Isolated Gate Drive Circuit for 3-Phase Inverter

Reference Guide

RD238-RGUIDE-01

Toshiba Electronic Devices & Storage Corporation

Table of Contents

1. Introduction

This Reference Guide (hereafter, this guide) describes the specifications and operation procedures of the Isolated Gate Drive Circuit for 3-Phase Inverter (hereafter, this design).

3-phase inverters which is capable of converting power are indispensable for not only industrial inverters but also for renewable energy such as photovoltaic power generation and will become increasingly important in the future.

This design allows isolated gate drive of power modules used in 3-phase inverter circuits. It incorporates various protective functions and uses the smart gate driver coupler TLP5222 that does not require complicated external circuit, realizing a 7-channel (U-, V-, and W-phase high-side low-side and braking circuit) gate drive circuit on a small board. UVLO monitors and protects against the drop in gate-drive-voltage, overcurrent protection by detecting DESAT (non-saturation) and self-turn-on prevention by active miller clamp can be equipped to safely drive the power semiconductor module.

It is also possible to adjust each component according to the actual circuit designs. Refer to TLP5222 datasheet, related documentation, RD238 Design Guide, etc. for adjusting each component.

When this design is considered to use actual application, refer to the TLP5222 datasheet and design circuits to make operation conditions and environments meet applied safety standard.

Fig. 1 Photograph of This Design

2. Specifications

Table 2.1 lists the main specifications of this design.

Table 2.1 Board Specifications of Isolated Gate Drive Circuit for 3-Phase Inverter

Item	Specifications
Power supply voltage for control	DC 24V
Number of driving channels	7 ch: U-phase (low-side, high-side) V-phase (low-side, high-side) W-phase (low-side, high-side) Brake circuit
Gate control signal input Enable signal input	5V CMOS
Gate drive frequency	20kHz
Gate drive output	+16V / -8V
Maximum gate drive peak current	±2.5A
Error detection output	Open collector output (with pull-up resistor)
Temperature detection terminal	NTC with built-in external power module
Power module protection function	Overcurrent protection and soft shutdown by detecting DESAT Active miller clamp (AMC) Gate-drive under voltage lock out (UVLO)
Board size	100mm x 100mm
Board layer configuration	FR-4 1.6mm thickness 4 layers Copper foil thickness: Outer layer 18µm, Inner layer 35µm Double-sided silk, double-sided mounting

2.1. Circuit Block Diagram

Fig. 2.1 shows the block diagram of this design.

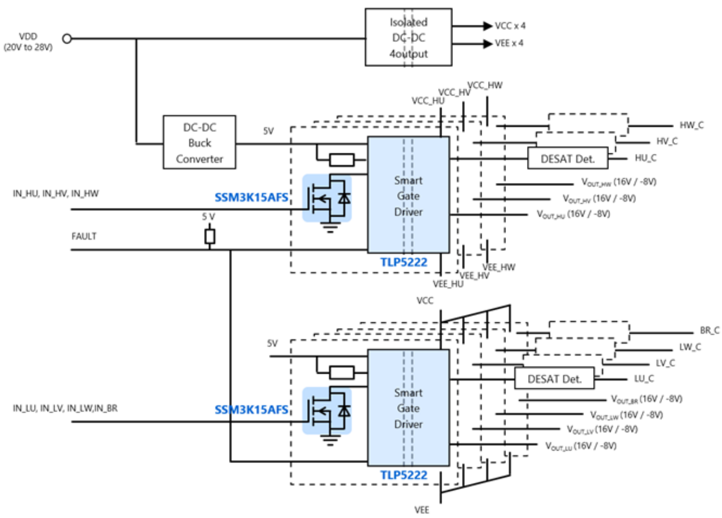


Fig. 2.1 Block Diagram of Isolated Gate Drive Circuit for 3-Phase Inverter

2.2. Appearance and Component Arrangement

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

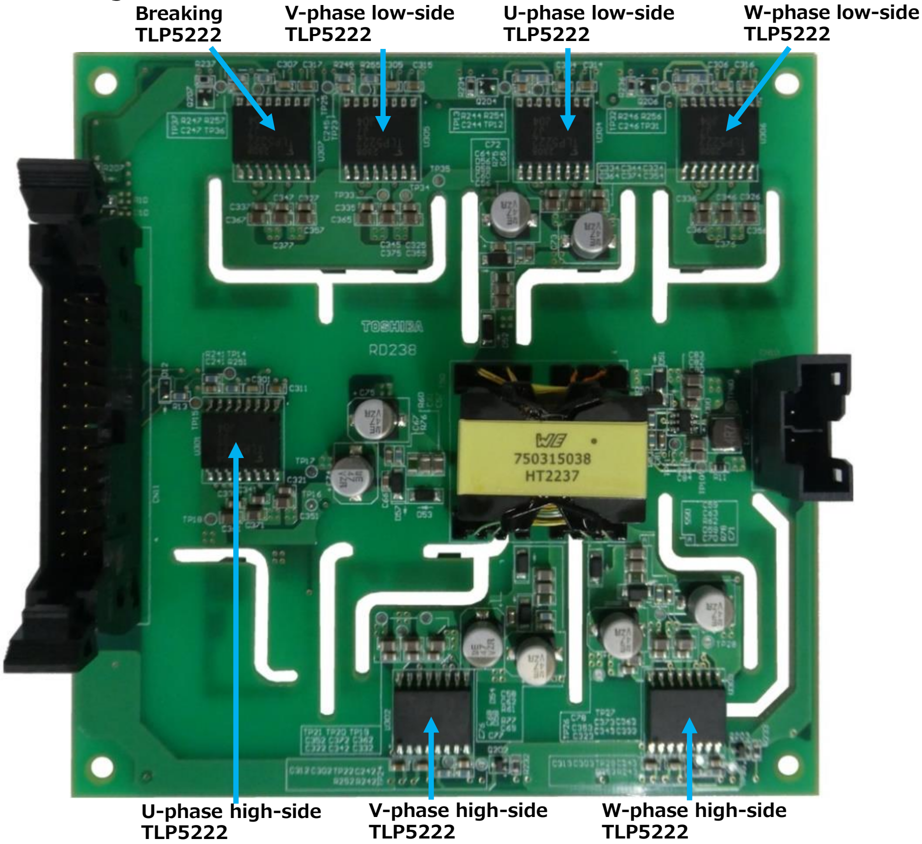


Fig. 2.2 Board (Top View)

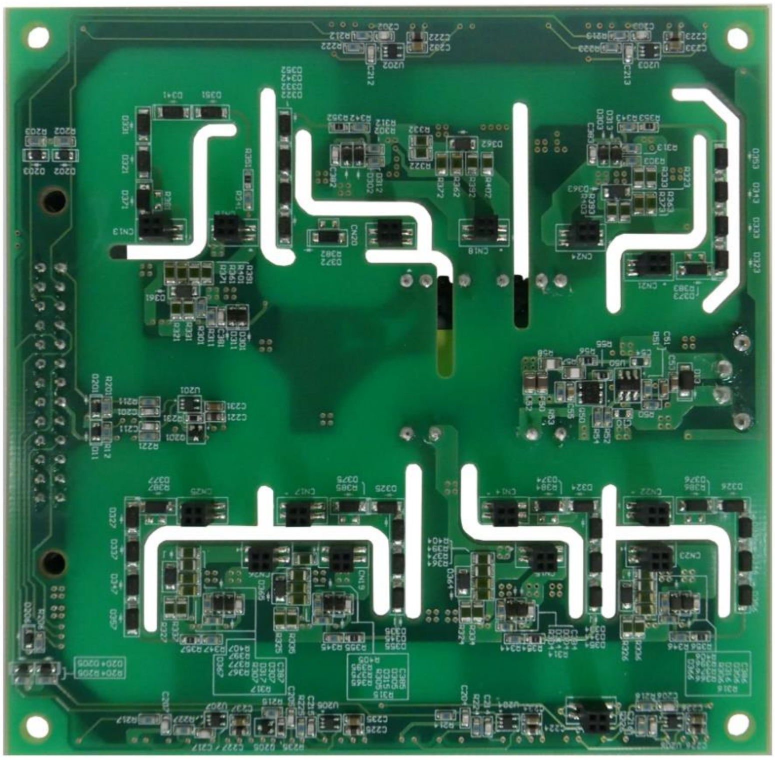


Fig. 2.3 Board (Bottom View)

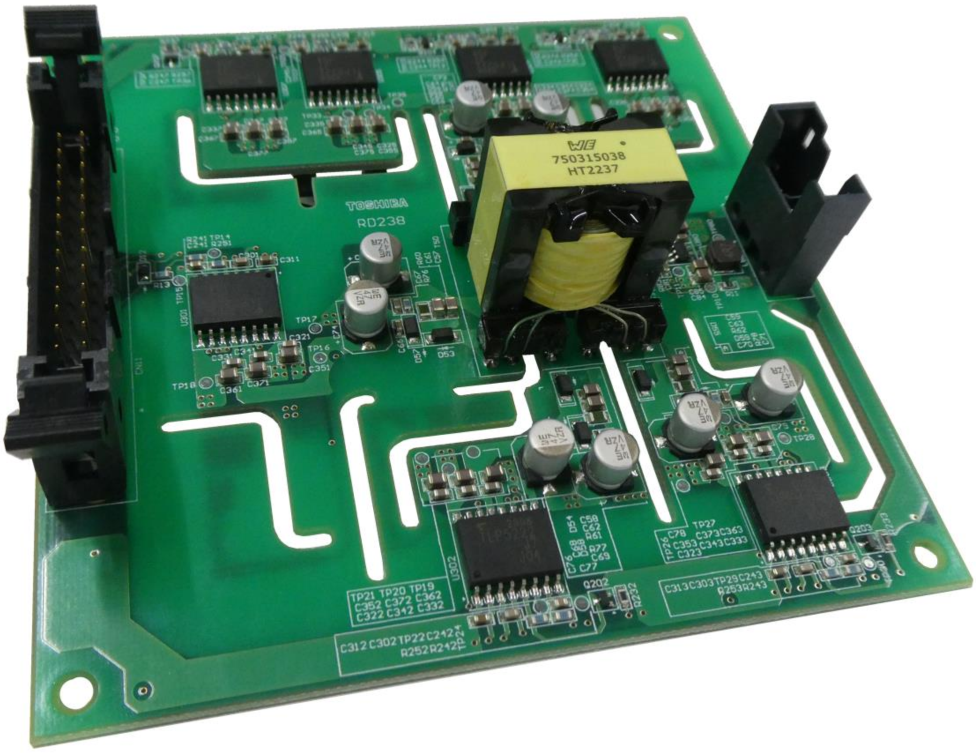


Fig. 2.4 Board (Side View)

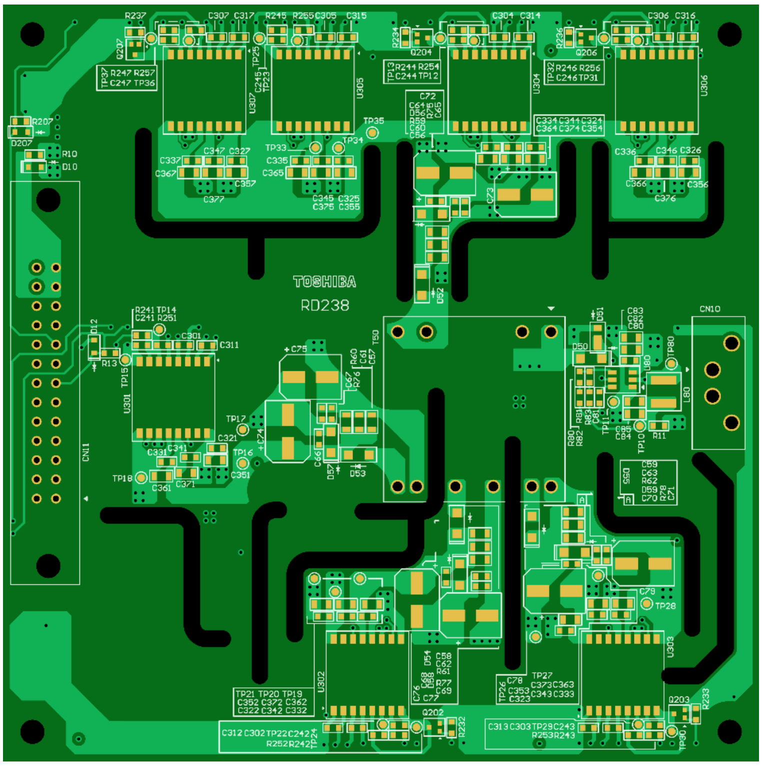


Fig. 2.5 Layout of Main Components (Top View)

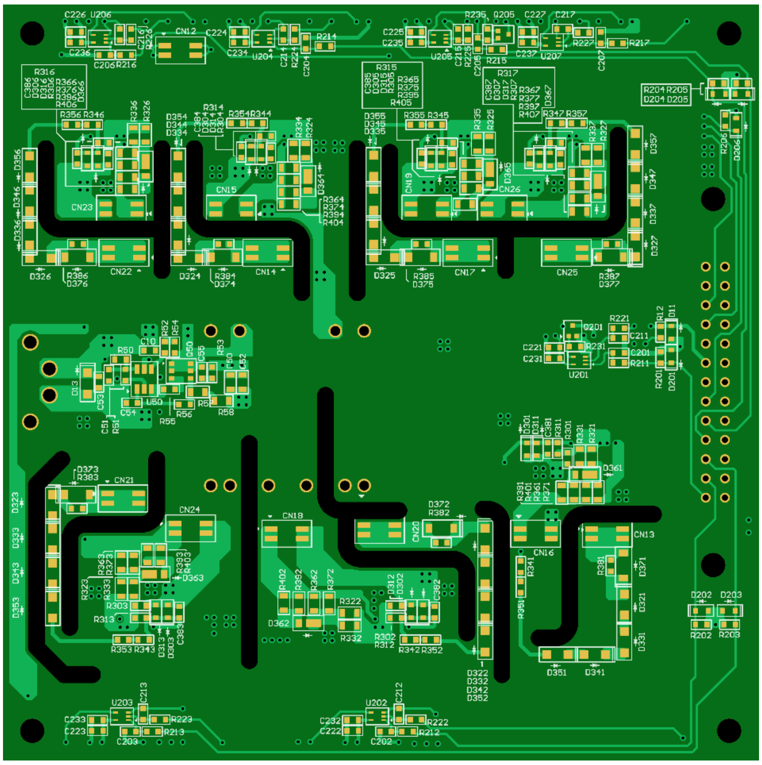


Fig. 2.6 Layout of Main Components (Bottom View)

3. Schematic, Bill of Materials, and PCB Pattern Diagram

3.1. Schematic

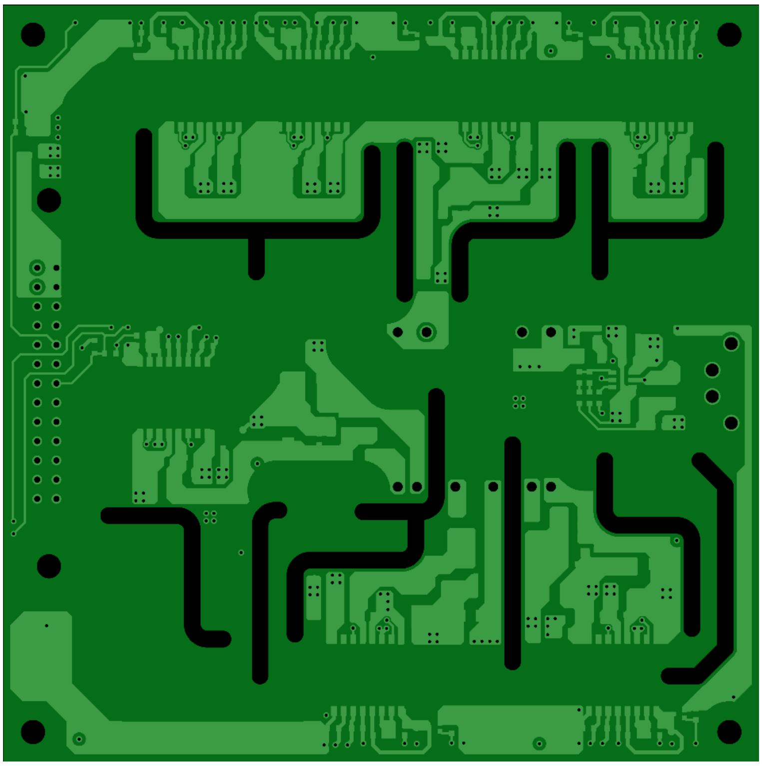
Refer to the file below.
RD238-SCHEMATIC-xx.pdf
(xx is the revision number.)

3.2. Bill of Materials

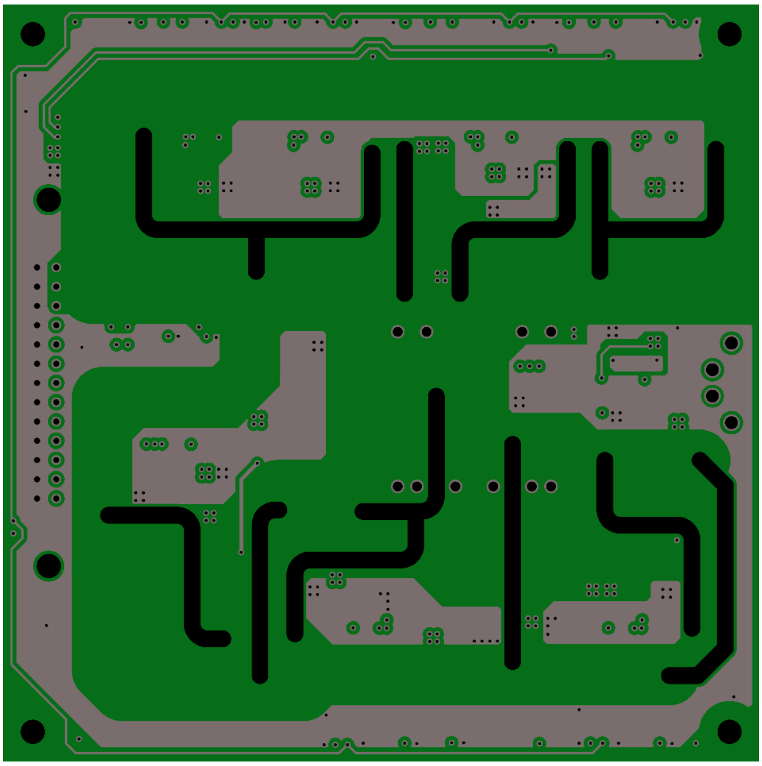
Refer to the file below.
RD238-BOM-xx.pdf
(xx is the revision number.)

3.3. PCB Pattern Diagram

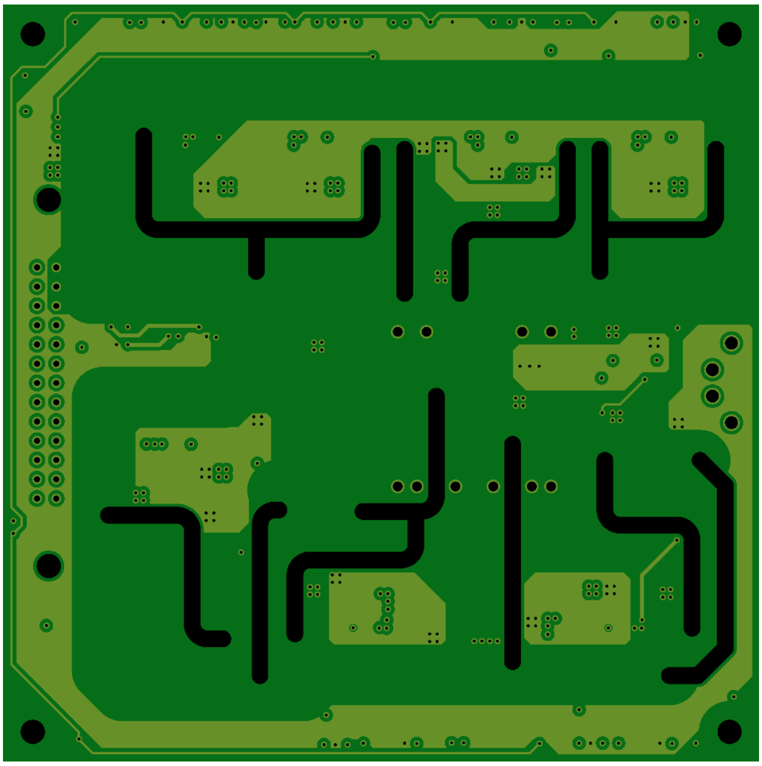
Fig. 3.1 shows the pattern diagram of this design.
Also refer to the following file:
RD238-LAYER-xx.pdf
(xx is the revision number.)



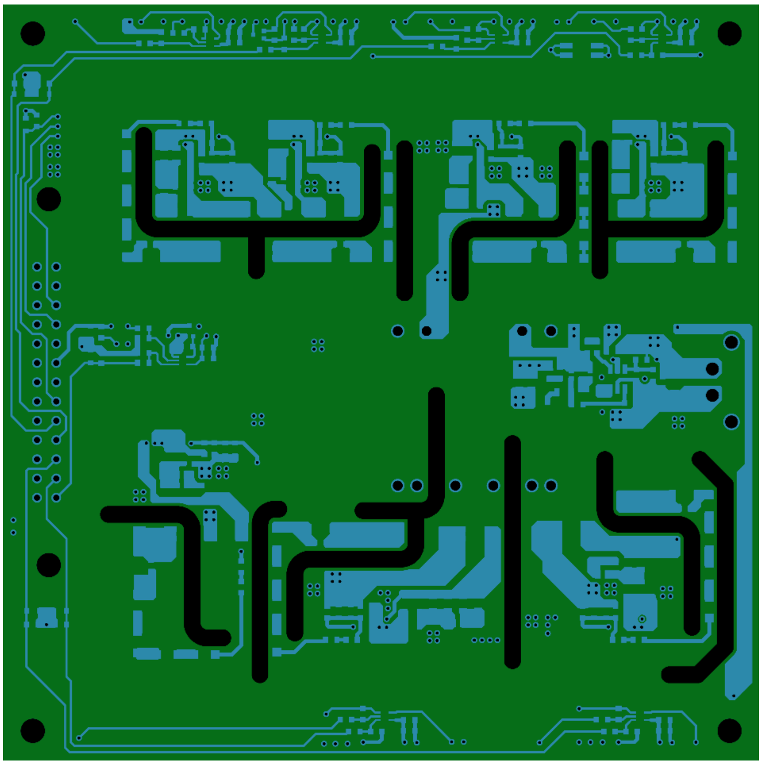
<Layer 1 Front>



< Layer 2>



< Layer 3>



< Layer 4 >

Fig. 3.1 PCB Pattern Diagram (Front View)

4. Names and Functions of Components

4.1. Input/Output Signal Connector (CN11)

This connector is used for Input/output signals. XG4A-2632 (made by OMRON, with 2.54mm pitch) is used.

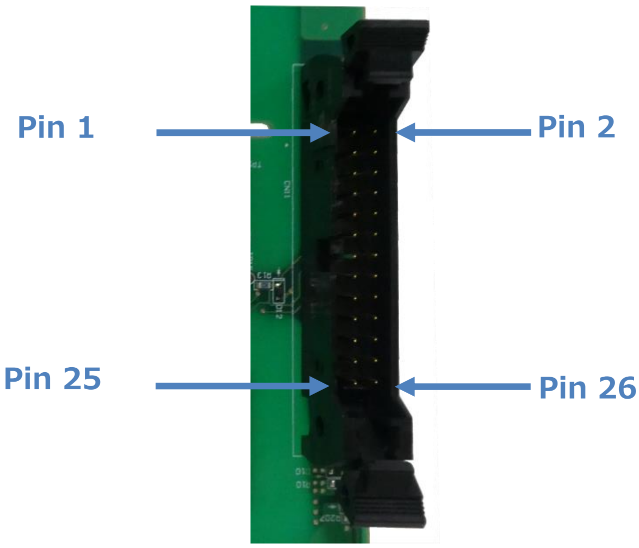


Fig. 4.1 Input/Output Signal Connector (CN11)

Table4.1 Specifications of Input/Output Signal Connector (CN11)

<table>
<tr><th>Pin#</th><th>Signal name</th><th>I/O</th><th>Description</th><th>Pin#</th><th>Signal name</th><th>I/O</th><th>Description</th></tr>
<tr><td>1</td><td>IN_HU</td><td>I</td><td>U-phase high-side signal input</td><td>2</td><td rowspan="13">GND</td><td rowspan="13">-</td><td rowspan="13">GND</td></tr>
<tr><td>3</td><td>IN_HV</td><td>I</td><td>V-phase high-side signal input</td><td>4</td></tr>
<tr><td>5</td><td>IN_HW</td><td>I</td><td>W-phase high-side signal input</td><td>6</td></tr>
<tr><td>7</td><td>IN_LU</td><td>I</td><td>U-phase low-side signal input</td><td>8</td></tr>
<tr><td>9</td><td>IN_LV</td><td>I</td><td>V-phase low-side signal input</td><td>10</td></tr>
<tr><td>11</td><td>IN_LW</td><td>I</td><td>W-phase low-side signal input</td><td>12</td></tr>
<tr><td>13</td><td>EN</td><td>I</td><td>Enable signal input</td><td>14</td></tr>
<tr><td>15</td><td>FAULT</td><td>O</td><td>Fault Detection Output
(pull-up resistor collector output)</td><td>16</td></tr>
<tr><td>17</td><td>IN_BR</td><td>I</td><td>Gate signal input for brake</td><td>18</td></tr>
<tr><td>19</td><td>TH1</td><td>O</td><td>Temperature detection terminal 1</td><td>20</td></tr>
<tr><td>21</td><td>TH2</td><td>O</td><td>Temperature detection terminal 2</td><td>22</td></tr>
<tr><td>23</td><td rowspan="2">(5V)</td><td rowspan="2">-</td><td rowspan="2">Terminal for applying external power 5V
(Optional)</td><td>24</td></tr>
<tr><td>25</td><td>26</td></tr>
</table>

4.2. Control Power Supply Connector (CN10)

This connector is used for applying control power supply voltage. XW4M-02D1-V1DS (made by OMRON, with 3.5mm pitch) is used.

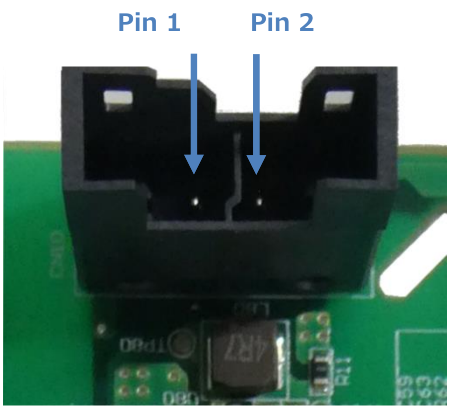


Fig. 4.2 Control Power Supply Connector (CN10)

Table 4.2 Specifications of Control Power Connector (CN10)

Pin#	Signal name	Description	Pin#	Signal name	Description
1	VDD	Power supply voltage for control	2	GND	GND

4.3. Power Module Connectors

These are the high-side, low-side and brake-circuit gate-drive output connectors for each phase (phase U, V, and W), and DESAT detection connectors. 62300421021 (made by Würth Elektronik) is used.

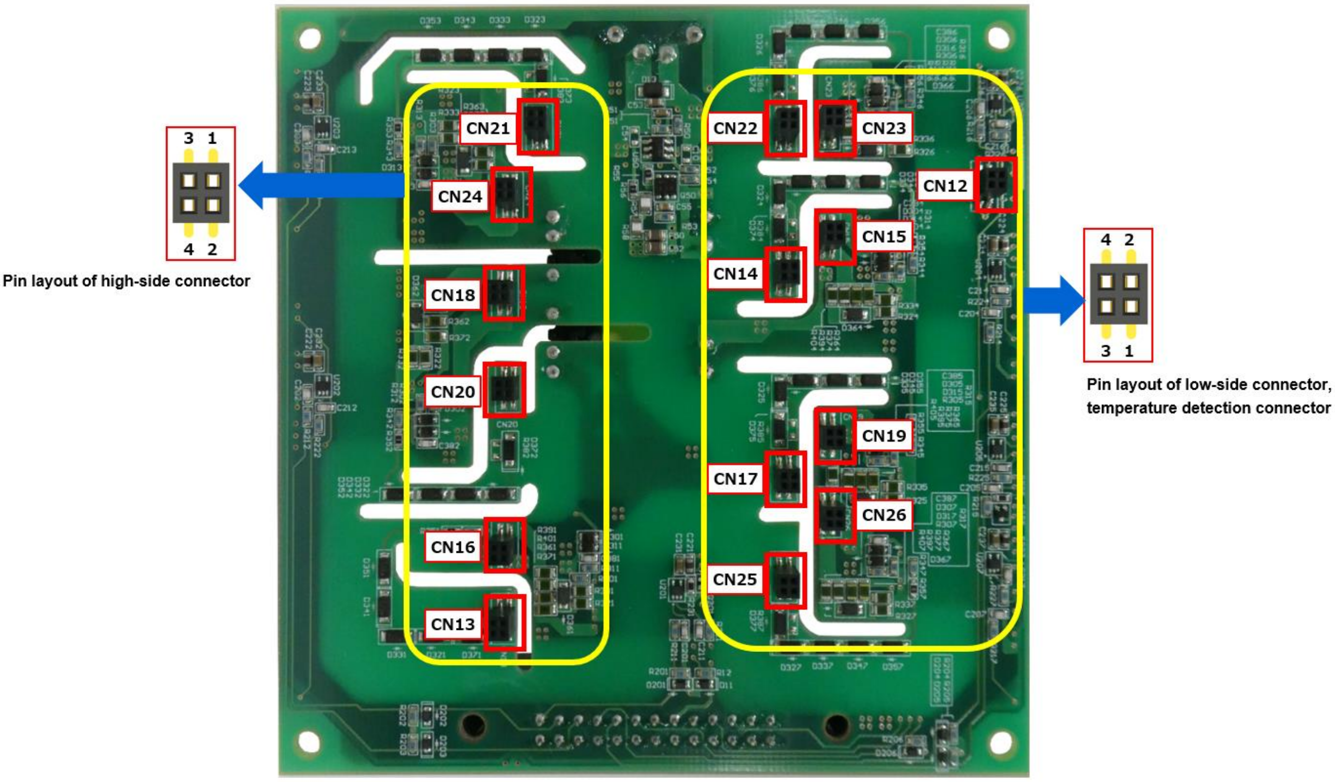


Fig. 4.3 Layout of Power Module Connectors (on Back Side of the Board)

Table 4.3 Specifications of Power Module Connectors

	Pin#	Description		Pin#	Description
CN21	1,2,3,4	W-phase high-side collector	CN22	1,2,3,4	W-phase low-side collector
CN24	1,3	W-phase high-side gate	CN23	1,3	W-phase low-side gate
	2,4	W-phase high-side emitter		2,4	W-phase low-side emitter
CN18	1,3	V-phase high-side gate	CN12	1,3	Temperature detection 1
	2,4	V-phase high-side emitter		2,4	Temperature detection 2
CN20	1,2,3,4	V-phase high-side collector	CN15	1,3	U-phase low-side gate
CN16	1,3	U-phase high-side gate		2,4	U-phase low-side emitter
	2,4	U-phase high-side emitter	CN14	1,2,3,4	U-phase low-side collector
CN13	1,2,3,4	U-phase high-side collector	CN19	1,3	V-phase low-side gate
				2,4	V-phase low-side emitter
			CN17	1,2,3,4	V-phase low-side collector
			CN26	1,3	Brake gate
				2,4	Brake emitter
			CN25	1,2,3,4	Brake collector

4.4. Jumper Resistors for External 5V (R10, R11)

An external 5V is applied to Pin23 and Pin25 of CN11, which can be used instead of the internal voltage. The jumper resistors (R10, R11) are then implemented as shown in Table4.4.

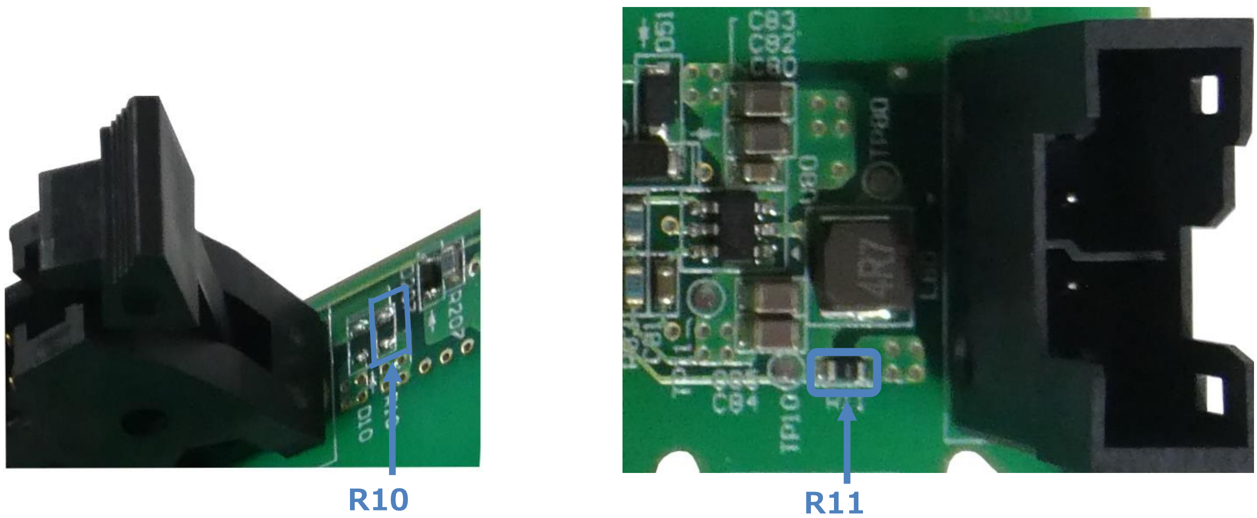


Fig. 4.4 Jumper Resistor for External 5V

Table 4.4 Mounting Specifications for Jumper Resistors

Component	Internal 5V power use	External 5V application
R10	Not Mount	Mount (0Ω resistance)
R11	Mount (0Ω resistance)	Not Mount

5. Operation

5.1. Operation Check

This section explains the operation of the circuit board alone and the power module connection status.

5.1.1. Operation Check of the Board Alone

Power module is not connected in this operation check. The operation checking details are as follows.

(1) Internal 5V output and isolated power supply output
(2) Gate-drive output and error detection signal output when DESAT detection is enabled
(3) Gate-drive output and error detection signal output when DESAT detection is disabled

(1)Check 5V output and isolated power output.
Insert the socket with lead into CN10 and the socket with flat cable into CN11 to turn on the 24V power supply for control of CN10.
Check that 5V regulator output and isolated DC-DC power output are as shown in Table 5.1.

Table 5.1 Operation Check

Item		Output	Measurement point
Internal 5V power		5V±5%	TP10 (+)-TP11 (-): Red circle
For U-phase gate drive	Positive supply voltage	16V±5%	TP16 (+)-TP17 (-): Orange circle
For V-phase gate drive			TP19 (+)-TP20 (-): Blue circle
For W-phase gate drive			TP26 (+)-TP27 (-): Black circle
For driving the low-side gate			TP33 (+)-TP34 (-): Purple round
For U-phase gate drive	Negative supply voltage	-8V±5%	TP18 (+)-TP17 (-): Orange circle
For V-phase gate drive			TP21 (+)-TP20 (-): Blue circle
For W-phase gate drive			TP28 (+)-TP27 (-): Black circle
For driving the low-side gate			TP35 (+)-TP34 (-): Purple round

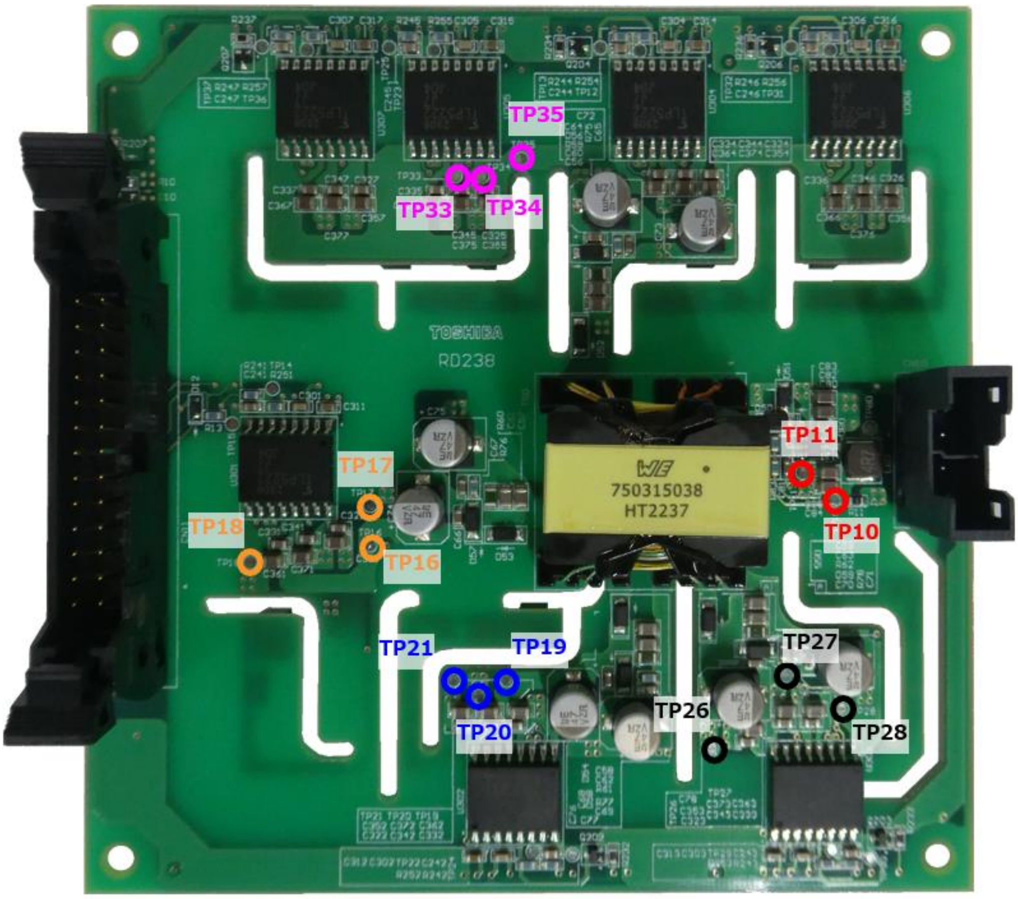


Fig. 5.1 Measurement Positions for Checking Operation

(2)Check of gate-drive output and error detection signal output when DESAT is detected

Apply voltage to the gate control signal pin and enable signal pin according to Table 5.2, and check the gate drive output and error detection output.

Table 5.2 Checking High-Side and Low-Side Operation

Gate control signal Input voltage	Enable signal Input voltage	Gate drive output voltage	Error detection output voltage
No-input or 0V	No-input or 5V	-8.0V±5%	5V
5V			0V
No-input or 0V	0V		5V
5V			

Since a pull-down resistor is mounted on the gate control signal input pin, the gate drive output is turned-8.0V even if the gate control signal is not input.

The enable signal input pin has a pull-up resistor inside, when no signal input, it is a high level. To set it to a low level, input a 0V signal.

Refer to Table 4.1 for the input voltage application terminals.

<Gate drive output measurement location>

・Voltage between Pin1 (3) and Pin2 (4) on the connectors below
CN16 (U-phase high-side), CN18 (V-phase high-side), CN24 (W-phase high-side),
CN15 (U-phase low-side),CN19 (V-phase low-side), CN23 (W-phase low-side),
CN26 (braking)

<Error detection output measurement location>

・Error detection output pin: Voltage between Pin15(FAULT) and Pin2 of CN11

(3) Checking gate-drive output and error-detection-signal output when no DESAT is detected

After turning OFF the control power supply, short-circuit the gate-drive-output and DESAT detection connectors with lead clips, etc. as shown in Table 5.3. Turn on the control power supply voltage 24V again, apply a voltage to the gate control signal input pin and enable signal input pin according to Table 5.4, and check the gate drive output and error detected output.

Table 5.3 Short Positions

Phase	Connectors to be shorted	
U-phase high-side	CN16/2pin	CN13/1pin
U-phase low-side	CN15/2pin	CN14/1pin
V-phase high-side	CN18/2pin	CN20/1pin
V-phase low-side	CN19/2pin	CN17/1pin
W-phase high-side	CN24/2pin	CN21/1pin
W-phase low-side	CN23/2pin	CN22/1pin
Brake	CN26/2pin	CN25/1pin

Refer to Fig. 4.3 for the connector position and terminal arrangement to be shorted.

Table 5.4 Checking High-Side and Low-Side Operation

<table>
<tr><th>Gate control signal
Input voltage</th><th>Enable signal
Input voltage</th><th>Gate drive output voltage</th><th>Error detection
output voltage</th></tr>
<tr><td>No-input or 0V</td><td rowspan="2">Non-input or 5V</td><td>-8.0V±5%</td><td rowspan="4">5V</td></tr>
<tr><td>5V</td><td>16V±5%</td></tr>
<tr><td>No-input or 0V</td><td rowspan="2">0V</td><td rowspan="2">-8.0V±5%</td></tr>
<tr><td>5V</td></tr>
</table>

Terminals input to the gate control signal and enable signal in Table 5.4 and measurement locations of gate drive output and error detection output are the same as those described in Table 5.2.

When the board is confirmed as normal, proceed with “Power Module Connection Operation Check”.

5.1.2. Power Module Connection Operation Check

Connect this design, the converter board for connecting the power module, and the power module, and apply 24V to CN10. Then, apply high voltage to the power module.

When a gate control signal (low-side or high-side) is input from an external controller to CN11 of this design, the connected power module will switch based on the gate control signal.

When operating the power module complementarily, the gate control signals on the high-side and low-side must have a dead-time. Never operate the power module on the high-side and low-side simultaneously (arm short-circuit).

This design does not have a dead-time generation function.

<Reference>

Fig. 5.2 shows the connection example of this design, the Power module connection board, and the power module.

Fig. 5.3 shows the measurement block diagram.

Fig. 5.4 shows the switching waveform example (U-phase low-side) when a power module is connected.

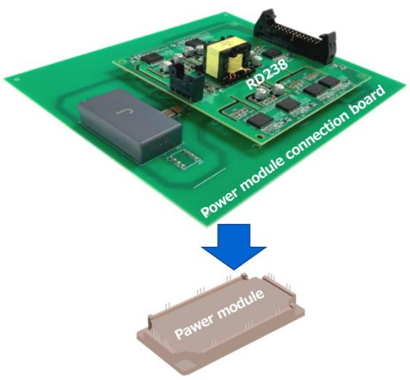


Fig. 5.2
Connection Example of
a Power Module Connection Board

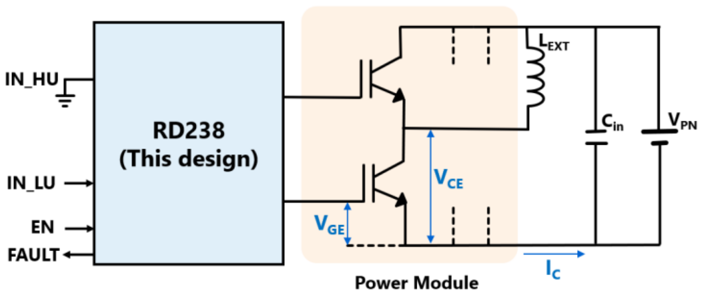


Fig. 5.3 Measurement Block Diagram

Measuring conditions: V_{PN} = 600 V, I_D =150 A, Inductive-load L_{EXT} = 200μH, T_a = 25°C, U-phase low-side, Cin = 0.22μF

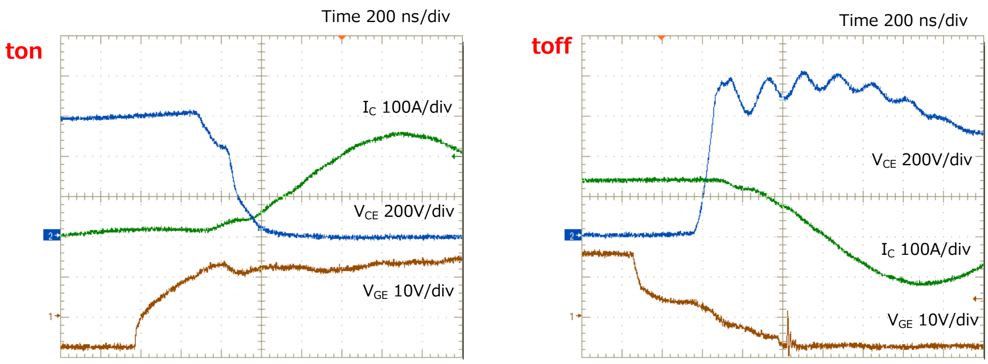


Fig. 5.4 Switching Waveforms Example

Prepare a separate power module connection board so that the power module pins can be connected to the connector of this design according to Table 4.3.

5.1.3. Each Protection Function

The protection functions include DESAT detection for overcurrent protection/short-circuit protection, under voltage lock out (UVLO) of gate-voltage for overheat protection of the power module, and active miller clamp for self-turn-on protection. Only when DESAT detector operates, the gate-drive voltage is soft-shut down, and FAULT signal of Pin15 of CN11 becomes L-level. Then, FAULT is returned to H-level automatically by function of TLP5222. Each protection operation is as follows.

(1) UVLO (Under Voltage Lock Out)

Prerequisites: For gated input signal (5V applied) and enable input signal (open or 5V applied), the same operation is performed on 7 channels.

① V_{UVLO-} (Gated Positive Power UVLO Detect)

If VCC2 - VE is reduced from normal operation (VCC2 – VE = 16V), UVLO runs in VCC2 - VE < 10V (Typ.) and the gate-drive-voltage is turned VE – VEE = -8.0V to turn off the power module.

② V_{UVLO+} (Gated Positive Power UVLO Cancel)

If VCC2-VE is increased, UVLO is released at VCC2 - VE > 11.4V (Typ.), the gate-drive-voltage is turned VCC2 – VE = 16V, and the power module is turned on.

(2) Overcurrent protection by detecting DESAT (UVLO is inactive)

① 5V is applied to Pin1 of CN11 and the gate-drive-voltage is normally turned on. (normal operation)

② DESAT detection operates in comparing the DESAT pin voltage, which changes based on collector-emitter voltage, and DESAT threshold voltage (6.6V (Typ.)).

③ When the DESAT pin voltage exceeds the DESAT threshold voltage of 6.6V (Typ.), it detects the overcurrent and initiates the protection operation.

④ Soft shutdown (gradual OFF transition) of the gate-drive voltage to turn off the power module.

⑤ Error detection signal (FAULT signal) changes from 5V to 0V to notify the error.

(3) Prevention of malfunction by active miller clamp

If noise is applied externally to the capacitive component that exists between the collector and gate of the power module, an unintended current is generated, causing malfunction. The active miller clamp prevents this malfunction.

5.2. Adjusting Circuits

5.2.1. Adjusting the Gate Resistance

This design implements a forward diode in the turn-off current path. You can adjust the turn-on and turn-off times to match the actual specifications. Adjust while paying attention to the operation and heat generation of each component. Table 5.5 shows the resistor specifications implemented in this design.

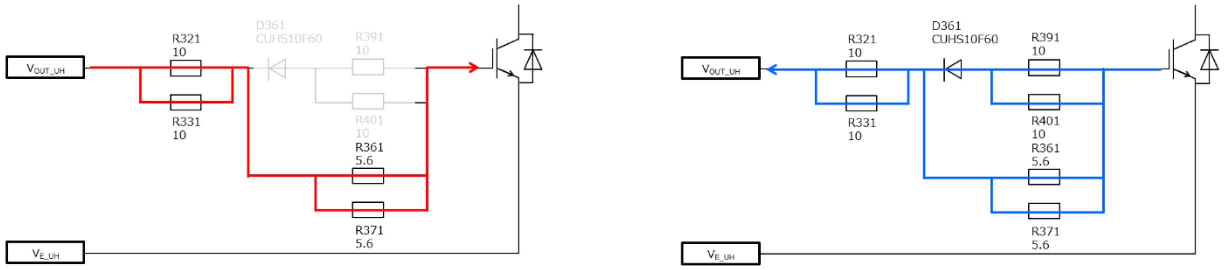


Fig. 5.5 Gate Resistance Configuration Diagram of Turn-on / Turn-off

Table 5.5 Gate Resistance Specifications

Component Number	Configuration	Resistance at turn-on	Resistance at turn-off	Resistance Specifications
R32x	Parallel	✓	✓	Rectangular chip resistor (0.5W,10Ω,2012mm)
R33x		✓	✓	
R36x	Parallel	✓	✓	Rectangular chip resistor (0.5W,5.6Ω,2012mm)
R37x		✓	✓	
R39x	Parallel	-	✓	Rectangular chip resistor (0.5W,10Ω,2012mm)
R40x		-	✓	

Component number suffix indicates the number of each phase as shown below.

U-phase high-side : 1, V-phase high-side : 2, W-phase high-side : 3

U-phase low-side: 4, V-phase low-side: 5, W-phase low-side: 6, Braking: 7

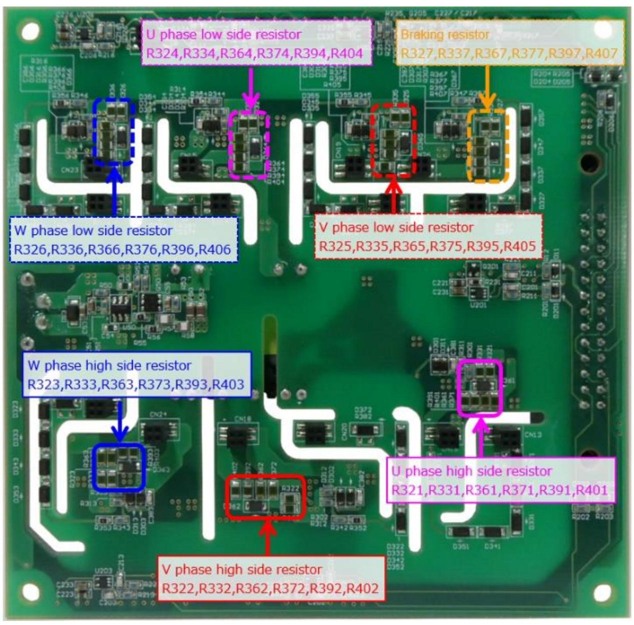


Fig. 5.6 Gate Resistor Layout

5.2.2. Adjusting DESAT Detection Voltage (R34x, R35x, D32x, D33x, D34x, D35x, D37x)

This design has R34x = 820Ω /R35x = 0Ω, high withstand voltage diodes at D32x/D33x/D34x/D35x, and a zener diode at D37x. DESAT detection voltage can be changed by adjusting the resistor value, number of high withstanding voltage diodes in series, and zener voltage according to the actual specifications.

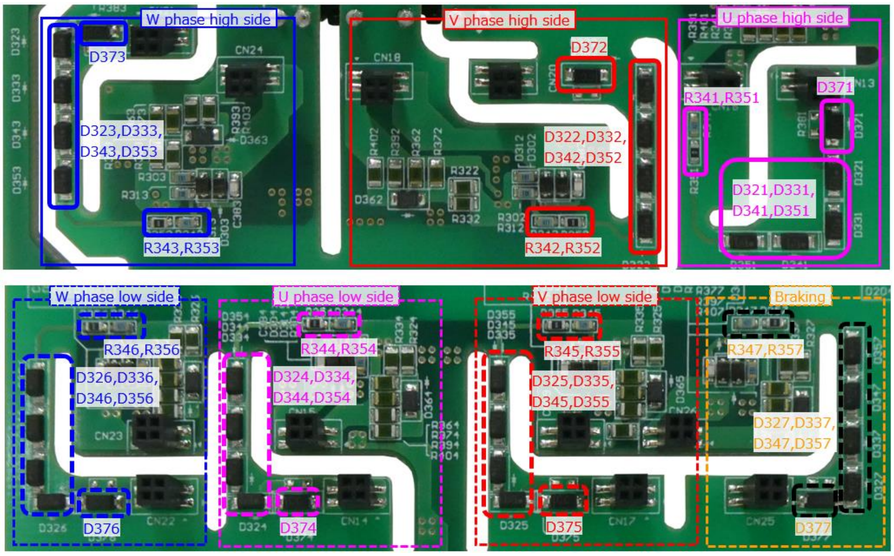


Fig. 5.7 DESAT Detection Resistor Layout

5.2.3. Adjusting DESAT Detection Duration (C38x, R31x)

This design includes a 100pF blanking capacitor (C38x) and a 30kΩ V_{OUT}-DESAT resistor (R31x). Set the protective function in C38x and R31x within the short-circuit withstand time of the power module.

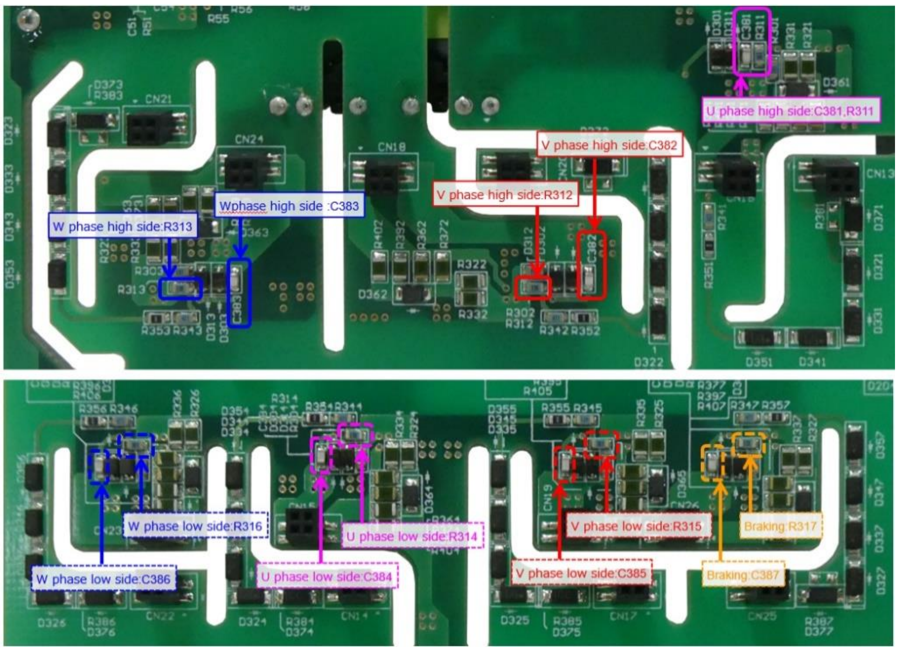


Fig. 5.8 Blanking Capacitor Layout

5.2.4. Adjusting the Input-Signal RC Filter (C20x/R21x)

This design has a RC filter (C20x = 470pF, R21x = 1kΩ) mounted on the gate-control input to prevent malfunction due to external noises.

Adjust the filter constant to increase the noise suppression effect according to the actual environment.

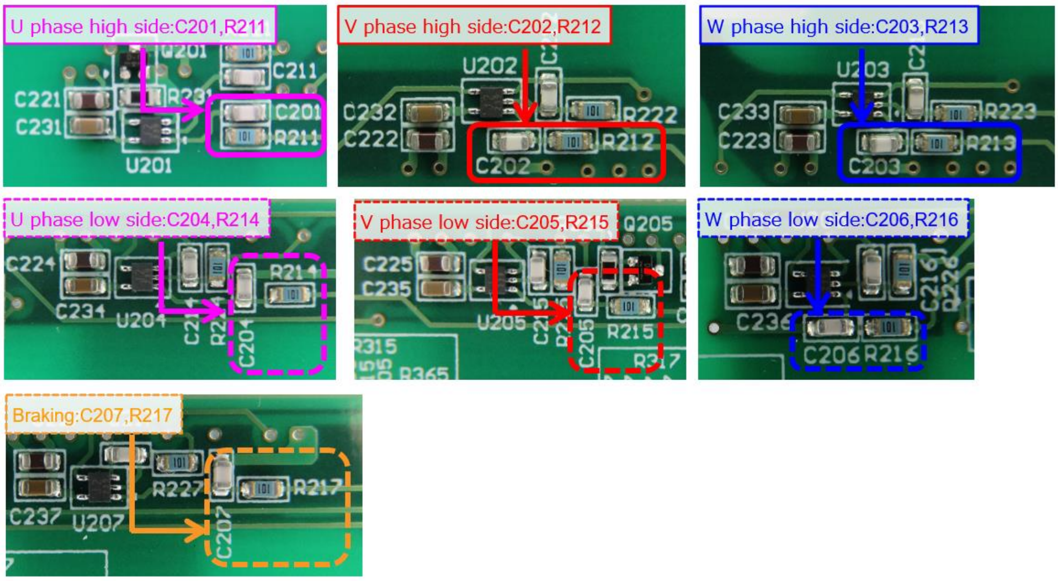


Fig. 5.9 RC Filter Layout

5.3. Precautions

Pay special attention to the following when operating.

- Make sure that the polarities of the connectors and terminals are correct before supplying power.
- High voltage is applied to the smoothing capacitor, and it takes time to fully discharge the capacitor even after the power is turned off. Make sure that the capacitor is sufficiently discharged before touching the BOARD.
- When checking the operation, cover the BOARD with an acrylic case for safety.
- MOSFETs and other components generate heat during operation. Be careful not to get burned when handling them.

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