Gate Drive Circuit
for SiC MOSFET Module

Reference Guide

RD237-RGUIDE-03

Toshiba Electronic Devices & Storage Corporation

Table of Contents

1. Introduction

This reference guide (hereafter referred to as this guide) describes the specifications and operation procedures of the Gate Drive Circuit for SiC MOSFET Module (hereafter referred to as this design).

SiC (Silicon Carbide) MOSFETs have been developed in recent years because they allow the reduction of on-resistance while maintaining a higher breakdown voltage compared to the conventional Si (Silicon) MOSFETs. Therefore, these are being evaluated and adopted more and more with the aim of improving inverter efficiency.

SiC MOSFET modules equipped with SiC MOSFET chips are used in power conversion in motor drives used in industrial applications and inverters for railroad cars contributing to a more efficient and compact industrial equipment.

This design uses the pre-driver TLP5231 that is capable of high-current gate drive by using external buffer MOSFETs and has various protection functions to achieve isolated gate drive for high-current and high-voltage SiC MOSFET modules.

This design is optimized for driving the gates of Toshiba's Dual SiC MOSFET modules (MG600Q2YMS3, MG400V2YMS3, MG250YD2YMS3). By using this design, the application circuit of the SiC MOSFET module can be configured.

It is equipped with two gate drive circuits to match the above-mentioned SiC MOSFET modules, and in addition it is miniaturized to the same size as that of the module so that it can be mounted directly on top of the module, therefore creating an excellent solution for suppressing parasitic inductance in wiring.

This design features a variety of the protection circuits, including DESAT (desaturation) detection function, active mirror clamp function, etc. In addition, each component can be adjusted according to the actual target specifications.

For more details about Toshiba's SiC MOSFET modules, kindly refer to their datasheets and other related documents.

When using a SiC MOSFET module other than the above-mentioned modules, each component needs to be adjusted. Refer to the datasheet and other related documents of TLP5231, the design guide of this reference design, etc. for adjusting each component.

When applying this design to an actual application, refer to the TLP5231 data sheet and design it to meet the safety standards to which the operating conditions and environment apply.

* Each Dual SiC MOSFET module has been tested under the following conditions.

MG600Q2YMS3: VDS ≦ 800V, ID ≦ 600A

MG400V2YMS3: VDS ≦ 1200V, ID ≦ 400A

MG250YD2YMS3: VDS ≦ 1200V, ID ≦ 250A

Image of this design attached directly to the Toshiba's Dual SiC MOSFET Module

2. Specifications

Table 2.1 lists the main specifications of this design.

Table 2.1 Specifications of the Gate Drive Circuit for SiC MOSFET Module

Item	Specifications
Power supply voltage for control	DC 24V
Number of driving channels	2 ch: Low side, High side
Gate control signal input	5V CMOS
Gate drive frequency	50kHz (Max.)
Enable signal input	5V CMOS
Gate drive output	+ 20V (Typ.) / -6.7V (Typ.)
Fault detection output	Collector output (2ch)
Temperature detection output	SiC MOSFET module Built-in NTC
Protection functions	Low gate-drive voltage detection (UVLO) Short-circuit proof (using DESAT detection) Self-Turn-On Protection (using Active Miller Clamp) (AMC)
Board size	62 x 100mm
Board layer configuration	FR-4 1.6mm thick 4 layers Copper foil thickness: outer layer 18µm, inner layer 35µm Double-sided silk, double-sided mounting

2.1. Block Diagram

Fig. 2.1 shows the block diagram of this design.

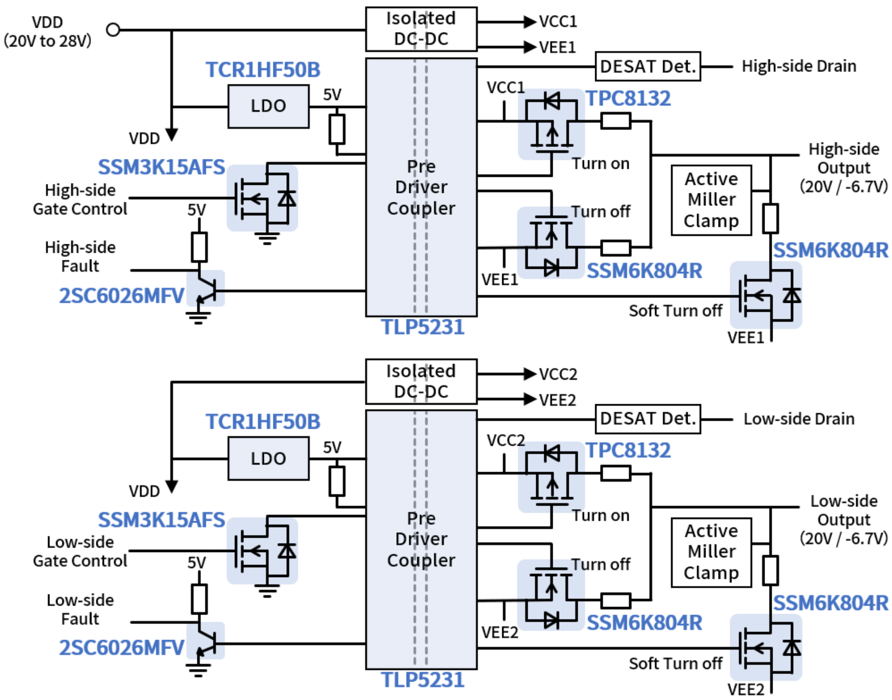


Fig. 2.1 Block Diagram of the Gate Drive Circuit for SiC MOSFET Module

2.2. Appearance and Component Layout

The appearance of this design is shown in Fig. 2.2 to 2.4, and the layout of main components is shown in Fig. 2.5 and 2.6.

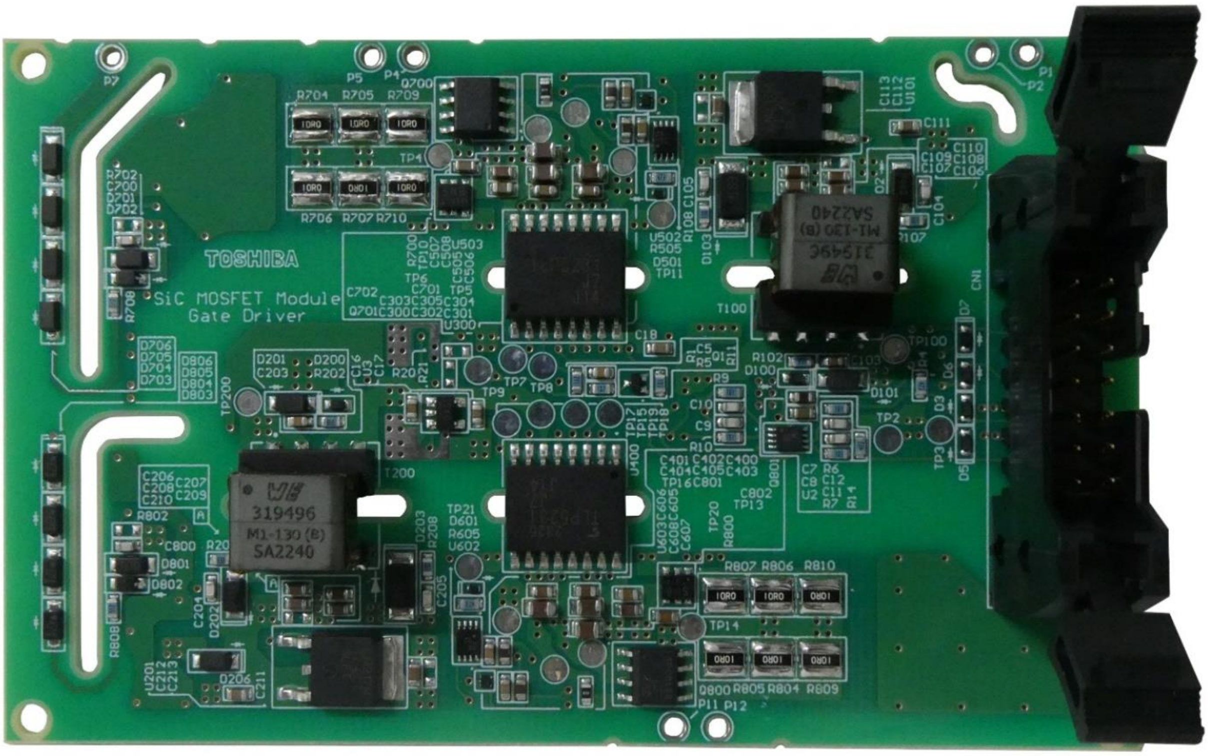


Fig. 2.2 Board (Front)

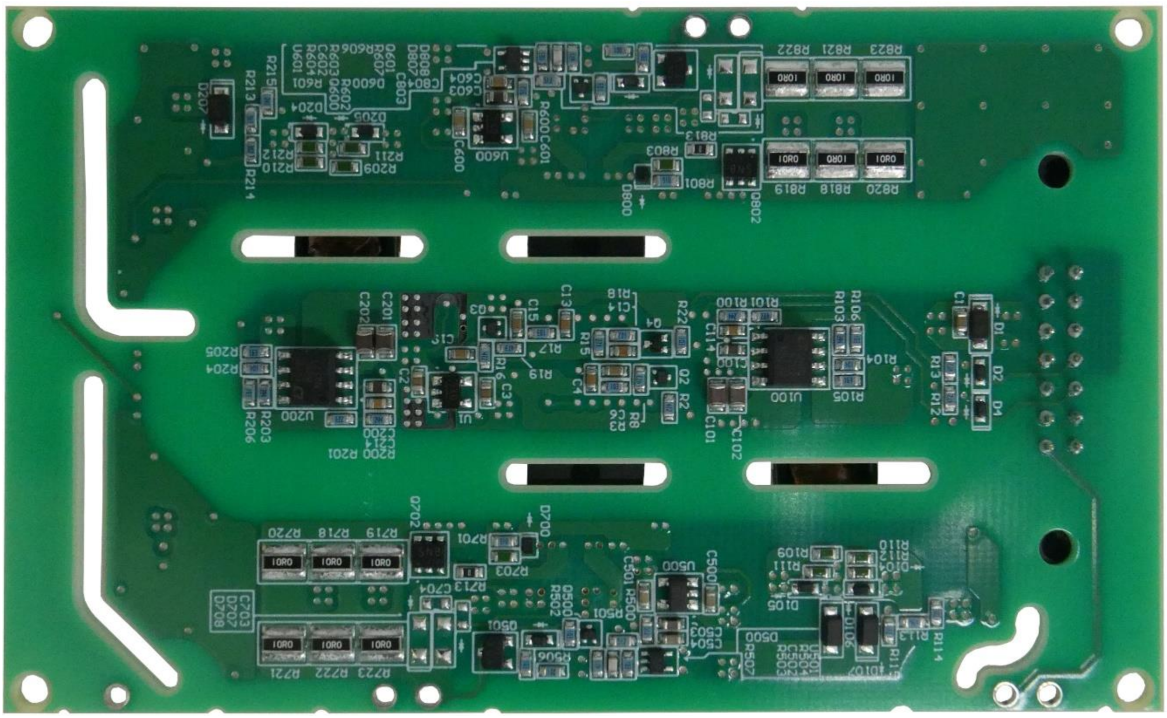


Fig. 2.3 Board (Back)

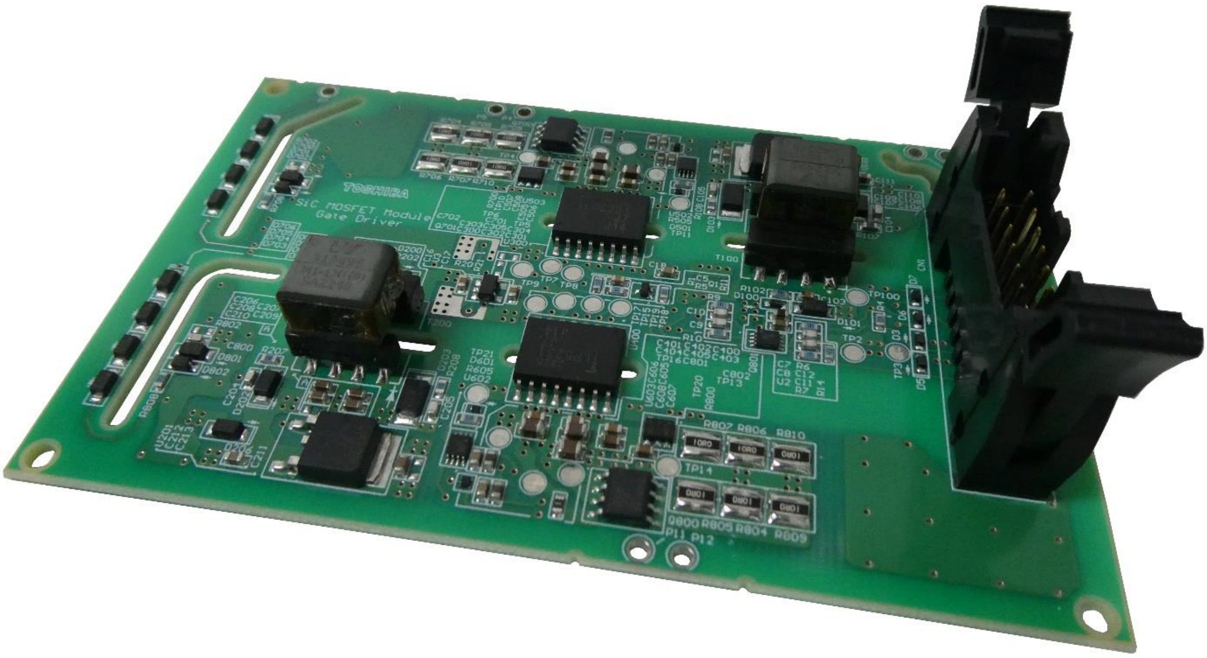


Fig. 2.4 Board (Side)

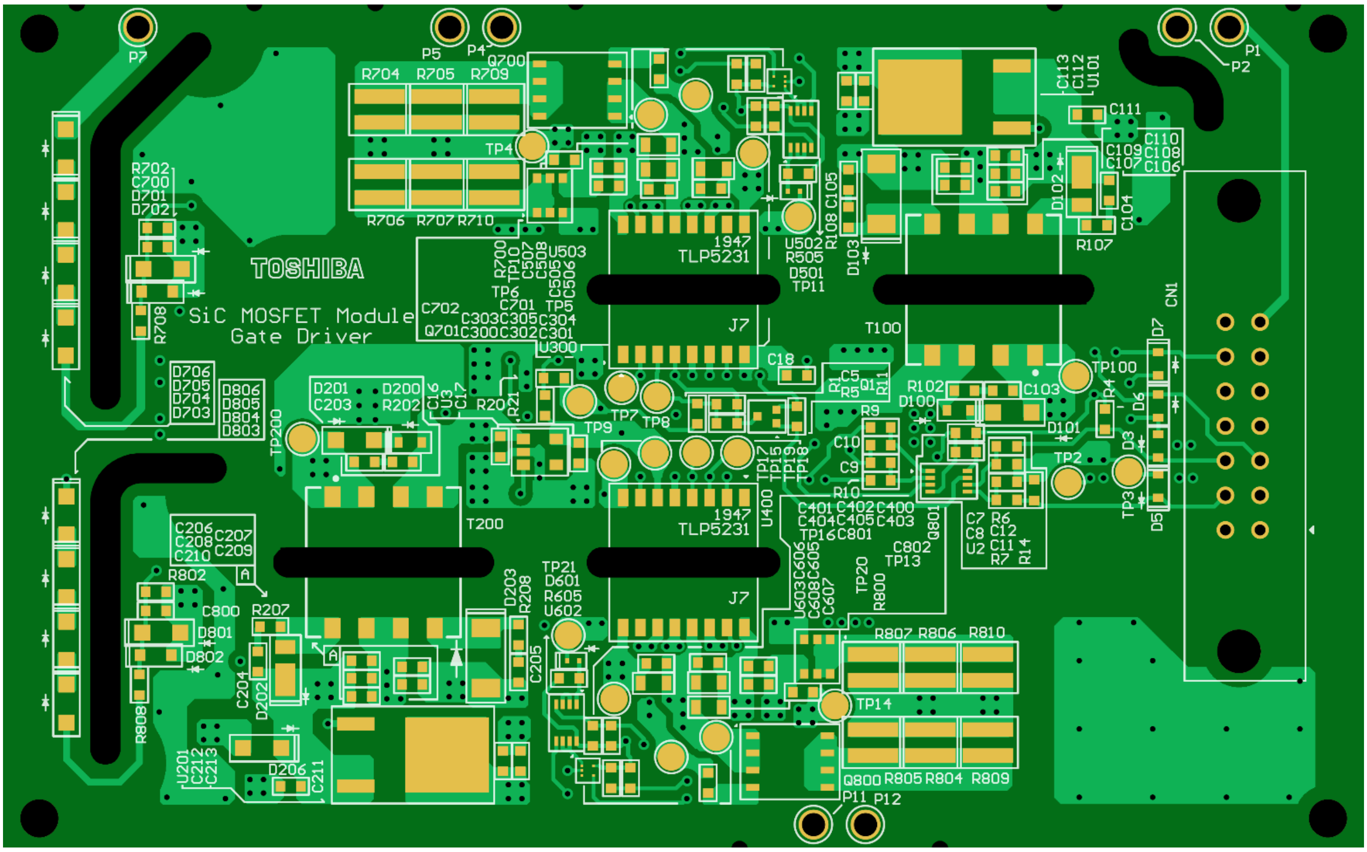


Fig. 2.5 Layout of Main Components (Front)

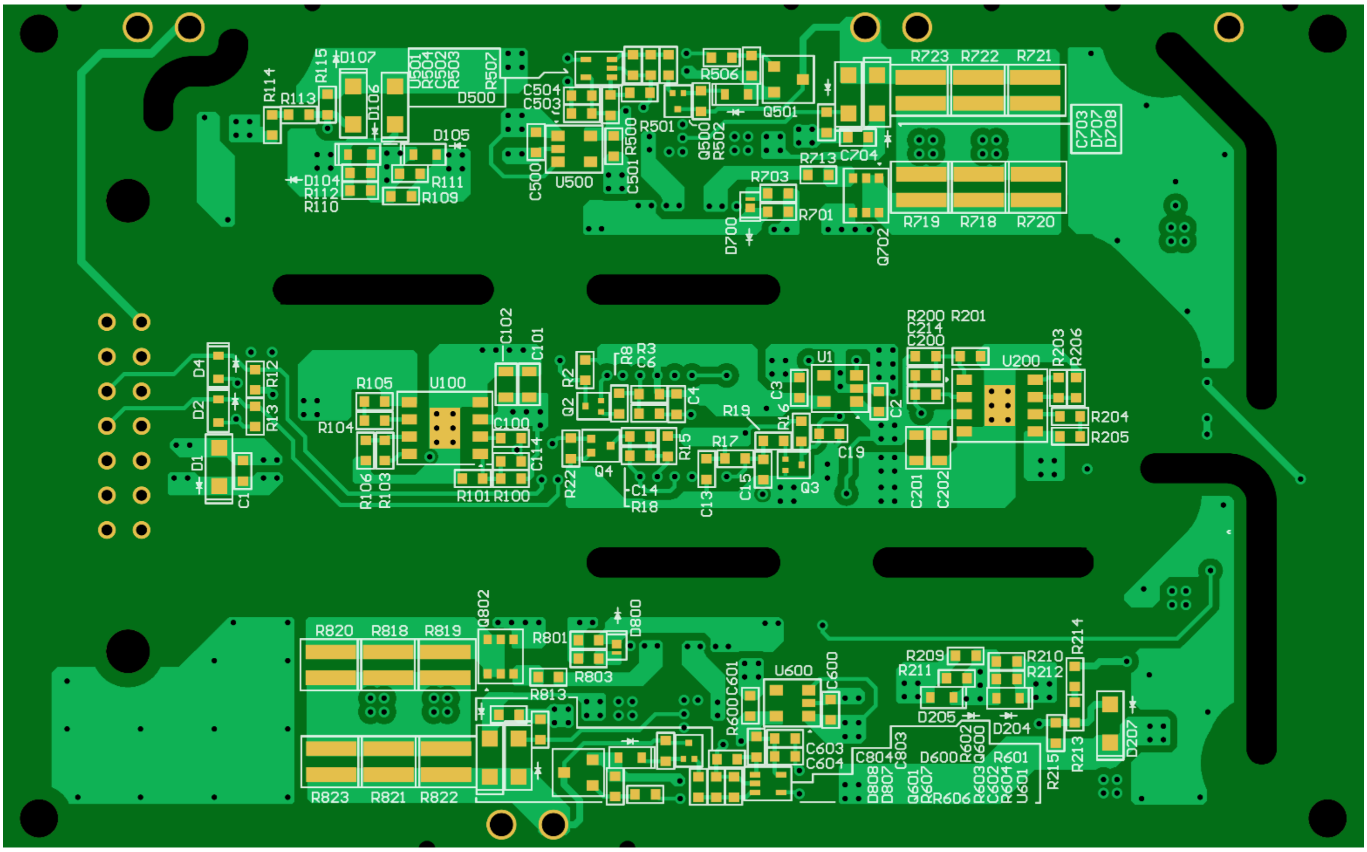


Fig. 2.6 Layout of Main Components (Back)

3. Schematic, Bill of Materials, and PCB Pattern

3.1. Schematic

Refer to the following file:

RD237-SCHEMATIC-xx.pdf

(xx is the revision number.)

3.2. Bill of Materials

Refer to the following file:

RD237-BOM-xx.pdf

(xx is the revision number.)

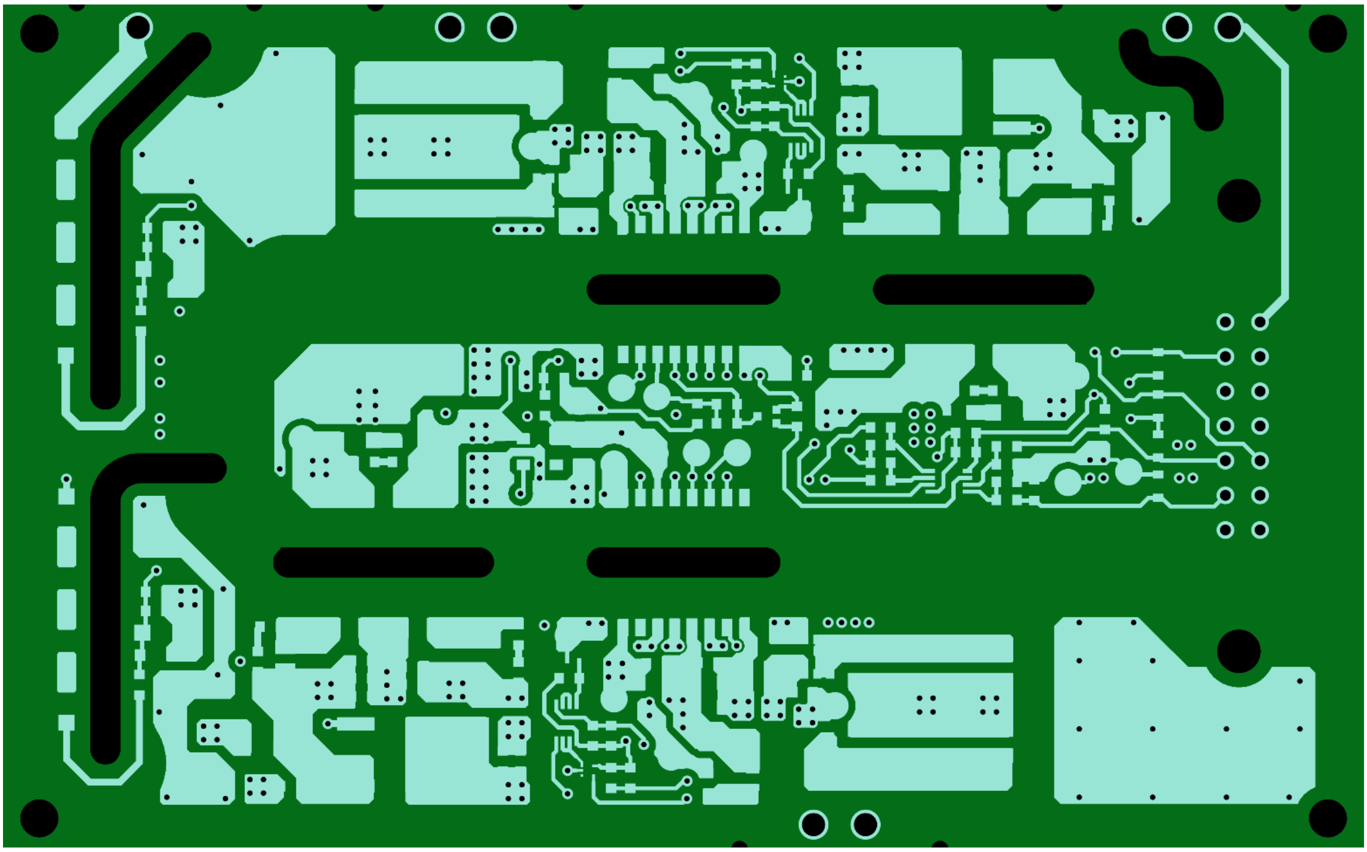
3.3. PCB Pattern

Fig. 3.1 shows the PCB pattern of this design.

Also refer to the following file:

RD237-LAYER-xx.pdf

(xx is the revision number.)



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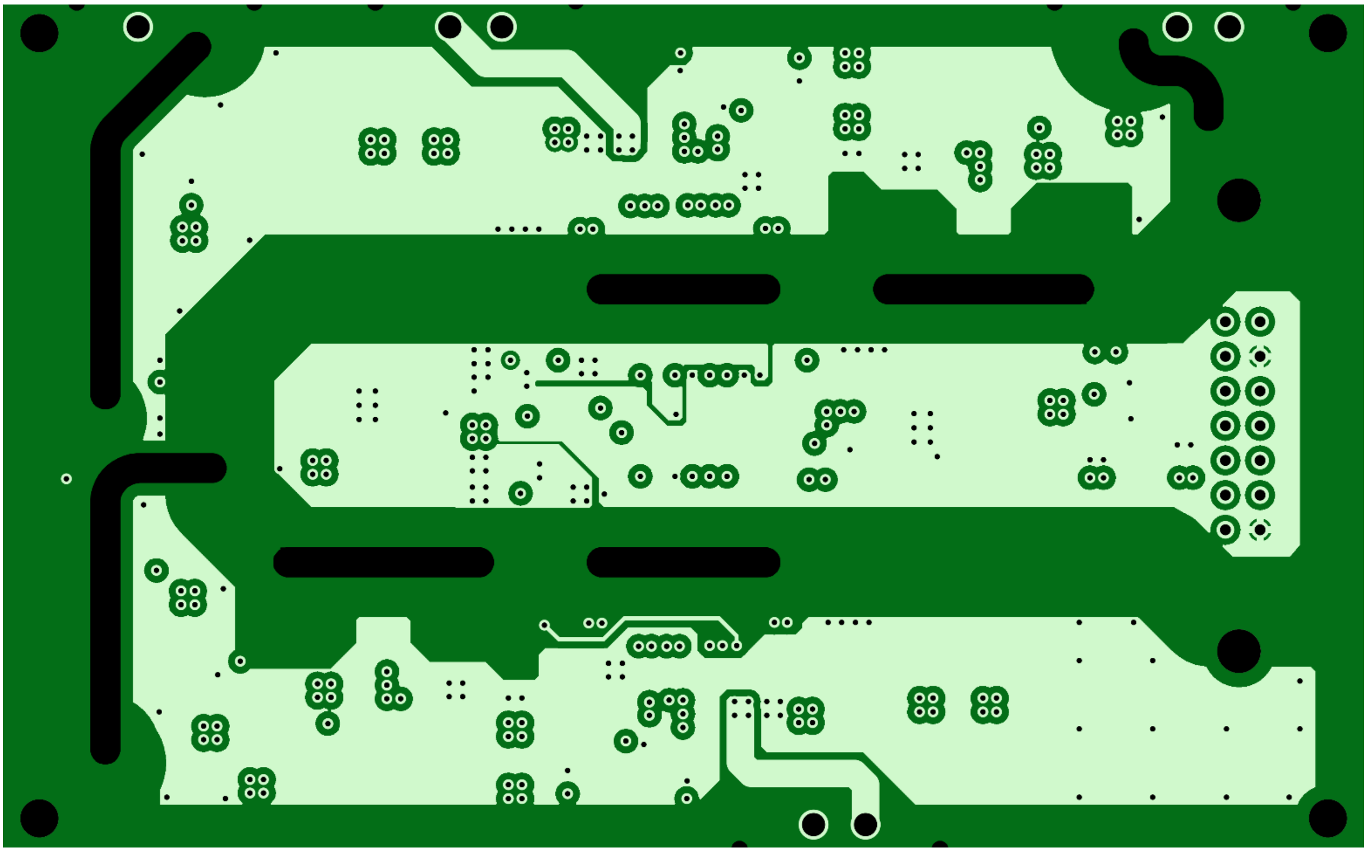
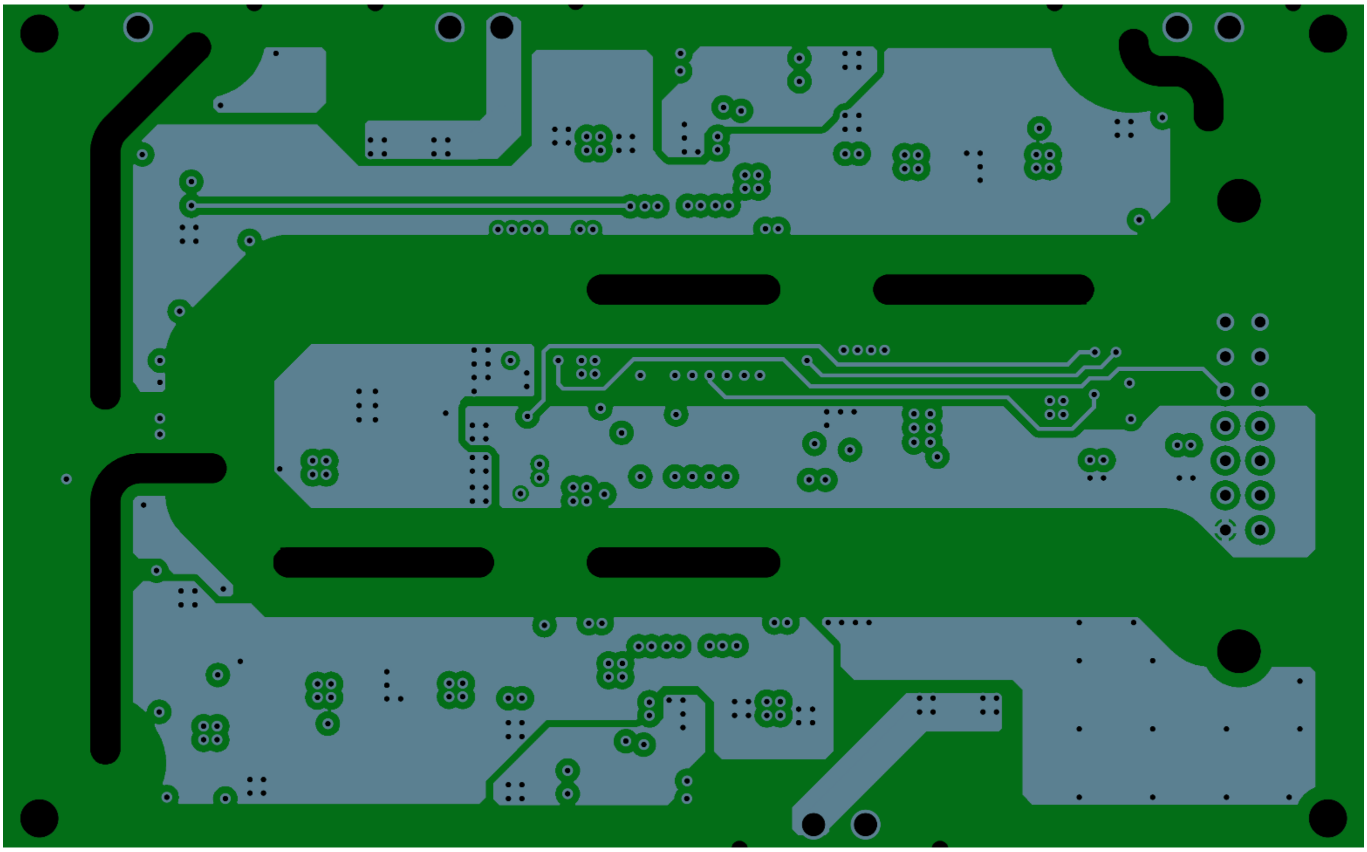
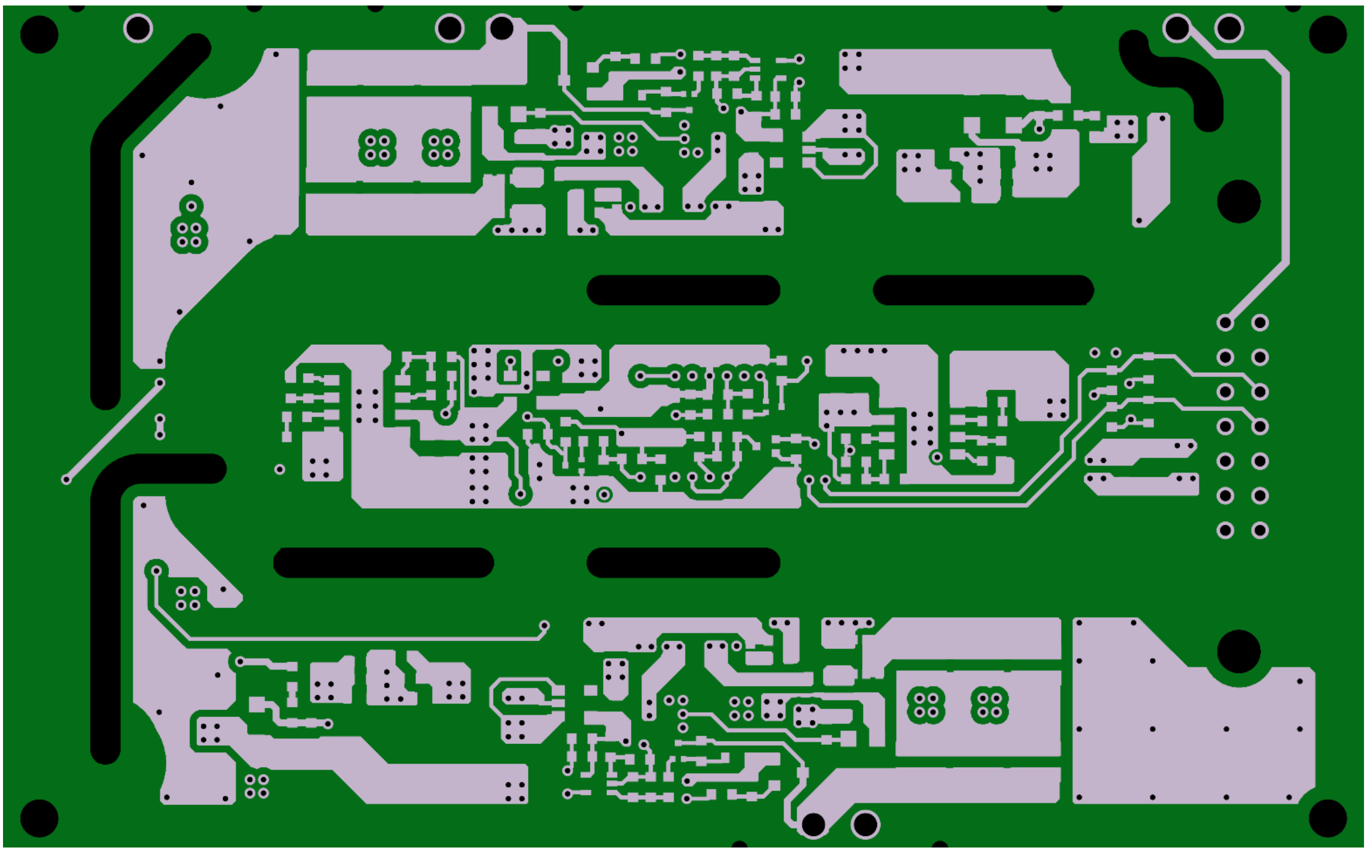


< Layer 2>



< Layer 3>



< Layer 4 >

Fig. 3.1 PCB Pattern (Front View)

4. Operation

This section explains outline of each component, operation check, and order of operation.

4.1. Name and Function of Components

4.1.1. Controller Connector (CN1)

External interface connector for connecting a controller. XG4A-1431 (OMRON) is used.

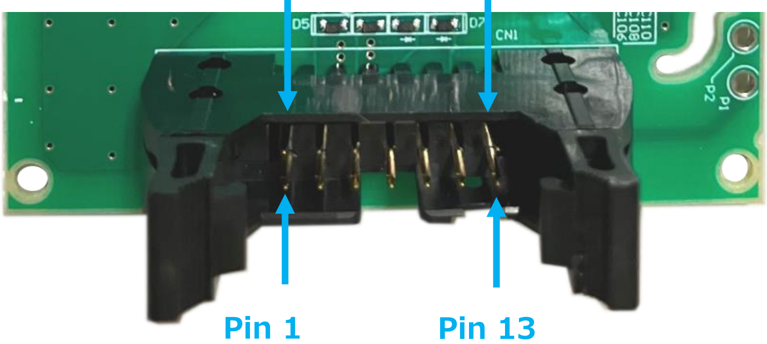


Fig. 4.1 Controller Connector (CN1)

Table 4.1 Controller Connector (CN1) Specifications

Pin#	Signal Name	I/O	Description	Pin#	Signal Name	I/O	Description
1	GND	-	GND	2	VDD	-	Power supply voltage for control
3	(N.C.)	-		4	B_INA	I	Low-side gate control signal input
5	B_FLT	O	Low-side fault detection output (Resistor collector output)	6	B_ENA	I	Low-side enable signal input
7	A_INA	I	High-side gate control signal input	8	(N.C.)	-	
9	A_ENA	I	High-side enable signal input	10	(5V)	-	External 5V power supply pin (Optional)
11	GND	-	GND	12	A_FLT	O	High-side fault detection output (Resistor collector output)
13	TH1	O	Temperature detection output 1	14	TH2	O	Temperature detection output 2

4.1.2. Through-Holes for Connecting SiC MOSFET Module. (P1, P2, P4, P5, P7, P11, P12)

Through hole to insert terminals of SiC MOSFET module.

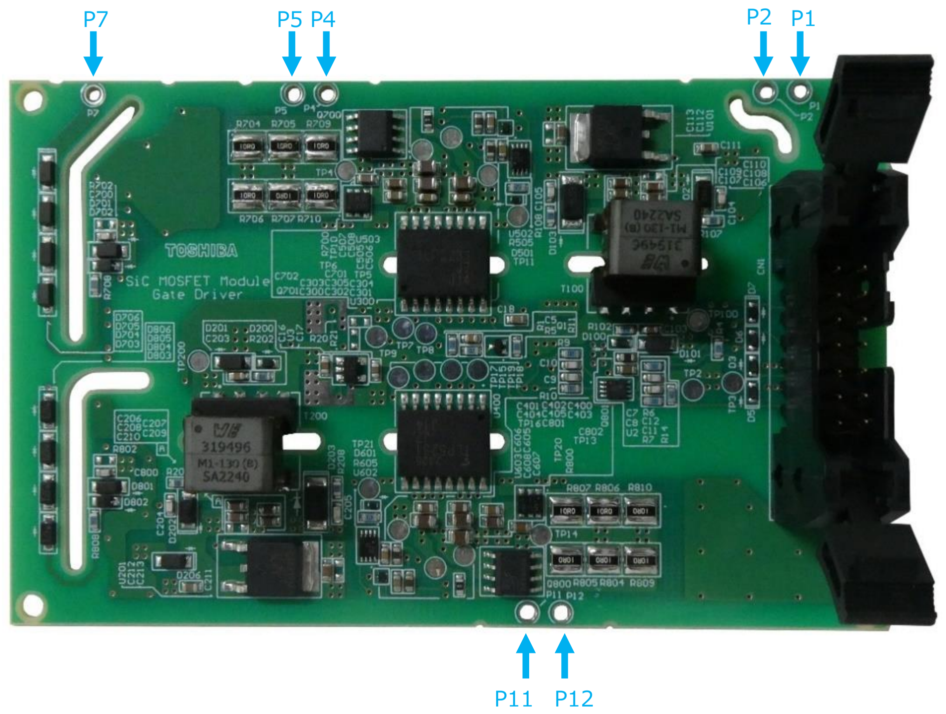


Fig. 4.2 Through-Hole Layout (Board Front Side)

Table 4.2 Through-Hole specifications

Through-Hole Name	Description (SIC MOSFET Module Terminal)
P1	Thermistor terminal
P2	Thermistor terminal
P4	High-side gate terminal
P5	High-side source sense/low-side drain sense shared terminal
P7	High-side drain sense terminal
P11	Low-side gate terminal
P12	Low-side source sense terminal

4.1.3. Jumper Resistor for External 5V Power Supply (R20, R21) and Internal 5V LDO Power Supply (U1, U3)

An external 5V can be connected to pin 10 of the connector (CN1) to replace the internal 5V LDO power supply. In this case, 0Ω jumper resistors must be mounted in the place of resistors R20 and R21, and 5V power supply LDO regulators (U1, U3) must be unmounted.

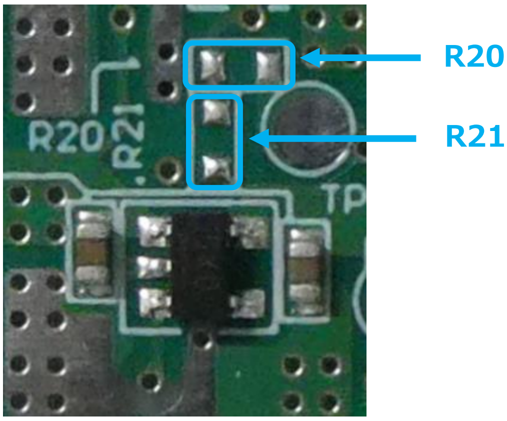


Fig. 4.3 Jumper Resistors (R20, R21) for External 5V Power Supply Application

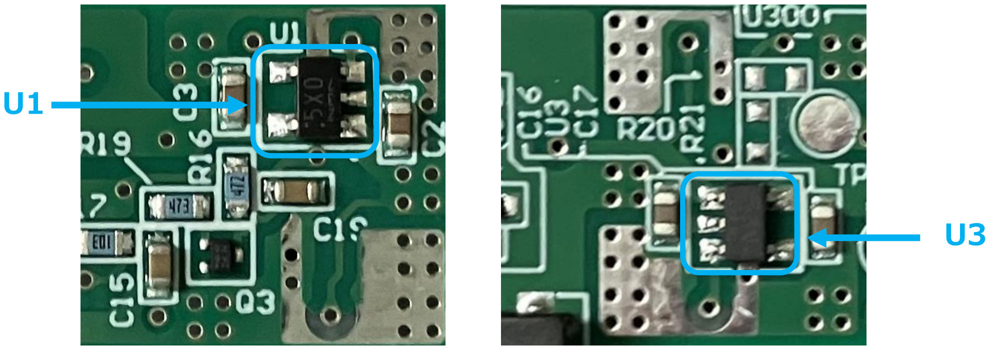


Fig. 4.4 Internal 5V Power Supply LDO Regulators (U1, U3)

Table 4.3 Component Mounting Configuration for Using External 5V Power Supply

Part Number	Normal Use	External 5V Voltage Application
R20	Not mounted	Mounted (0Ω resistance)
R21		
U1	Mounted	Not mounted
U3		

4.2. Operation Check

4.2.1. Operation Check of the Board Alone (Without SiC MOSFET Module)

During this operation check, this design is not connected to the SiC MOSFET module.

(1) Insert the socket with flat cable into the connector (CN1) and turn on the 24V power supply (for control) of CN1.

(2) Check that 5V VLDO regulator output and isolated DCDC converter output are as shown in Table 4.4.

Table 4.4 Operation Check

	High side	Measurement point	Low side	Measurement point
5V LDO regulator power supply	5V±5%	TP9(+)-TP3(-): Red circle	5V±5%	TP15(+)-TP3(-): White circle
Positive power supply voltage for gate drive	20V±5%	TP6(+)-TP4(-): Orange circle	20V±5%	TP13(+)-TP14(-): Brown circle
Negative power supply voltage for gate drive	-6.7V±5%	TP5(+)-TP4(-): Blue circle	-6.7V±5%	TP16(+)-TP14(-): Green circle

(3) Apply voltage to the gate control signal pin and enable signal pin according to Table 4.5, and check the gate drive output and fault detection output.

Table 4.5 High-Side and Low-Side Operation Check

<table>
<tr><th>Gate control signal
Input voltage
(CN1: pin 4, pin 7)</th><th>Enable signal
Input voltage
(CN1: pin 6, pin 9)</th><th>Gate drive output voltage
Measurement location:
P4(+)-P5(-), P11(+)-P12(-)</th><th>Fault detection output voltage
Measurement location:
CN1(pin 5, pin 12)</th></tr>
<tr><td>No-input or 0V</td><td rowspan="2">No-input or 5V</td><td rowspan="4">-6.7V±5%</td><td>5V</td></tr>
<tr><td>5V</td><td>0V</td></tr>
<tr><td>No-input or 0V</td><td rowspan="2">0V</td><td rowspan="2">5V</td></tr>
<tr><td>5V</td></tr>
</table>

Measurement locations P4,P5,P11,P12 are the through holes for inserting the terminals of SiC MOSFET module.Since a pull-down resistor is mounted on the gate control signal input pin, the gate drive output is becomes -6.7V even if the gate control signal is not input.

(4) Turn OFF the power supply for control once, and then short-circuit P5, P7, and P11 with a hook-clip, etc. Do not solder yet, as SiC MOSFET module will be connected after this operation check.
Turn on the 24V power supply voltage (for control) again, apply voltage to the gate control

signal input terminal and enable signal input terminal according to Table 4.6, and check the gate drive output and fault detection output.

Table 4.6 High-Side and Low-Side Operation Check

Gate control signal Input voltage (CN1: pin 4, pin 7)	Enable signal Input voltage (CN1: pin 6, pin 9)	Gate drive output voltage Measurement location: P4(+)-P5(-), P11(+)-P12(-)	Fault detection output voltage Measurement location: CN 1 (pin 5, pin 12)
No-input or 0V	No-input or 5V	-6.7V±5%	5V
5V		20V±5%	
No-input or 0V	0V	-6.7V±5%	
5V			

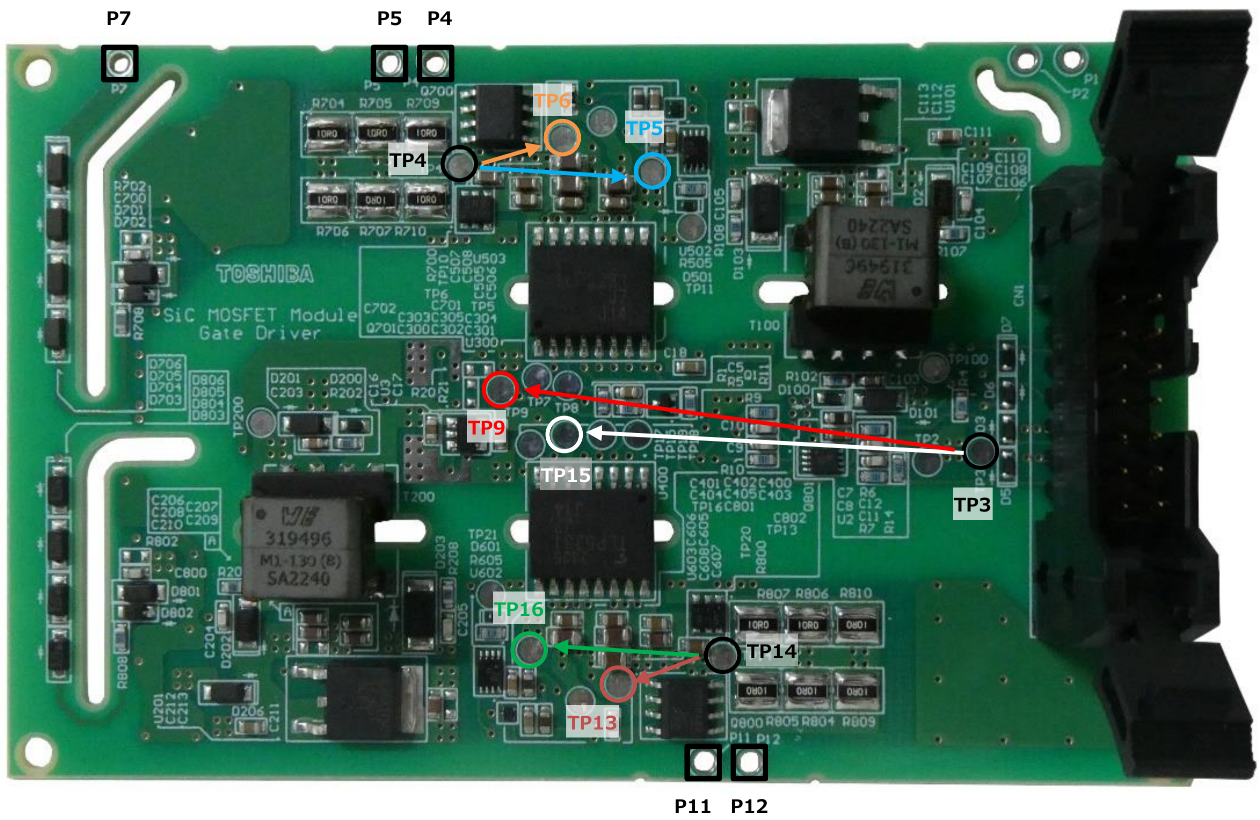


Fig. 4.5 Connection Example for Checking Operation of the Board Alone

4.2.2. Preparation

- Place the PCB of this design on the SiC MOSFET module. Make sure that the seven terminals fit into the through holes in the PCB of this design. (Refer to red circles in Fig. 4.9)
- When mounting the board to the module, tighten the screws before soldering the signal terminals.
- Tighten the screws by hand. Do not tighten repeatedly. (Refer to blue circles in Fig. 4.9)
- Use tapping screws for resin, and select screws that do not exceed the maximum length listed in Table 4.7.

Table 4.7 Nominal Diameter and Maximum Length of the Board Mounting Screws

Recommended screw size	Max. thread length
2.5 to 2.6mm	12mm (Board Thickness 1.6 to 2mm)

- Solder the seven signal terminals (red circles) with the through holes of the PCB of this design to connect them electrically.

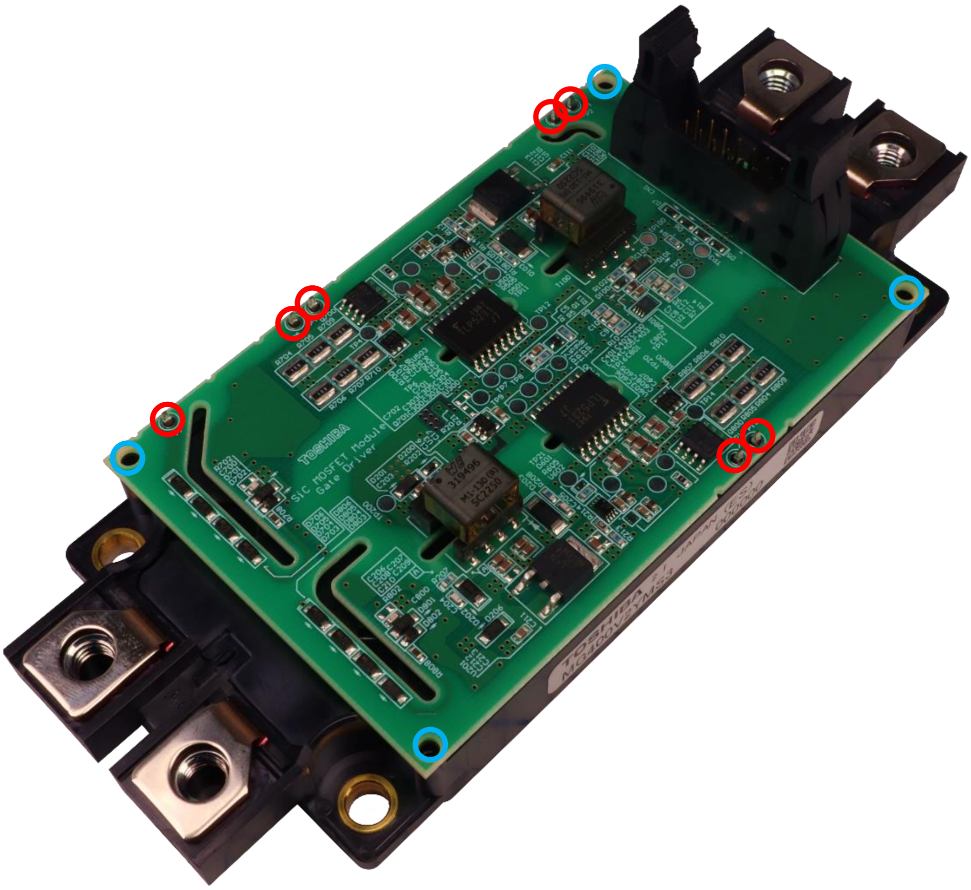


Fig. 4.6 Example of Connection for Checking Operation When SiC MOSFET Module is Connected

4.2.3. Operation Check of the Board (With SiC MOSFET Module Connected)

During this operation check, this design is electrically connected to the SiC MOSFET module.

Note that when not connected, the short-circuit protection function will operate, and the gate drive output will not be output normally.

Follow the steps below to check DC operation.

(1) Insert the socket with flat cable into the connector (CN1).

(2) Turn on the 24V power supply (for control) of CN1 without applying any voltage to the main terminals (P and N terminals) of SiC MOSFET module.

(3) Apply voltage to the gate control signal input pin and enable signal input pin according to Table 4.8, and check the gate drive output and fault detection output.

Table 4.8 High-Side and Low-Side Operation Check

<table>
<tr><th>Gate control signal
Input voltage
(CN1:pin 4, pin 7)</th><th>Enable signal
Input voltage
(CN1:pin 6, pin 9)</th><th>Gate drive output voltage
Measurement location:
P4(+)-P5(-), P11(+)-P12(-)</th><th>Fault detection output voltage
Measurement location:
CN 1 (5 pin, 12 pin)</th></tr>
<tr><td>No-input or 0V</td><td rowspan="2">No-input or 5V</td><td>-6.7V±5%</td><td rowspan="4">5V</td></tr>
<tr><td>5V</td><td>20V±5%</td></tr>
<tr><td>No-input or 0V</td><td rowspan="2">0V</td><td rowspan="2">-6.7V±5%</td></tr>
<tr><td>5V</td></tr>
</table>

When the gate control signal (low side, high side) is output from the controller, and the connected SiC MOSFET module switches according to the gate control signal.

While operating SiC MOSFET module in a complementary manner, provide enough dead-time between the high-side and low-side gate-control signals and never turn on the high-side and low-side of the SiC MOSFET module simultaneously (arm short-circuited).

This design does not have the dead time generation function.

<Reference>

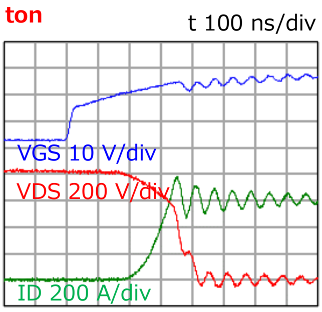
The following shows an example of the procedure for a double-pulse test to check the switching characteristics.

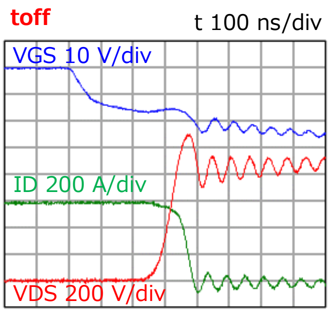
Be sure to disable the DC voltage before changing the connection.

(1) For double-pulse testing on the high side, connect an inductive load to the AC and N terminals of the SiC MOSFET module.
(2) Set the gate-control signals (low-side and high-side) below 1 V and apply DC voltage to the main terminals (P and N terminals) of the SiC MOSFET module.
(3) Apply pulse to the high-side gate control signal. And measure the switching characteristics (drain voltage and drain current) of the high-side MOSFET of the SiC MOSFET module.
(4) For double-pulse testing on the low side, connect an inductive load to the AC and P terminals of the SiC MOSFET module.
(5) Set the gate-control signals (low-side and high-side) below 1 V and apply DC voltage to the main terminals (P and N terminals) of the SiC MOSFET module.
(6) Apply pulse to the low-side gate control signal. And measure the switching characteristics (drain voltage and drain current) of the low-side MOSFET of the SiC MOSFET module.

Module: MG600Q2YMS3

Measuring conditions: V_{PN} = 800V, I_D = 600A, lead-load 100μH, T_a = 25°C





4.2.4. Each Protection Function

Protection functions include DESAT detection and low gate-drive voltage detection (UVLO). During protection operation, the output between Gate-Source of the SiC MOSFFET module is switched off and the FLT signal at the Controller Connector (CN1) pin 5 or pin 12 is switched to the L-level. When returning from protection operation, the FLT signal returns to H-level. Description of each protection operation is as follows.

(1) DESAT detection (UVLO is inactive)

① The input-on current $I_{F(ON)}$ flows and SiC MOSFET module turns on normally. (normal operation)

② Overcurrent is generated in SiC MOSFET module. The drain-to-source voltage rises.

③ When DESAT terminal voltage exceeds DESAT threshold voltage 8.0V (Typ.), the protection operation starts (detected).

④ MOSFET for soft turn-off is switched on and SiC MOSFET module is switched off.

⑤ Fault detection output (FLT signal) changes from 5V to 0V.

⑥ Follow the sequence of TLP5231 to recover from the protection operation.

(2) Low gate-drive voltage detection (UVLO)

① V_{UVLOP-} (UVLO protection operation during positive gate power supply)

- UVLO operates when the normal operation (V_{CC2}-V_E = 20V) changes to V_{CC2}-V_E < 12V (Typ.), and then the fault detection output (FLT signal) changes from 5V to 0V. The gate output voltage becomes V_{EE} and the SiC MOSFET module is turned off.

② V_{UVLOP+} (returning from UVLO protection operation during positive gate power supply)

- If V_{CC2}-V_E increases, UVLO is released at V_{CC2}-V_E > 13V (Typ.), and the fault detection output (FLT signal) changes from 0V to 5V. SiC MOSFET module turns on when the gate-output voltage becomes V_{CC2}-V_E = 20V.

③ V_{UVLON-} (UVLO protection operation during negative gate power supply)

- UVLO operates when the normal operation (V_{EE}-V_E = -6.7V) changes toV_{EE}-V_E > -5.3V (Typ.), and then the fault detection output (FLT signal) changes from 5V to 0V. The gate output voltage becomes V_{EE} and the SiC MOSFET module is turned off.

④ V_{UVLON+} (returning from UVLO protection operation during negative gate power supply)

- When V_{CC2}-V_E decreases, UVLO is released at V_{EE}-V_E < -5.0V (Typ.), and the fault detection output (FLT signal) changes from 0V to 5V. SiC MOSFET module turns on when the gate-output voltage becomes V_{CC2}-V_E = 20V.

4.3. Component Adjustment

4.3.1. Gate Resistance Adjustment

The turn-on and turn-off times can be adjusted using the gate resistors to match the actual specifications. The gate resistance of 3.3Ω (10Ω × 3 parallel resistors) is used in this design. When changing resistance, pay attention to resistance loss, operation of each component, heat generation, etc. while selecting the resistors.

Table 4.9 Gate Resistance Specifications

High Side/Low Side		Part Number	Resistor Specifications
High side	Turn on, 3 parallel	R704	Rectangular chip resistor (1W, 10Ω, 1632 Metric)
		R705	
		R709	
	Turn off, 3 parallel	R706	Rectangular chip resistor (1W, 10Ω, 1632 Metric)
		R707	
		R710	
Low side	Turn on, 3 parallel	R804	Rectangular chip resistor (1W, 10Ω, 1632 Metric)
		R805	
		R809	
	Turn off, 3 parallel	R806	Rectangular chip resistor (1W, 10Ω, 1632 Metric)
		R807	
		R810	

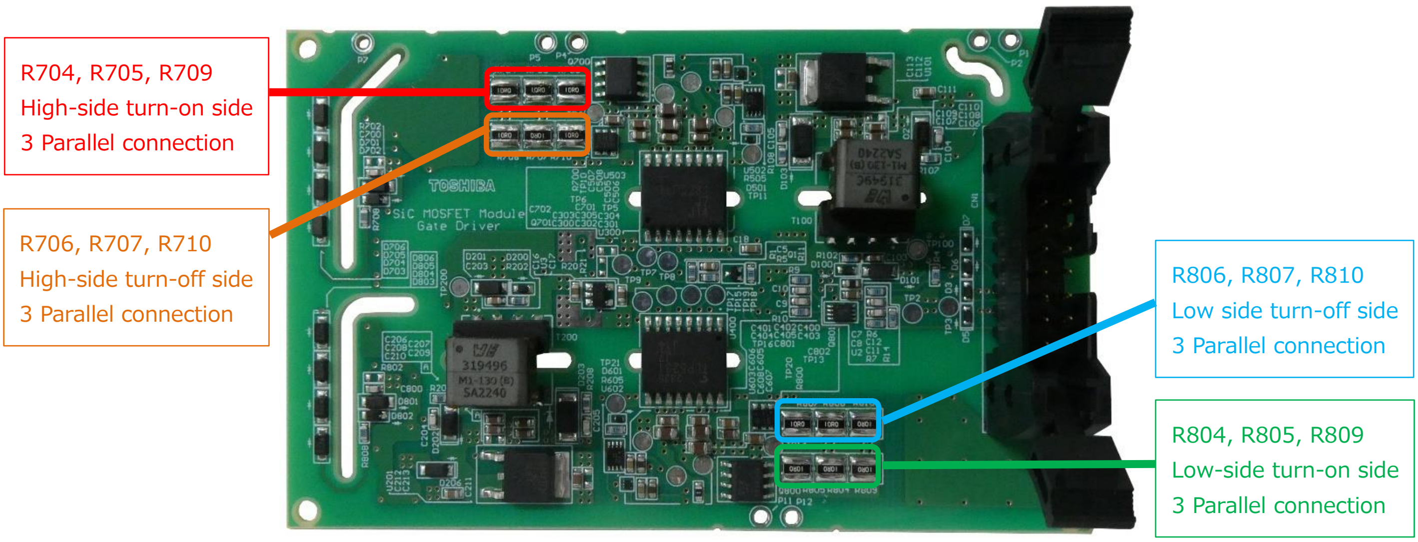


Fig. 4.7 Gate Resistor Layout

4.3.2. DESAT Detection Voltage Adjustment (R708, R808)

DESAT detection voltage can be changed by adjusting the resistance according to the actual specifications. 6.2kΩ resistors are used in this design. Also, when disabling DESAT detection function, a 0Ω jumper must be implemented at R702/R802.

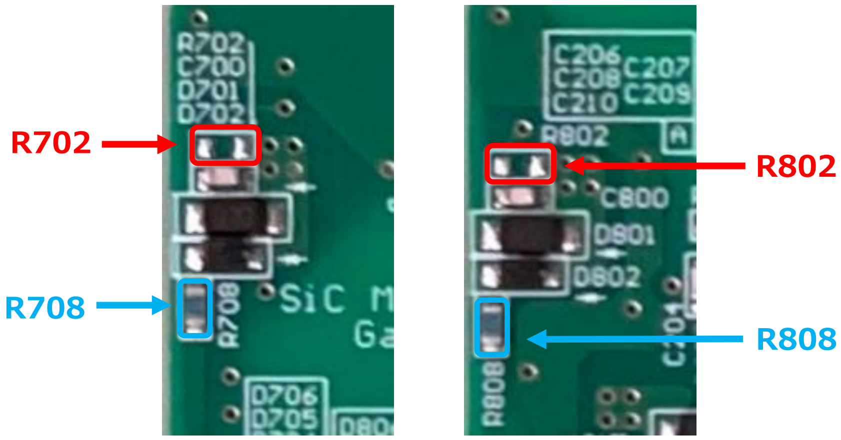


Fig. 4.8 DESAT Detection Resistor Layout

4.3.3. DESAT Detection Duration Adjustment (C700, C800)

The blanking capacitor is a RC filter for DESAT terminal due to its configuration with DESAT detection resistor, and prevents malfunction caused by external noises. 120 pF blanking capacitors are used in this design.

The blanking capacitor can be used to adjust the time to detect DESAT. However, if the capacitance of the blanking capacitor is increased to increase the anti-noise effectiveness, it will take longer to detect DESAT.

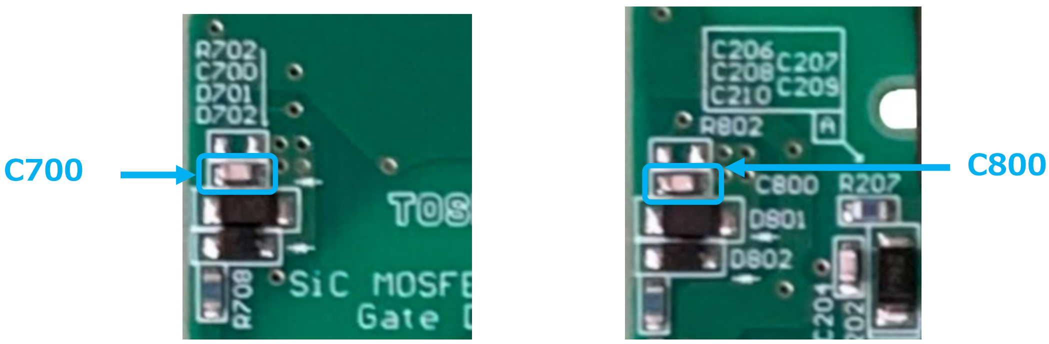


Fig. 4.9 Blanking Capacitor Layout

4.3.4. Soft Turn-off Time Adjustment (R718 to R723, R818 to R823)

This design uses 10Ω resistance (10Ω, 2 parallel 2 series) as a soft turn-off resistor. Slowly turning the gate off suppresses the spike-voltage caused by the parasitic inductance of the wire and prevents SiC MOSFET module from being destroyed. Soft turn-off time can be adjusted according to actual specifications.

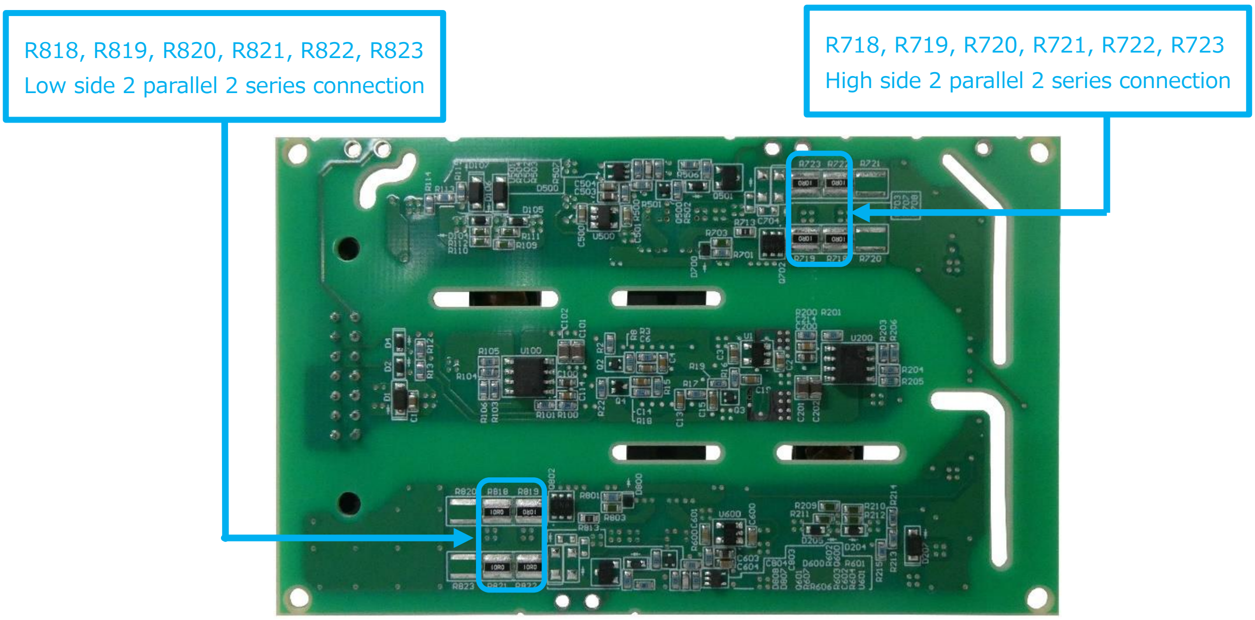


Fig. 4.10 Resistor Layout for Soft Turn-off

4.3.5. Input-Signal RC Filter Adjustment (C10/R9, C11/R7)

This design incorporates a RC filter to prevent malfunction due to external noises when inputting gate-control signals. Adjust the filter constant according to the actual specifications.

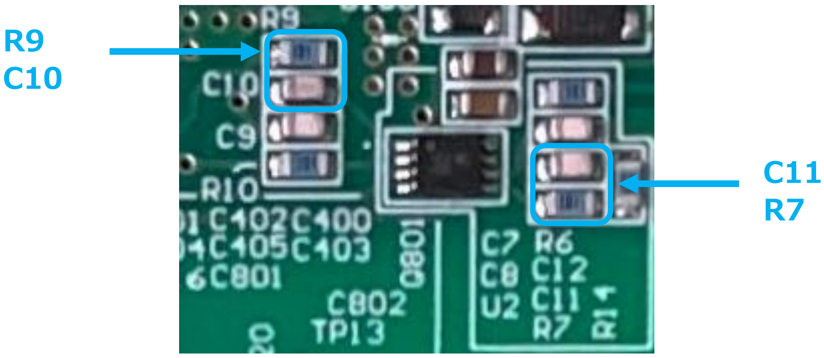


Fig. 4.11 RC Filter Layout

4.4. Precautions

Pay special attention to the following when using this design:

- Make sure that the polarities of all connections are correct before supplying electricity.
- A high voltage is applied to the smoothing capacitor, and it takes time for it to completely discharge even after the power is turned off. Make sure that the capacitor has been fully discharged before touching the board.
- When checking the operation, cover the board with an acrylic case for safety.
- MOSFET and other components may generate heat during operation. Be careful not to get burned while handling them.

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