3-Phase Inverter Using SiC MOSFET

Reference Guide

RD220-RGUIDE-02

TOSHIBA ELECTRONIC DEVICES & STORAGE CORPORATION

Table of Contents

1. Introduction

This Reference Guide (hereafter referred to as this Guide) describes the specifications and operation procedure of the 3-Phase Inverter (hereafter referred to as this Inverter) Using SiC MOSFET.

3-phase inverters are used to drive induction and synchronous motors used in industrial applications. At AC 400 V output, it is common to use an IGBT having a withstand voltage of 1200 V as a conventional switching device. However, SiC (silicon carbide) based SiC MOSFET developed in recent years, can reduce on-resistance while maintaining higher breakdown voltage compared to conventional Si (silicon) MOSFET. For the purpose of improving the inverter efficiency 1200 V SiC MOSFETs have been adopted and studied as switching elements to replace 1200 V IGBTs.

In this inverter, SiC MOSFET TW045Z120C (TO-247-4L(X) package) or TW045N120C (TO-247 package) is used to achieve higher efficiency for driving AC 440 V motors. TLP5774H is used as a gate driver to realize a high-speed isolated gate drive. And, the isolation amplifier TLP7820 is used to realizes isolated sensors such as motor phase current sensor and bus voltage sensor.

2. Specifications

Table 2.1 lists the main specifications of this inverter.

2.1 Specifications of the 3-Phase Inverter Using SiC MOSFET

Item	Specifications
Power In (AC-DC Board)	3-phase AC 340 to 440 V, 16 A (Max.)
Power Out (AC-DC Board)	DC 530 to 600 V
Control Power Out (AC-DC Board)	DC 20 V, 1.5 A (Max.)
Power Input (Inverter Board)	DC 530 to 670 V
Power Output (Inverter Board)	3-phase AC 340 to 440 V, 15 A
Control Power Input (Inverter Board)	DC 20 V
Inverter Drive System	2-level system
Switching Frequency	100 kHz (Max.) (set by software)
Sensor Output for Controller	Motor-output phase current (U-phase/V-phase/W-phase) Bus voltage Heat sink temperature
Fault Detection	Overcurrent error (U-phase/V-phase/W-phase) Bus overvoltage error Bus overcurrent error Overtemperature error (Heat sink temperature and Inrush prevention relay temperature)
Cooling System	Convection cooling, Forced air cooling
Board Size	250 x 145 mm
Board Layer Configuration	Four-layer through-hole (outer layer: 70 μm, inner layer: 70 μm)

2.1. Circuit Block Diagram

Figure 2.1 shows the block diagram of the inverter board of this inverter.

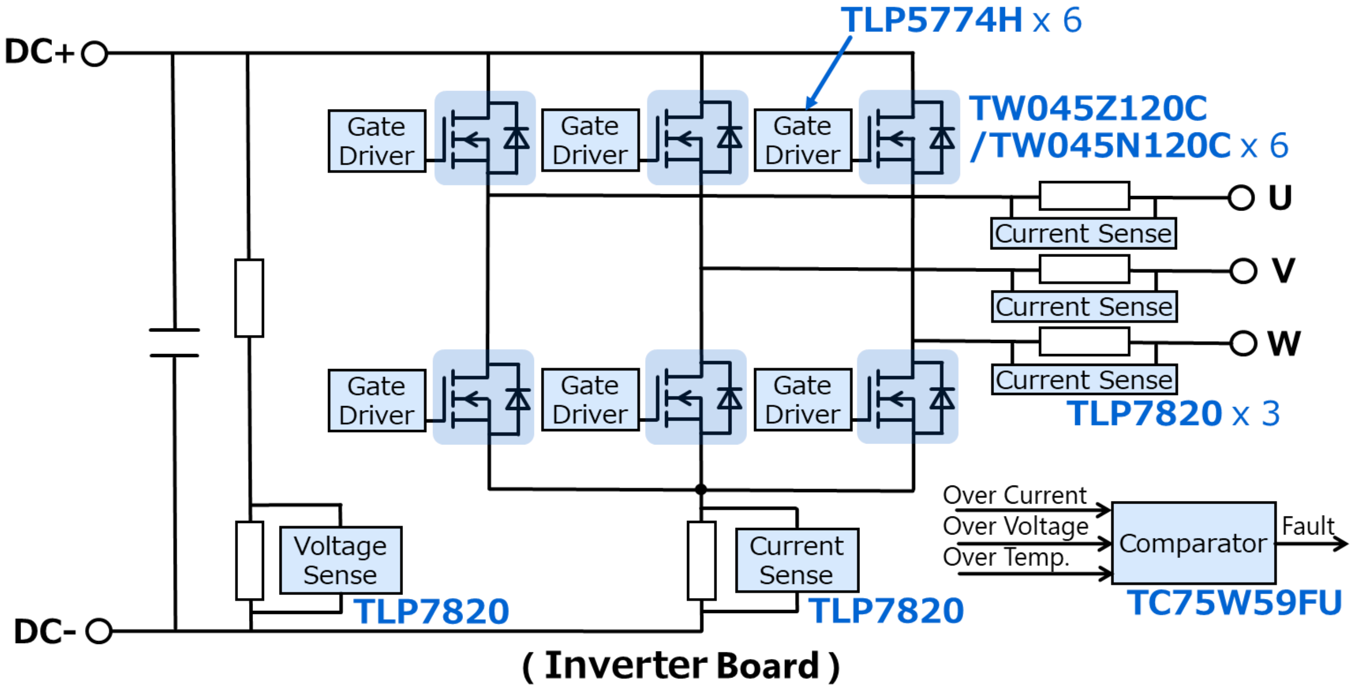

Fig. 2.1 3-Phase Inverter Using SiC MOSFET (Inverter Board)

2.2. Appearance and Component Layout

The appearance of this inverter is shown in Figures 2.2 to 2.5, and the layout of main components is shown in Figures 2.6 to 2.9.

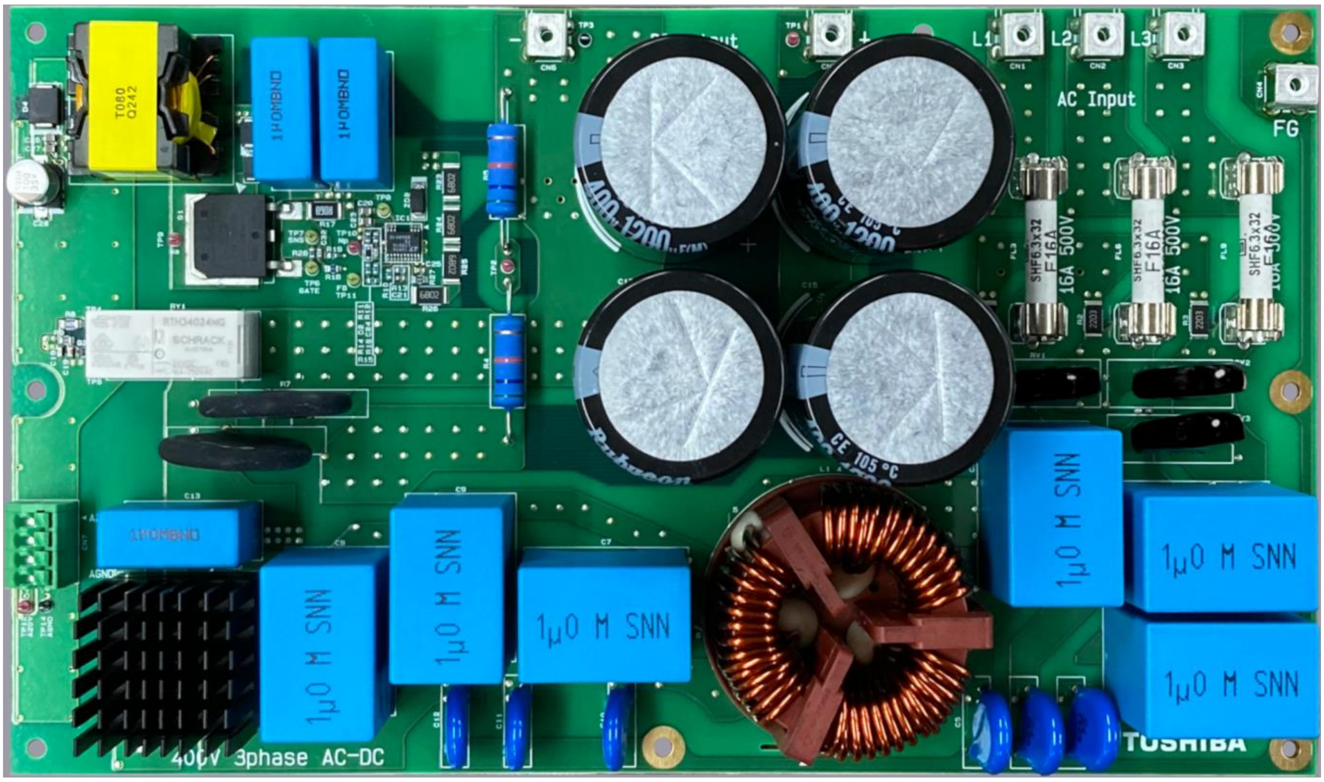

Fig. 2.2 3-Phase Inverter Using SiC MOSFET (AC-DC board) Front View

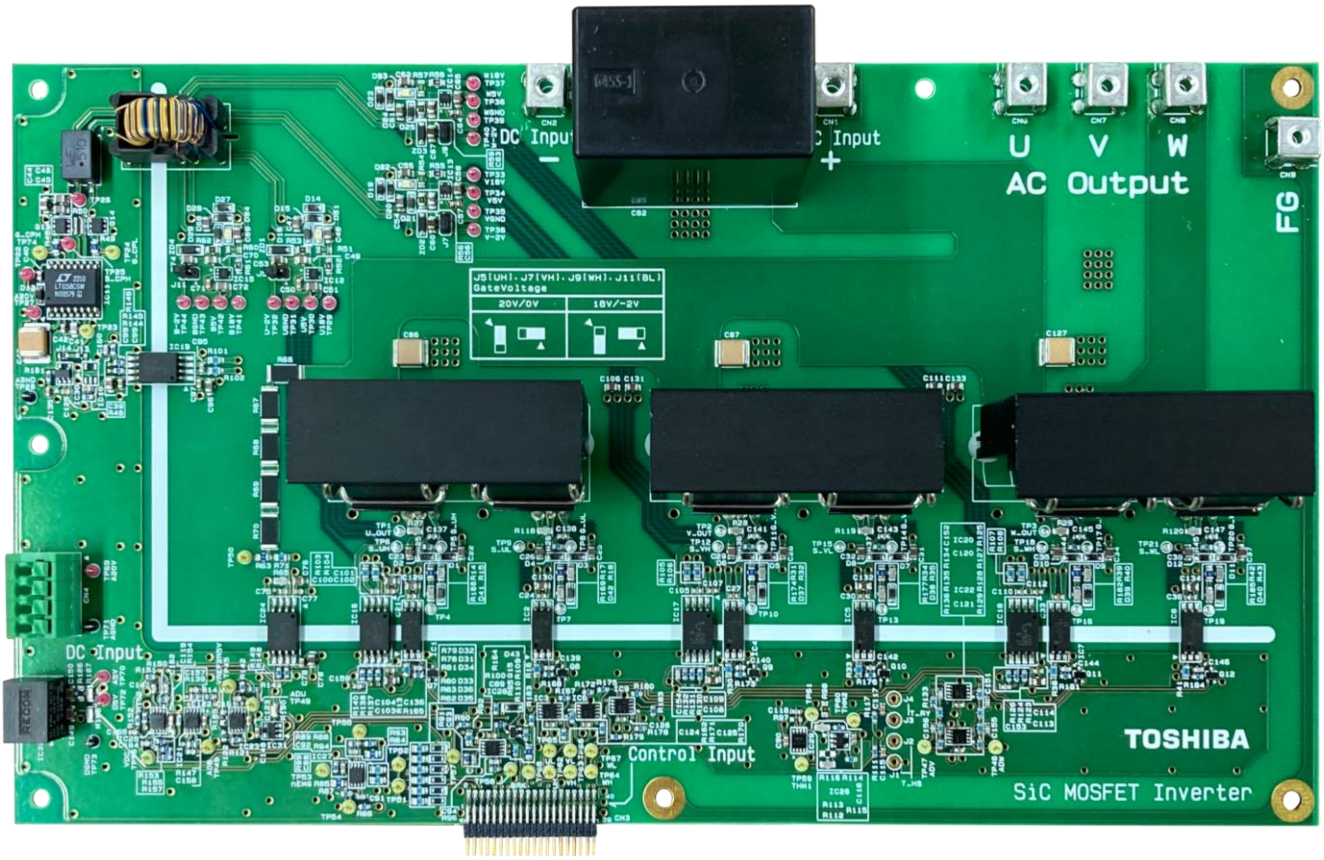

Fig. 2.3 3-Phase Inverter Using SiC MOSFET (Inverter Board) Front View

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Fig. 2.4 3-Phase Inverter Using SiC MOSFET (Inverter Board with TW045Z120C) Side View

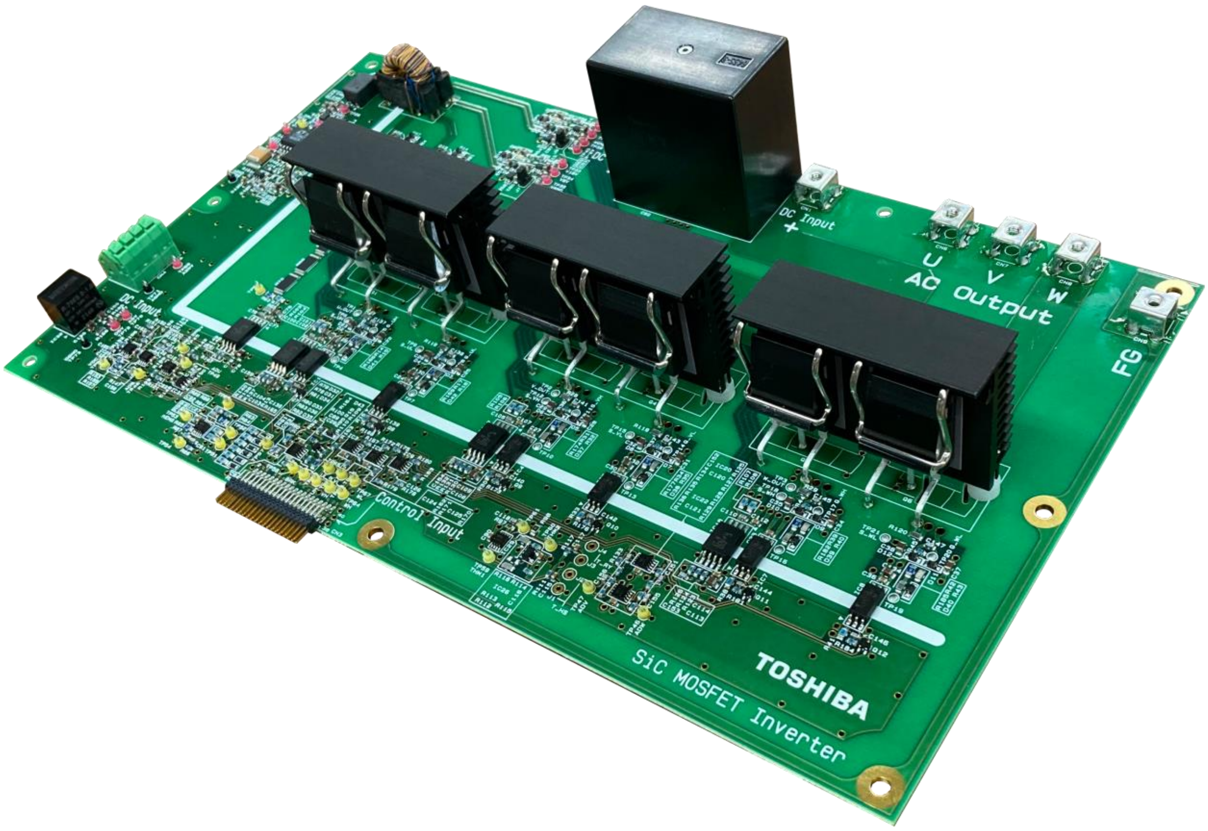


Fig. 2.5 3-Phase Inverter Using SiC MOSFET (Inverter Board with TW045N120C) Side View

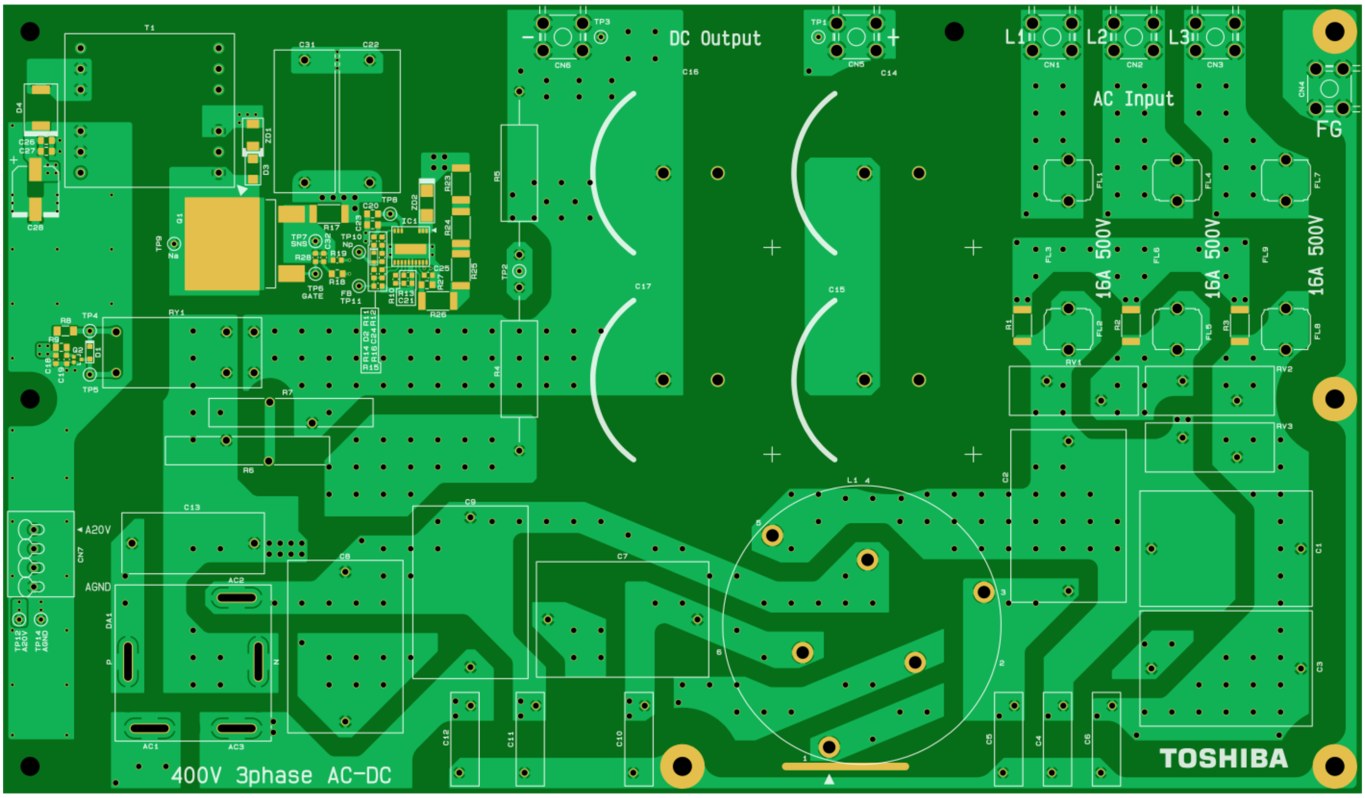


Fig. 2.6 Main Component Layout (AC-DC Board) Front

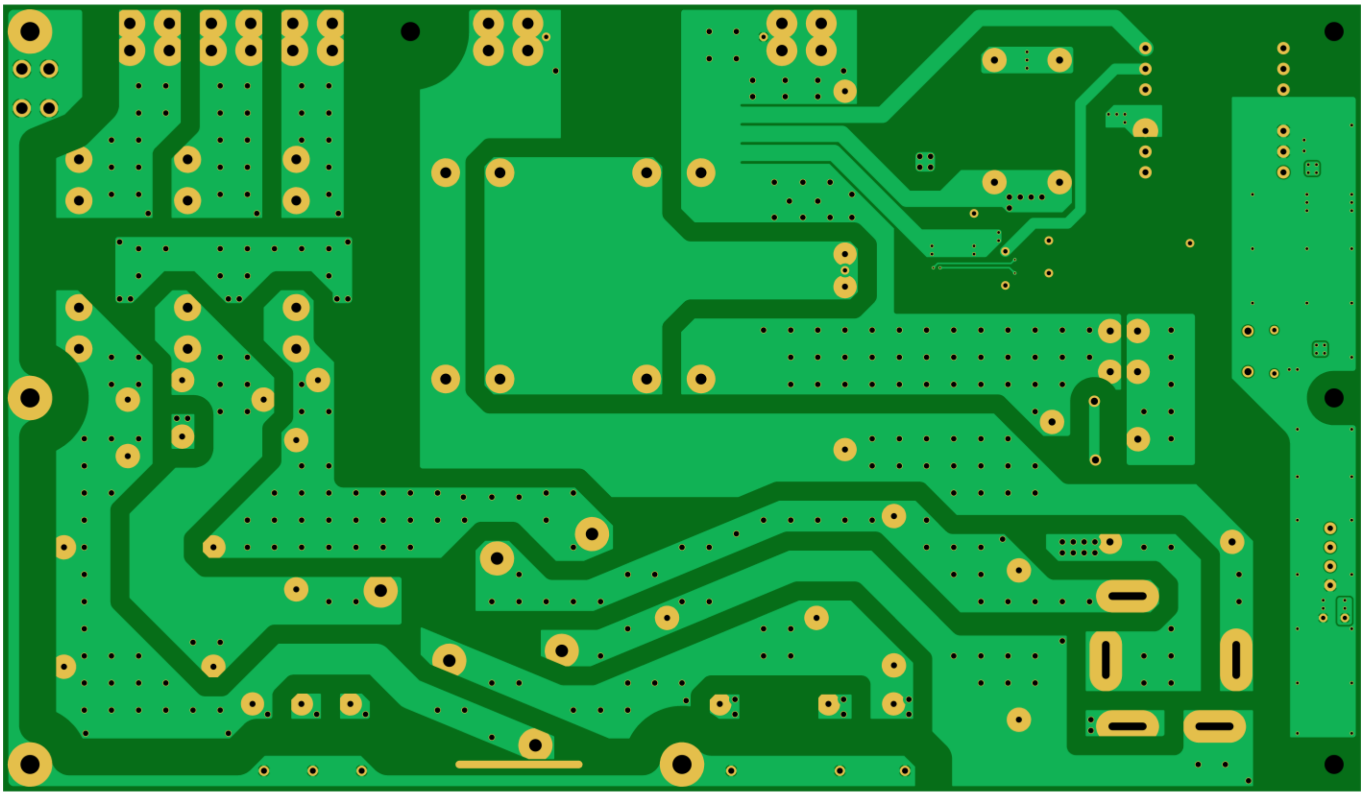


Fig. 2.7 Main Component Layout (AC-DC Board) Back

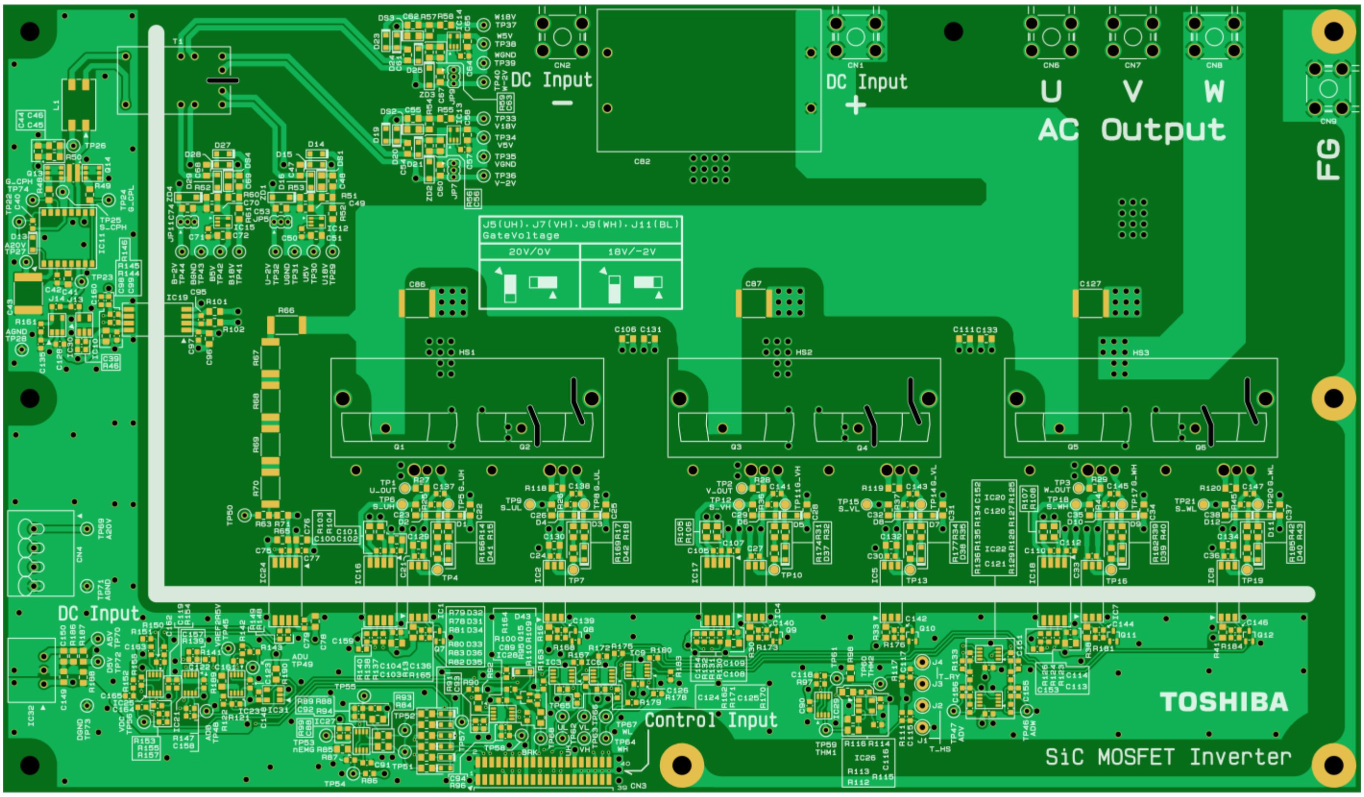


Fig. 2.8 Main Component Layout (Inverter Board) Front

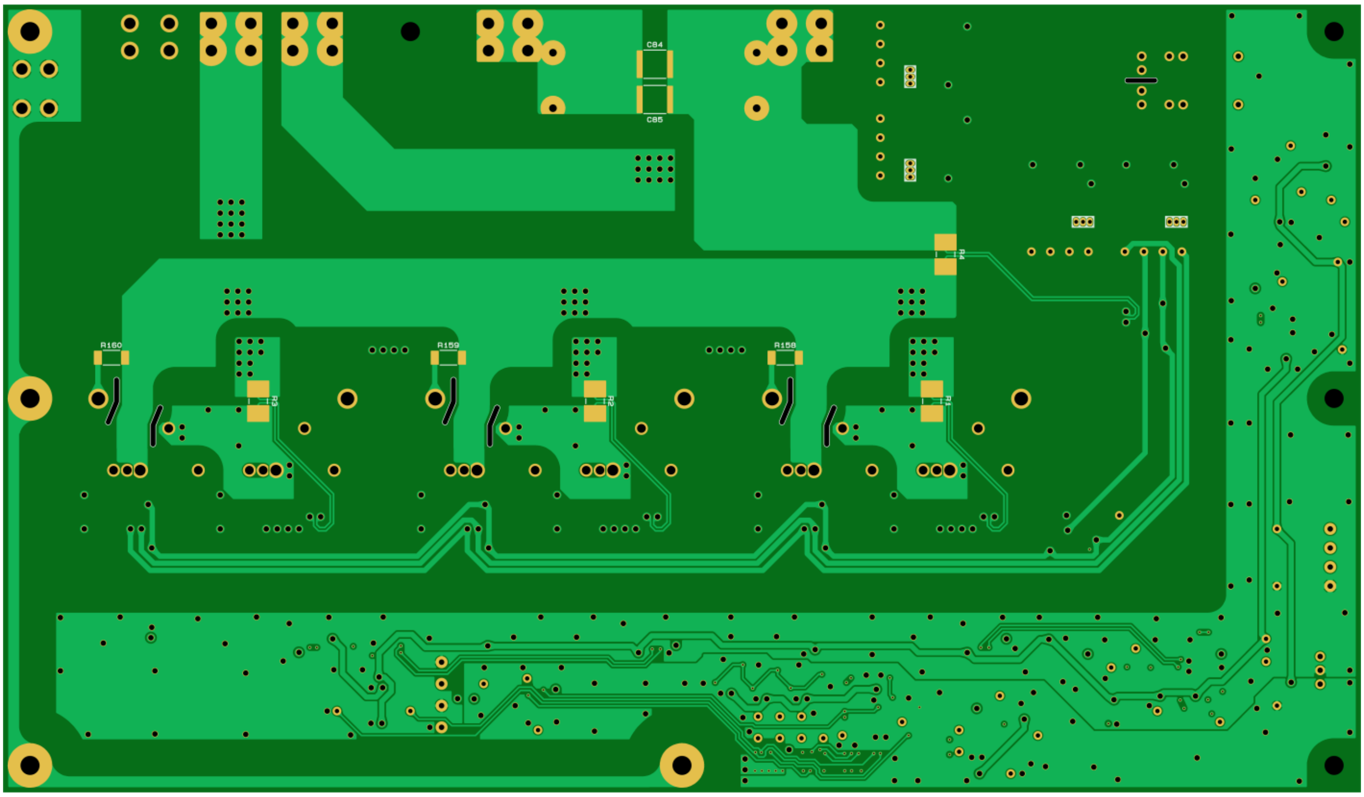


Fig. 2.9 Main Component Layout (Inverter Board) Back

3. Schematic, Bill of Material, and PCB Pattern

3.1. Schematic

Refer to the following files:

RD220-SCHEMATIC1-xx.pdf (AC-DC board)
RD220-SCHEMATIC2-xx.pdf (Inverter board)
(xx is the revision number.)

3.2. Bill of Material

Refer to the following files:

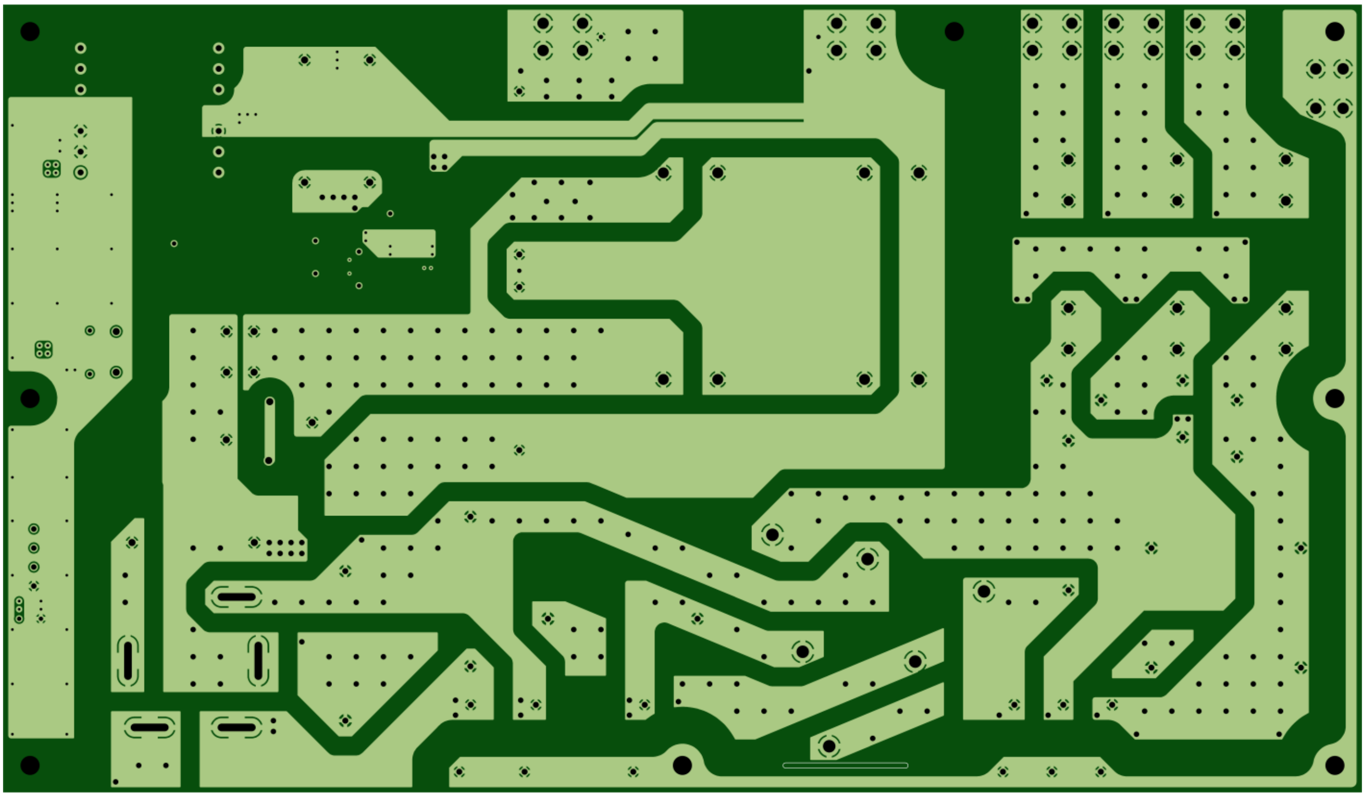
RD220-BOM1-xx.pdf (AC-DC board)
RD220-BOM2-xx.pdf (inverter board)
(xx is the revision number.)

3.3. PCB Pattern

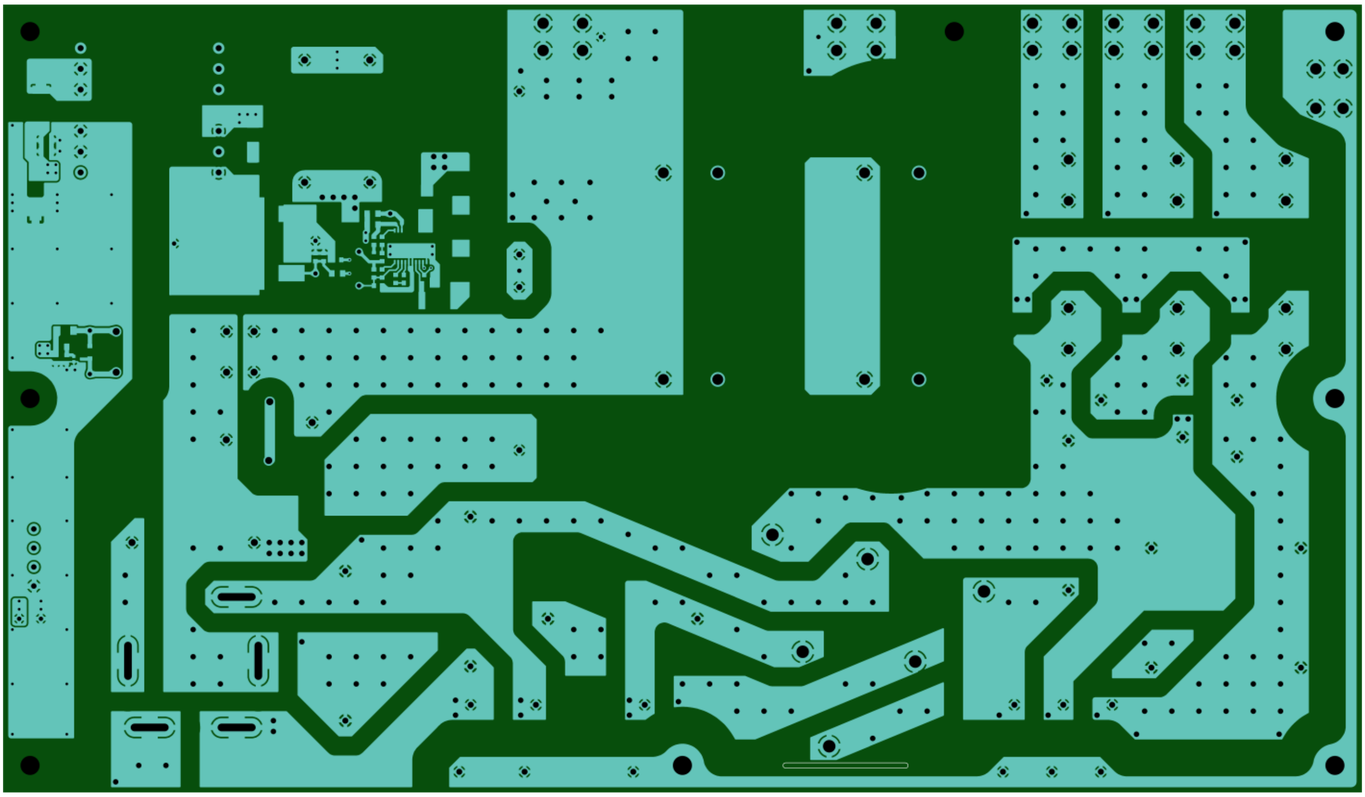
Fig. 3.1 shows the pattern diagram of this inverter.

Refer to the following files:

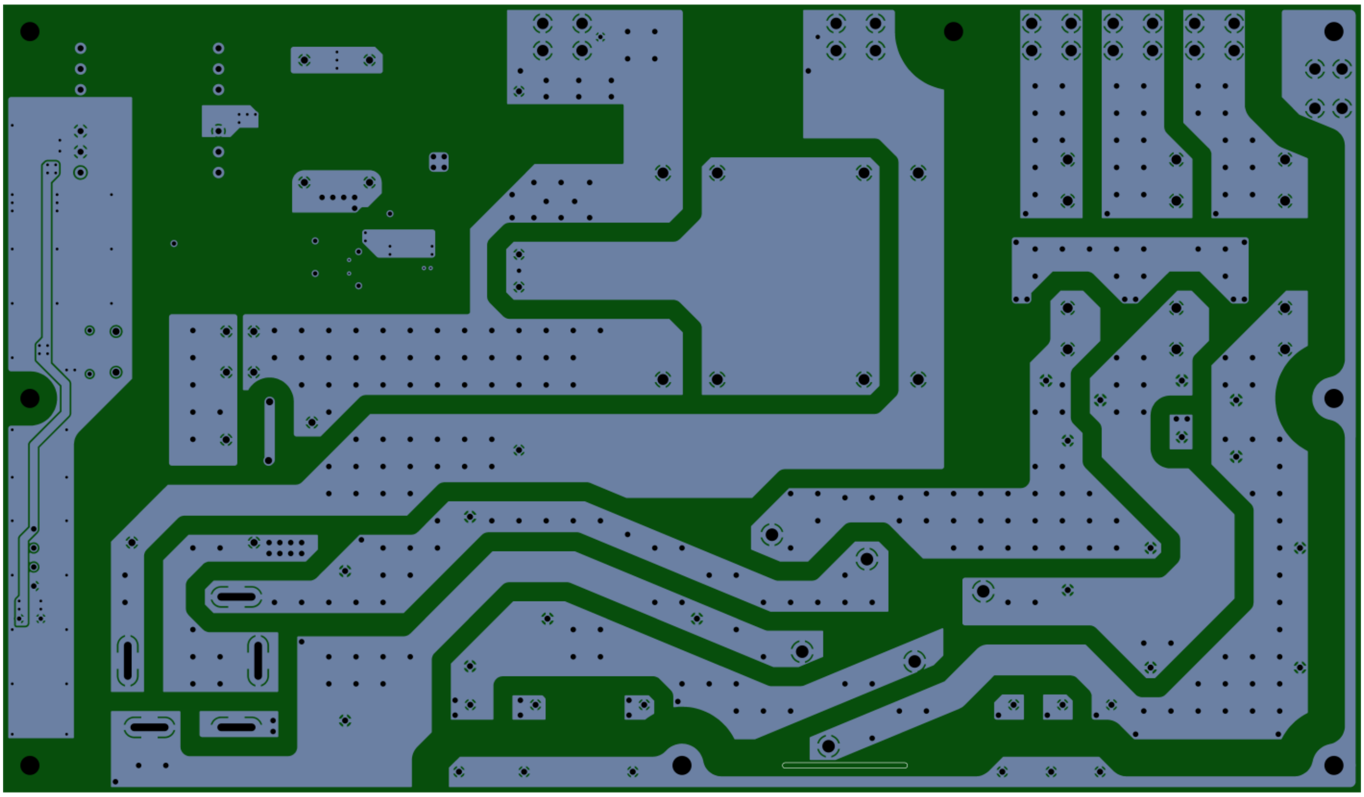
RD220-LAYER1-xx.pdf (AC-DC board)
RD220-LAYER2-xx.pdf (inverter board)
(xx is the revision number.)



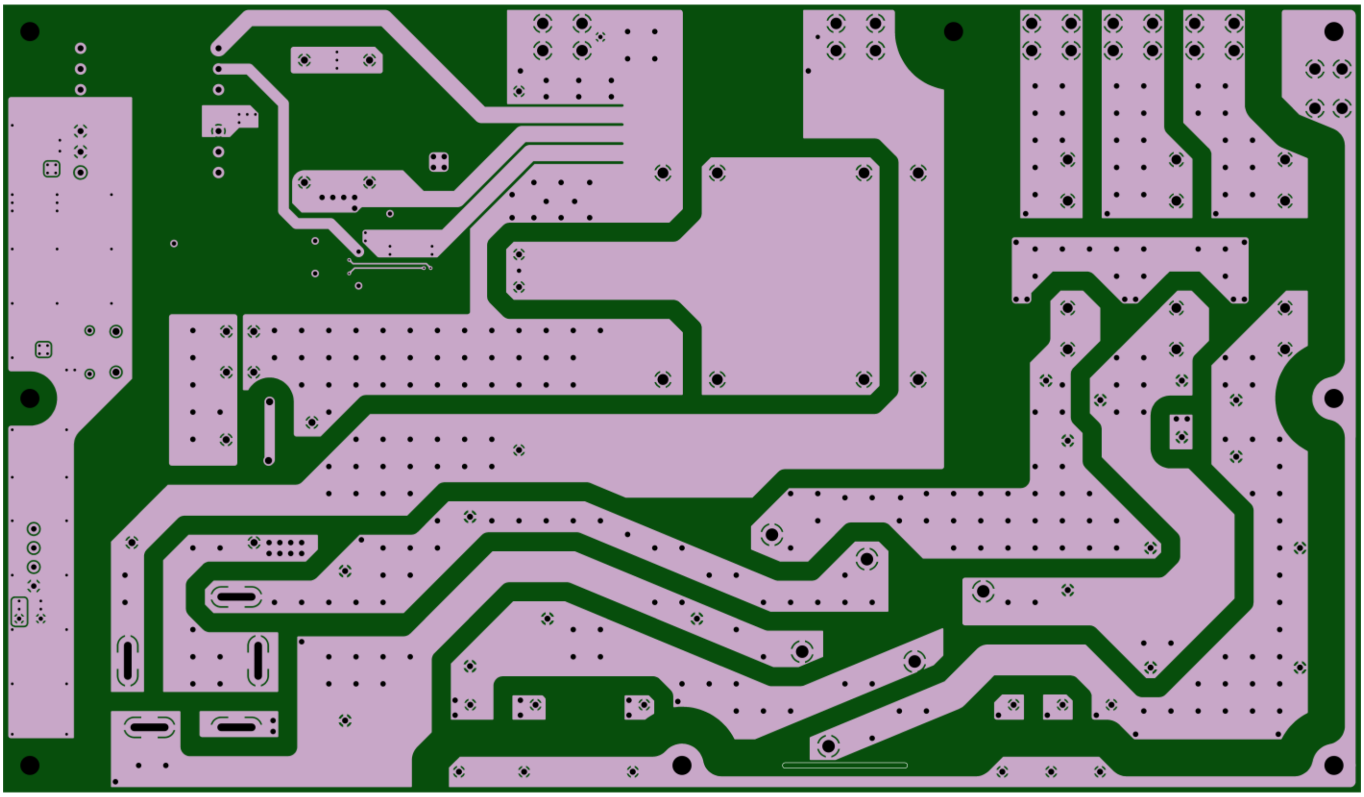
<AC-DC Board, Layer 1 Front>



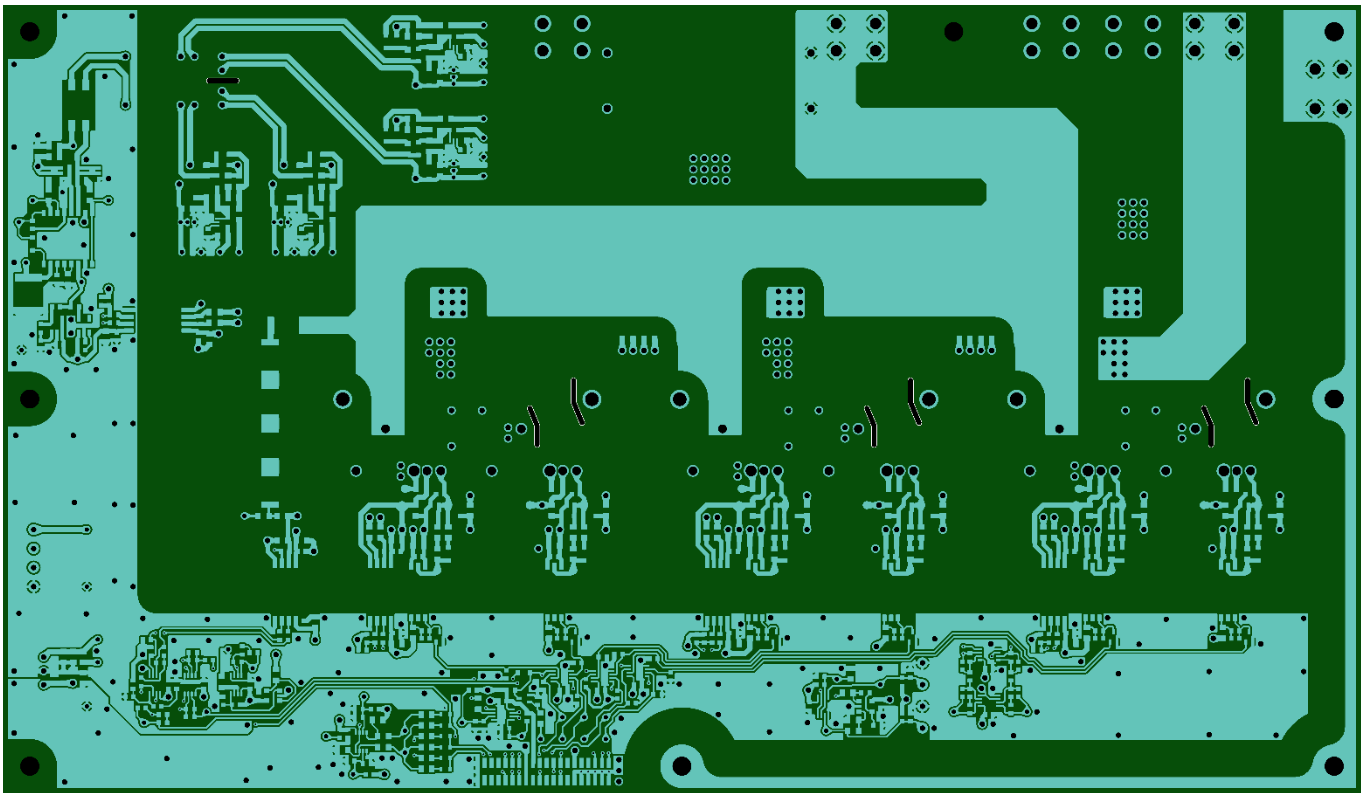
<AC-DC Board, Layer 2>



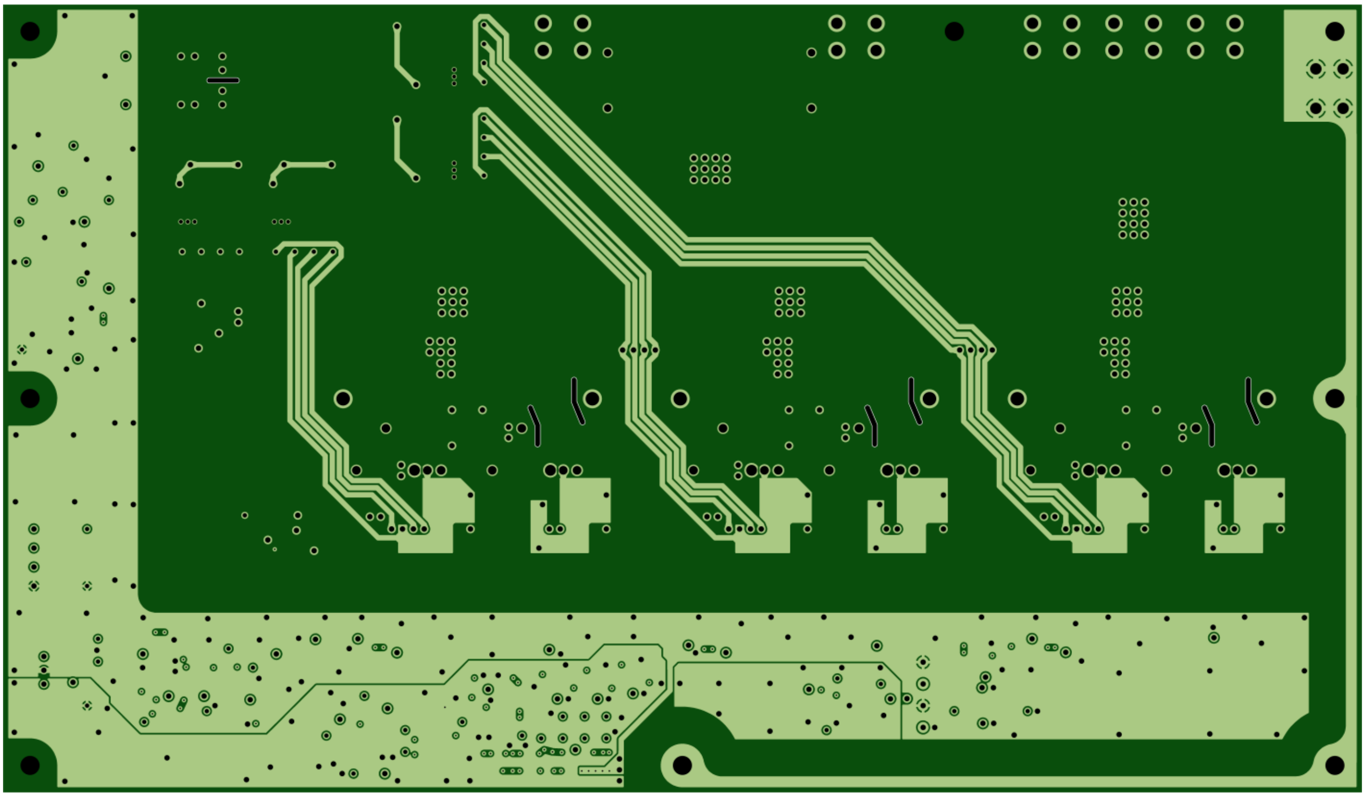
<AC-DC Board, Layer 3>



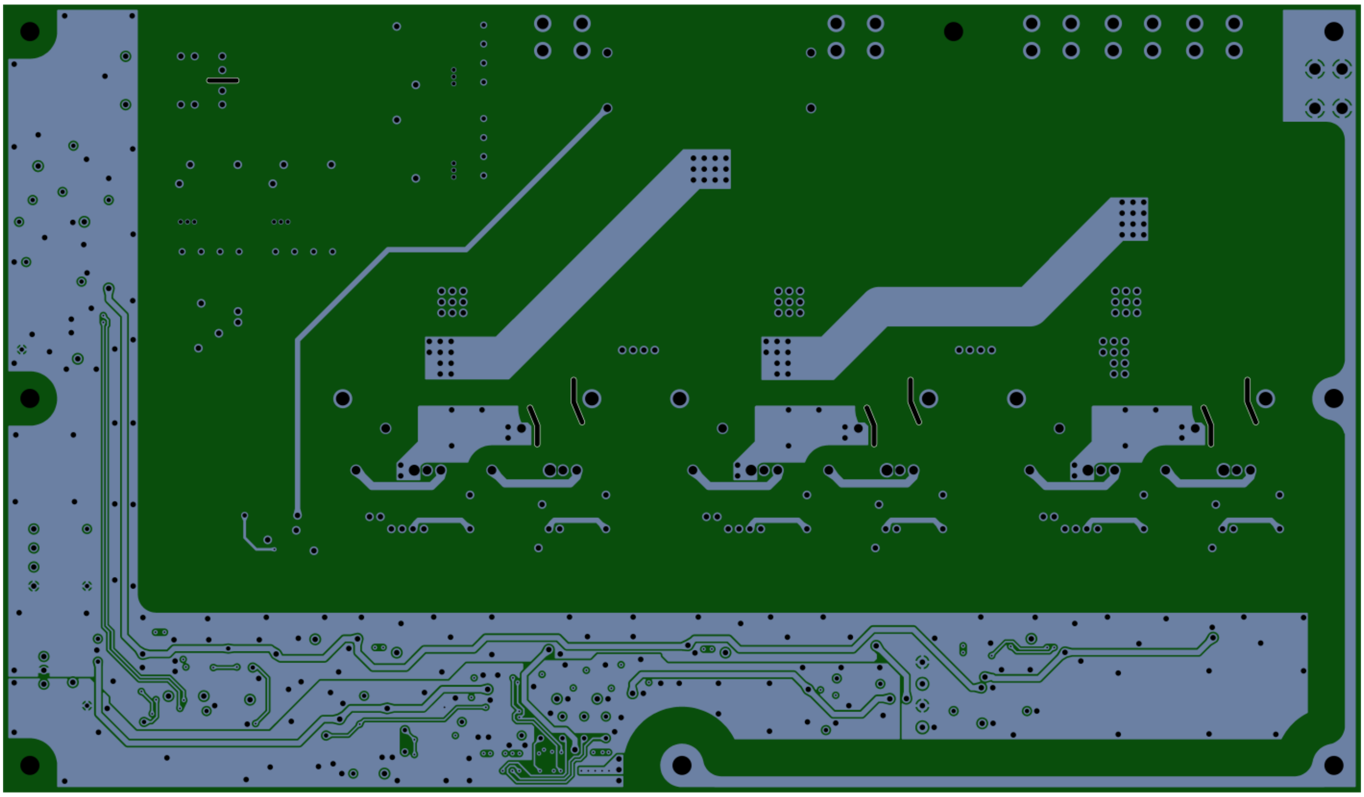
<AC-DC Board, Layer 4 Back>



< Inverter Board, Layer 1 Front >



< Inverter Board, Layer 2>



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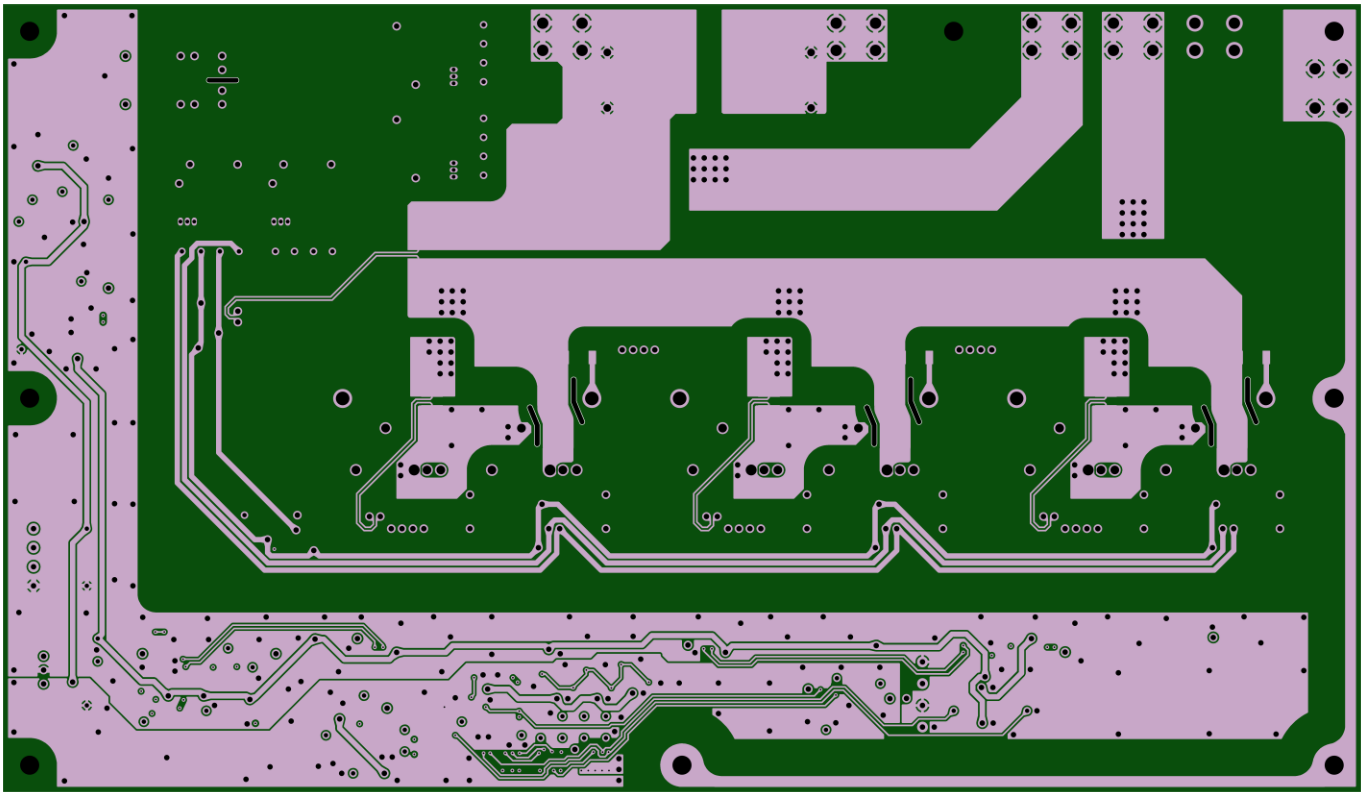

< Inverter Board, Layer 4 Back >

Fig. 3.1 PCB Pattern Diagram (Front View)

4. Operation

4.1. Names and Functions of Components

4.1.1. 3-Phase AC Input Terminal (AC-DC Board, CN1, CN2, CN3)

This is a terminal for 3-phase AC power input. OT-005 (Osada) is being used. Connect using a M3 ring terminal, etc. Every line is connected to AC-DC converted via AC 500 V, 16 A fuse (FL3, FL4, FL5) 8020.508 (SCHURTER).

Fig. 4.1 3-Phase AC Input Terminal (CN1, CN2, CN3)

Table 4.1 3-Phase AC Input Terminal Specifications

Connector	Signal Name	
CN1	L1	3-phase AC input (R)
CN2	L2	3-phase AC input (S)
CN3	L3	3-phase AC input (T)

4.1.2. FG Terminal (AC-DC Board, CN4)

This is frame ground terminal. OT-005 (Osada) is being used. Connect to an appropriate frame ground with a M3 ring terminal, etc.

Fig. 4.2 FG Terminal (CN4)

Table 4.2 FG Terminal Specifications

Connector	Signal Name	
CN4	GND_F	Frame ground

4.1.3. DC Output Terminal (AC-DC Board, CN5, CN6)

This is a terminal for DC power output. OT-005 (Osada) is being used. Connect using a M3 ring terminal, etc.

Fig. 4.3 DC Output Terminal (CN5, CN6)

Table 4.3 DC Output Terminal Specifications

Connector	Signal Name	
CN5	VP_DC	DC output (+)
CN6	GND_DC	DC output (-)

4.1.4. Control Power Output Terminal (AC-DC Board, CN7)

This is a terminal for control power output. 1984989 (Phoenix Contact) is used. Connect it to the control power input terminal (CN4) on the inverter board.

Fig. 4.4 Control Power Output Terminal (CN7)

Table 4.4 Control Power Output Terminal Specifications

Pin	Signal Name	
1	VDD20_A	Control power output (20 V)
2	-	(Not connected)
3	-	(Not connected)
4	GND_A	Control power output (GND)

4.1.5. DC Input Terminal (Inverter Board, CN1, CN2)

This is a terminal for DC power input. OT-005 (Osada) is being used. Connect using a M3 ring terminal, etc.

Fig. 4.5 DC Input Terminal (CN1, CN2)

Table 4.5 DC Input Terminal Specifications

Connector	Signal Name	
CN1	VP_DC	DC input (+)
CN2	GND_DC	DC input (-)

4.1.6. 3-Phase AC Output Terminal (Inverter Board, CN6, CN7, CN8)

This is a terminal for 3-phase AC output. OT-005 (Osada) is being used. Connect to a motor, etc. using a M3 ring terminal, etc.

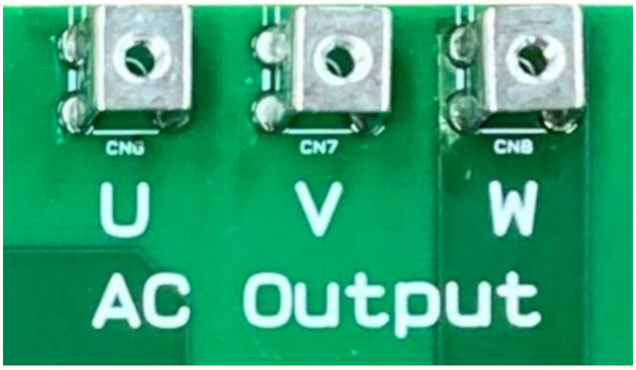

Fig. 4.6 3-Phase AC Output Terminal (CN6, CN7, CN8)

Table 4.6 3-Phase AC Output Terminal Specifications

Connector	Signal Name	
CN6	U	3-phase AC output (U)
CN7	V	3-phase AC output (V)
CN8	W	3-phase AC output (W)

4.1.7. FG Terminal (Inverter Board, CN9)

This is a frame ground terminal. OT-005 (Osada) is being used. Connect to an appropriate frame ground with a M3 ring terminal, etc.

Fig. 4.7 FG Terminal (CN9)

Table 4.7 FG Terminal Specifications

Connector	Signal Name	
CN9	GND_F	Frame ground

4.1.8. Control Power Input Terminal (Inverter Board, CN4)

This is a terminal for control power input. 1984989 (Phoenix Contact) is used. Connect it to the control power output terminal (CN7) on AC-DC board.

Fig. 4.8 Control Power Input Terminal (CN4)

Table 4.8 Control Power Input Terminal Specifications

Pin	Signal Name	
1	VDD20_A	Control power input (20 V)
2	-	(Not connected)
3	-	(Not connected)
4	GND_A	Control power input (GND)

4.1.9. Controller Connector (Inverter Board, CN3)

This is the connector for connecting a controller such as an external MCU. FTSH-120-04-L-DH-A-C (Samtec) is being used.

5 V I/O can be used. Refer to the Design Guide **RD220-DGUIDE** for the specifications of various sensor-outputs.

Fig. 4.9 Controller Connector (CN3)

Table 4.9 Controller Connector Specifications

Pin	Signal Name	I/O	Details	Pin	Signal Name	I/O	Details
1	GND_D	-	Digital signal ground	2	GND_D	-	Digital signal ground
3	-		(Not connected)	4	-		(Not connected)
5	-		(Not connected)	6	-		(Not connected)
7	-		(Not connected)	8	-		(Not connected)
9	UH	DI	U-phase high-side gate signal (active high)	10	UL	DI	U-phase low-side gate signal (active high)
11	VH	DI	V-phase high-side gate signal (active high)	12	VL	DI	V-phase low-side gate signal (active high)
13	WH	DI	W-phase high-side gate signal (active high)	14	WL	DI	W-phase low-side gate signal (active high)
15	GND_D	-	Digital signal ground	16	GND_D	-	Digital signal ground
17	-		(Not connected)	18	VDD5_D		Digital-system power output (5 V)
19	BRK	DI	Gate signal disable (active high)	20	-		(Not connected)
21	-		(Not connected)	22	-		(Not connected)
23	-		(Not connected)	24	THM1	AO	Temperature sensor (T_HS) output
25	nEMG	DO	Fault detection output (active low)	26	VDC	AO	Bus voltage sensor output
27	-		(Not connected)	28	-	-	(Not connected)
29	GND_A	-	Analog signal ground	30	VDD5_A		Analog power output (5 V)
31	GND_A	-	Analog signal ground	32	-		(Not connected)
33	GND_A	-	Analog signal ground	34	-		(Not connected)
35	GND_A	-	Analog signal ground	36	ADU	AO	Phase current sensor output (U-phase)
37	GND_A	-	Analog signal ground	38	ADV	AO	Phase current sensor output (V-phase)
39	GND_A	-	Analog signal ground	40	ADW	AO	Phase current sensor output (W-phase)

4.1.10. Gate Voltage-Setting Jumpers (Inverter Board, JP5, JP7, JP9, JP11)

The gate-voltage driving SiC MOSFETs can be set by configuring these jumpers. In Fig. 4.10, pins 2 and 3 of all gate-voltage setting jumpers are shorted, so that the gates are driven with 18 V during on-state, and -2 V during off-state.

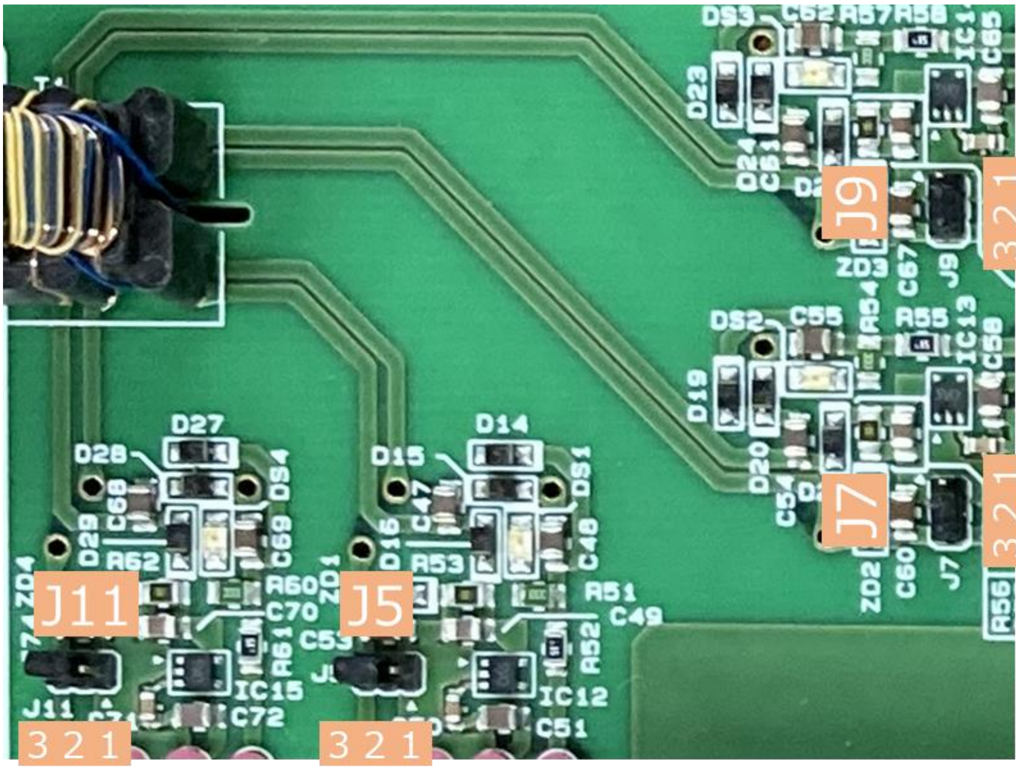

Fig. 4.10 Gate-Voltage Setting Jumpers (JP5, JP7, JP9, JP11)

Table 4.10 Gate Voltage Setting Jumpers Behavior

<table>
<tr><th>Jumper Pin</th><th>Gate Voltage Setting Target SiC MOSFET</th><th>Pin-1 Pin-2 Short Gate Voltage</th><th>Pin-2 Pin-3 Short Gate Voltage</th></tr>
<tr><td>J5</td><td>U-phase high-side (Q1)</td><td rowspan="4">20 V during Turn-on
0 V during Turn-off</td><td rowspan="4">18 V during Turn-on
-2 V during Turn-off</td></tr>
<tr><td>J7</td><td>V-phase high-side (Q3)</td></tr>
<tr><td>J9</td><td>W-phase high-side (Q5)</td></tr>
<tr><td>J11</td><td>U/V/W phase low-side (Q2, Q4, Q6)</td></tr>
</table>

4.1.11. Temperature Sensor Connection Terminal (Inverter Board, J1, J2, J3, J4)

This terminal allows two NTC thermistor temperature sensors to be connected to the inverter. Attach the sensor to the object whose temperature is to be measured and solder the leads of the sensor to this terminal (there is no polarity). Recommended temperature sensor is B57703M0103A017 (TDK) which has 1 kΩ resistance at 25 °C and B constant value of 3988 K.

Fig. 4.10 Temperature Sensor Connection Terminal (J1, J2, J3, J4)

Table 4.10 Temperature Sensor Connection Terminal Specifications

Temperature Sensor Connection Terminal	Temperature Sensor Name	Temperature Measurement Target (Example)	Controller Connection Output from the Connector	Used in Fault Detection
J1 - J2	T_HS	SiC MOSFET heat sink (inverter board)	Output from THM1 (CN3)	Yes
J3 - J4	T_RY	Inrush prevention relay (AC-DC board)	-	Yes

4.2. Operation Checking Procedure

4.2.1. Preparation

- Set the appropriate gate voltage using the gate setting jumper (JP5, JP7, JP9, JP11) on the inverter board.
- Attach the temperature sensor to the temperature sensor connecting terminal (J1, J2, J3, J4) on the inverter board.
- Secure AC-DC board and inverter board and connect an appropriate frame ground to each FG terminal.
- Connect AC-DC board's DC output terminal (CN5, CN6) to the inverter board's DC input terminal (CN1, CN2).
- Connect the control power output terminal (CN7) on AC-DC board to the control power input terminal (CN2) on the inverter board.
- Connect a controller, such as a MCU board, to the controller connector (CN3) on the inverter board.
- Connect a 3-phase motor to the 3-phase AC output terminal (CN6, CN7, CN8) on the inverter board.
- Connect the 3-phase AC power supply to the 3-phase AC input terminal (CN1, CN2, CN3) on the AC-DC board.

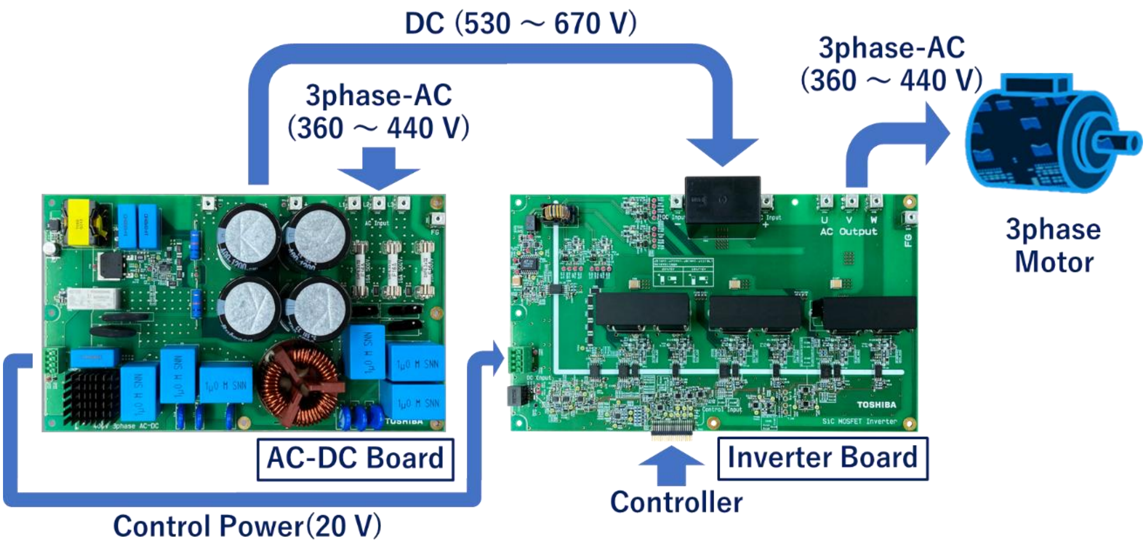

Figure 4.11 Example of Connection when Checking Operation

4.2.2. Operation Check

Turn on the AC power supply, then disable the BRK signal (by providing L-level signal output from the controller), and output the gate-drive signals (UH, UL, VH, VL, WH, WL) of each phase from the controller. SiC MOSFET in the inverter switches according to the corresponding gate signal.

4.2.3. Operation when Fault is Detected

If any of the following error is detected, the nEMG (Emergency) fault signal (pin 25 of the controller connector (CN3)) become low level, and the SiC MOSFETs are forced to be off even when BRK signal is disabled. nEMG returns to high level after recovering from error.

(1) U-phase overcurrent detection: When the U-phase current exceeds +45 A or falls below -45 A
(2) V-phase overcurrent detection: When the V-phase current exceeds +45 A or falls below -45 A
(3) W-phase overcurrent detection: When the W-phase current exceeds +45 A or falls below -45 A
(4) Bus overvoltage detection: When the inverter bus voltage exceeds 800 V
(5) Bus overcurrent detection: When the inverter bus current exceeds 160 A
(6) Overtemperature detection: When either of the temperature sensors (T_HS, T_RY) exceed 115 °C

4.3. 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.
- MOSFET and other components generate heat during operation. Be careful not to get burned while handling them.

5. Characteristics

This section shows the efficiency measurement results of this inverter.

Fig. 5.1 shows the measured inverter efficiency when using TW045Z120C as SiC MOSFET (Gate voltages are 18 V and -2 V), 3-phase 400 V 60 Hz of AC-DC board input, 3-phase 440 V 60 Hz of inverter board output, 5 kHz of switching frequency, and driving motor of 2.2 kW rated output. Inverter efficiency is 98.6 % at the 11.6 N·m of maximum torque.

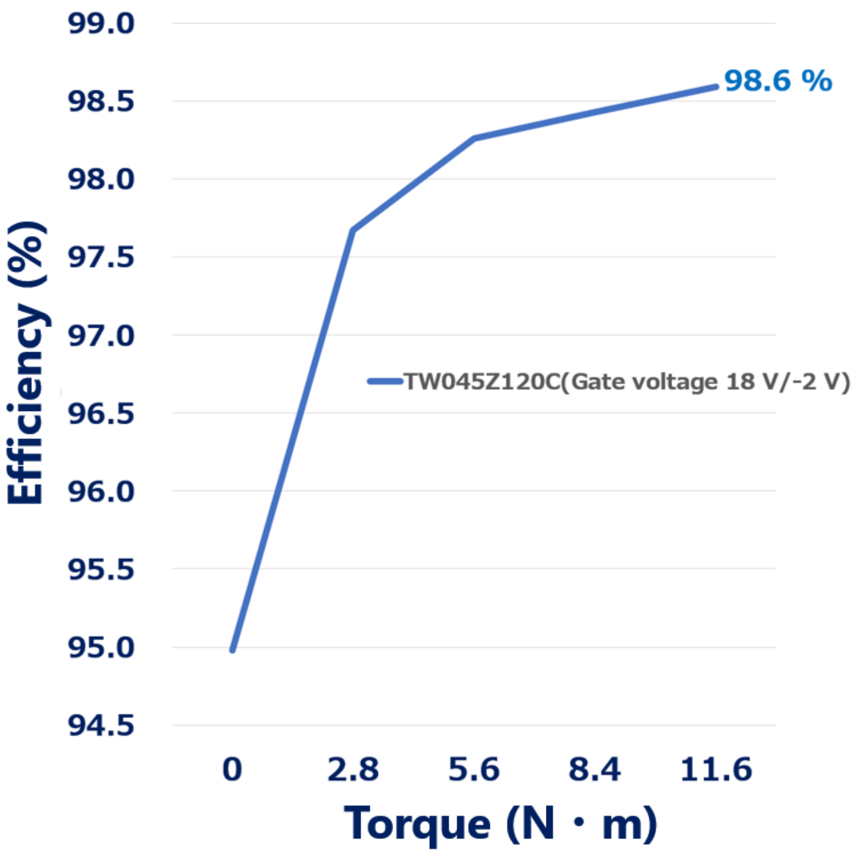

Fig. 5.1 Efficiency Measurement

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