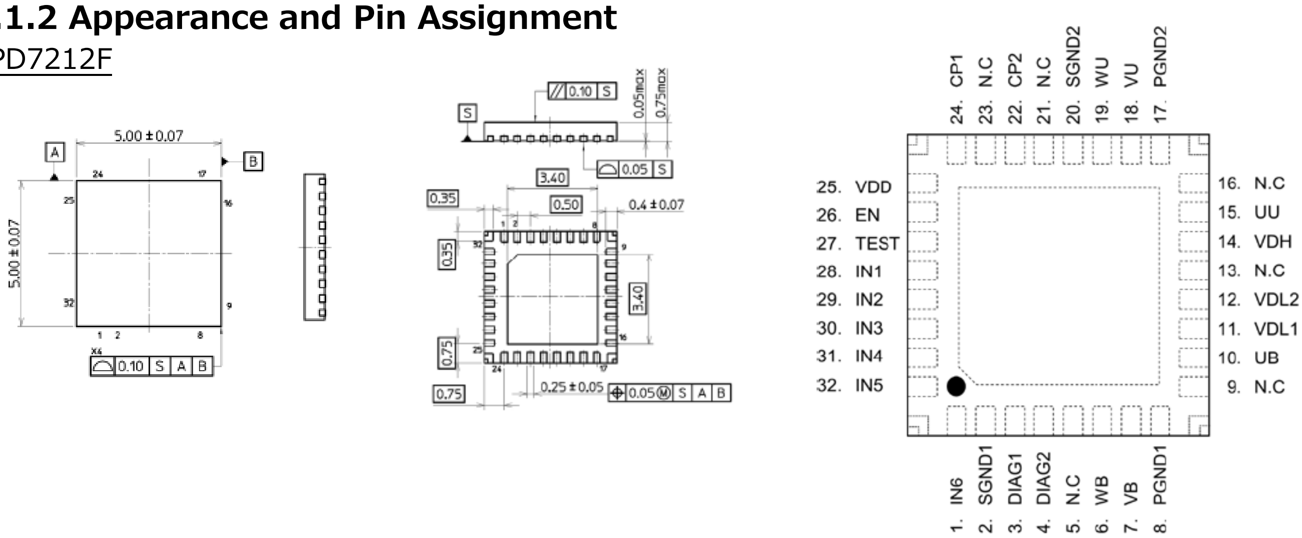
6.1.1 Overview

TPD7212F/FN is a power MOSFET gate driver for 3-phase full-bridge circuit with the charge-pump method by the BiCD process. The built-in charge pump circuit for the high side drive makes it easy to configure a 3-phase full-bridge circuit. It can also be used as an H-bridge circuit for DC motors by making one of the 3 phases unused.

- AEC-Q100 qualified
- Power MOSFET gate drivers for 3-phase DC motors and H-bridge DC motors
- Built-in diagnostic output function for driver power supply voltage and output voltage
- Built-in charge pump circuit
- WQFN32 package: TPD7212F
- SSOP30 package: TPD7212FN

6.1.2 Appearance and Pin Assignment

TPD7212F



TPD7212FN

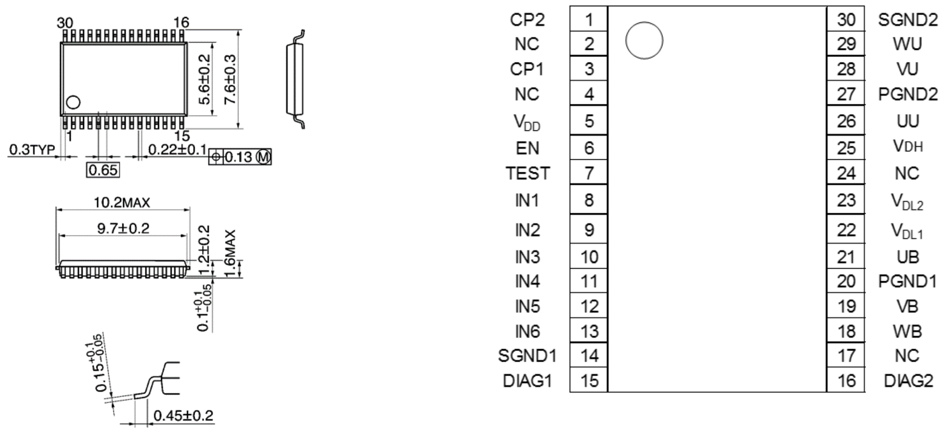


Figure 6.1 Appearance and Pin Assignment

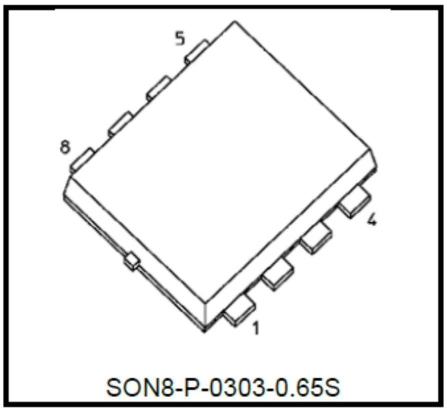
6.2 TPD7104AF

6.2.1 Overview

TPD7104AF is an N-channel power MOSFET gate driver for a 1channel output high-side switch. Built-in charge pump circuit allows easy configuration of high-side switches for high-current applications.

- AEC-Q100 qualified
- Built-in charge pump circuit
- Built-in load short-circuit (overcurrent) detection and power supply reverse connection protection function
- PS-8 package

6.2.2 Appearance and Pin Assignment



Weight: 0.017 g (Typ.)

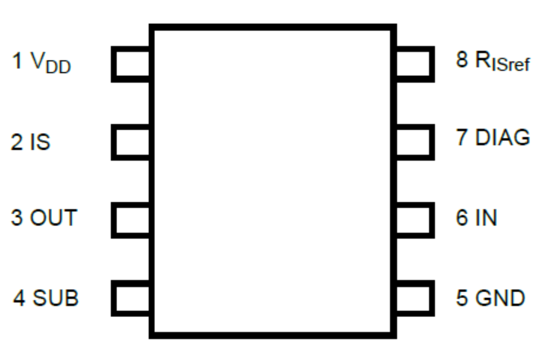


Fig. 6.2 Appearance and Pin Assignment

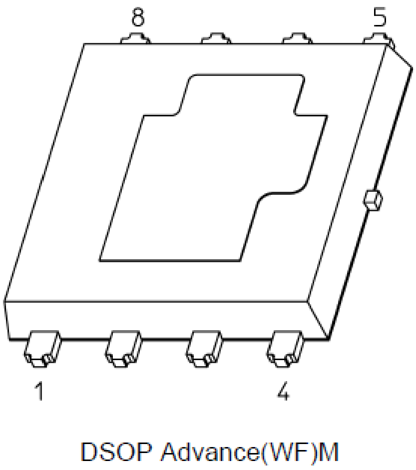
6.3 TPW1R104PB

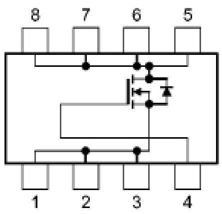
6.3.1 Overview

TPW1R104PB is fabricated with our latest low-voltage MOSFET processing U-MOSIX-H to achieve low on-resistance and high current rating.

- AEC-Q101 qualified
- Compact, thin and small mounting area
- Low on resistor: $R_{DS(ON)}$=0.95 mΩ (Typ.) (@V_{GS}=10 V)
- Lower leakage current: I_{DSS} = 10 μA (Max) (V_{DS} = 40 V)
- Easy-to-use enhancement types: V_{th} = 2.0-3.0 V (V_{DS} = 10 V, I_D = 0.5 mA)
- Maximum current rating :I_D=120 A (DC)
- Maximum voltage rating: V_{DSS} = 40 V

6.3.2 Appearance and Pin Assignment





1, 2, 3: Source
4: Gate
5, 6, 7, 8: Drain

Fig. 6.3 Appearance and Pin Assignment

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