Full SiC MOSFET 10kW Isolated Bidirectional DC-DC Converter

Reference Guide

RD264-RGUIDE-01

Toshiba Electronic Devices & Storage Corporation

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1. Introduction

This reference guide describes the specifications, usage, and characteristics of the Full SiC MOSFET 10kW Isolated Bidirectional DC-DC Converter (hereafter referred to as this design).

This design is a bidirectional DC-DC converter capable of supplying up to 10kW of power. It takes power from the high-voltage side (750V) and outputs power to the low-voltage side (400V), or takes power from the low-voltage side (400V) and outputs power to the high-voltage side (750V). This design adopts the DAB (Dual Active Bridge) topology with emphasis on efficiency. The DAB topology has a full-bridge configuration on both the high-voltage side and low-voltage side, and can handle higher power compared to the half-bridge topology. In addition, soft switching is possible due to power transfer by phase shifting, and a highly efficient DC-DC converter can be realized. It can be applied to various industrial equipment such as charging systems for electric vehicles (xEVs) and inverters for photovoltaic power generation.

The high-voltage side is assumed to operate at 750V input/output. The required switching voltage rating of the device exceeds 1000V, and therefore IGBTs are generally selected. However, when IGBTs are used, switching losses are large, and significant efficiency improvement cannot be expected. In this design, a 1200V SiC MOSFET TW060N120C is used to achieve both high-power conversion and high efficiency. In addition, the low-voltage side is assumed to operate at 400V input/output. A 650V SiC MOSFET TW048N65C is used to achieve high efficiency on the low-voltage side as well.

The gate driver uses a smart gate driver coupler TLP5214A, which has a 4A sink-source current capability sufficient to drive the gate charging and discharging current during SiC MOSFET switching, and is equipped with an overcurrent protection function and a UVLO function. In addition, an optically coupled isolation amplifier TLP7920, which provides high linearity accuracy and high common-mode transient immunity, is used for the voltage sensor circuitry requiring isolation.

2. Specifications

2.1. Specifications of This Design

Table 2.1 and Table 2.2 list the main specifications of this design.

Table 2.1 Step-down Operation Specifications

Parameters	Conditions	Min	Typ.	Max	Unit
Input/Output Characteristics					
High-voltage Side Voltage	Input Operation		750		V
Low-voltage Side Voltage	Output Operation		400		V
Low-voltage Side Current	Output Operation		25		A
Rated Power				10	kW
Switching Frequency			50		kHz

Table 2.2 Step-up Operation Specifications

Parameters	Conditions	Min	Typ.	Max	Unit
Input/Output Characteristics					
Low-voltage Side Voltage	Input Operation		400		V
High-voltage Side Voltage	Output Operation		750		V
High-voltage Side Current	Output Operation		13.3		A
Rated Power				10	kW
Switching Frequency			50		kHz

2.2. Block Diagram

Figure 2.1 shows a simplified block diagram of this design.

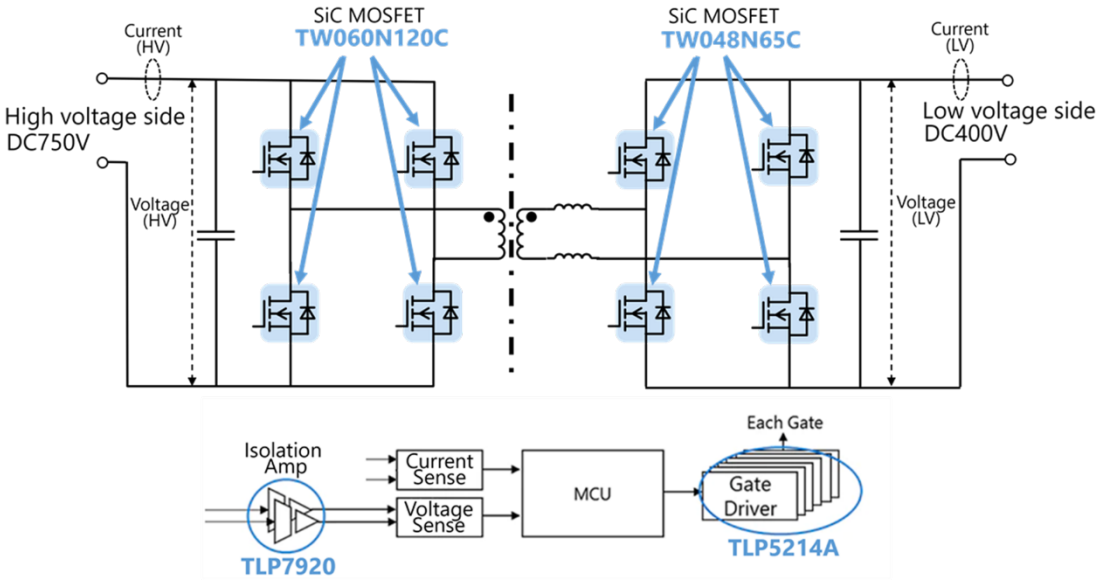
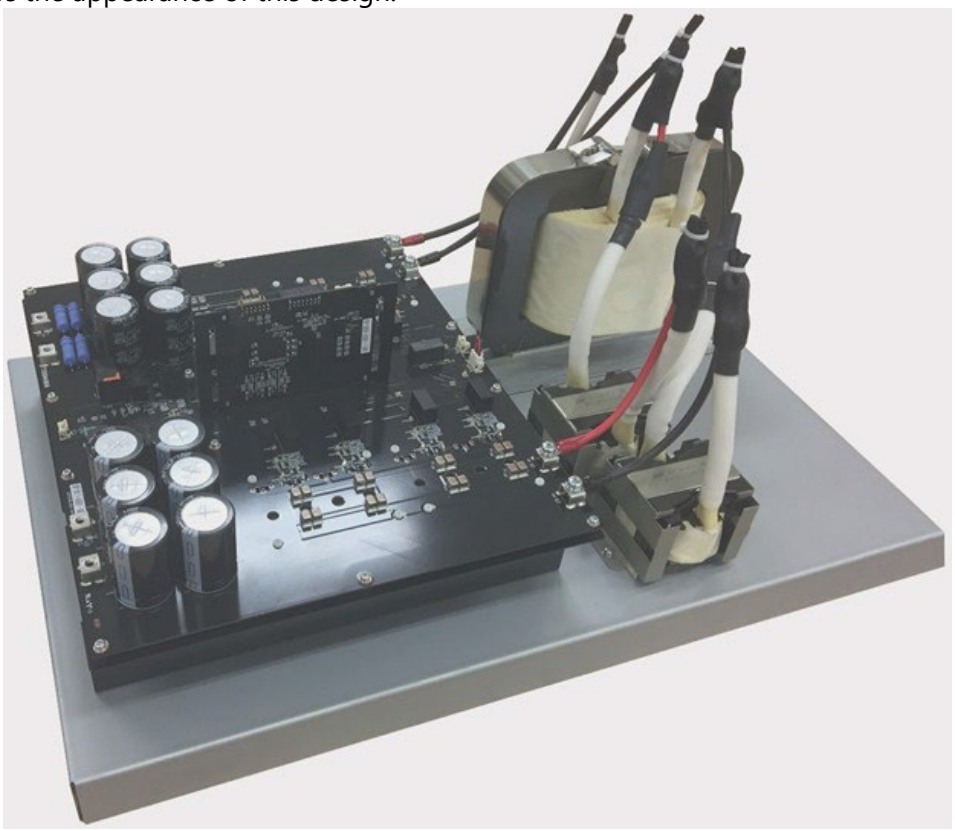


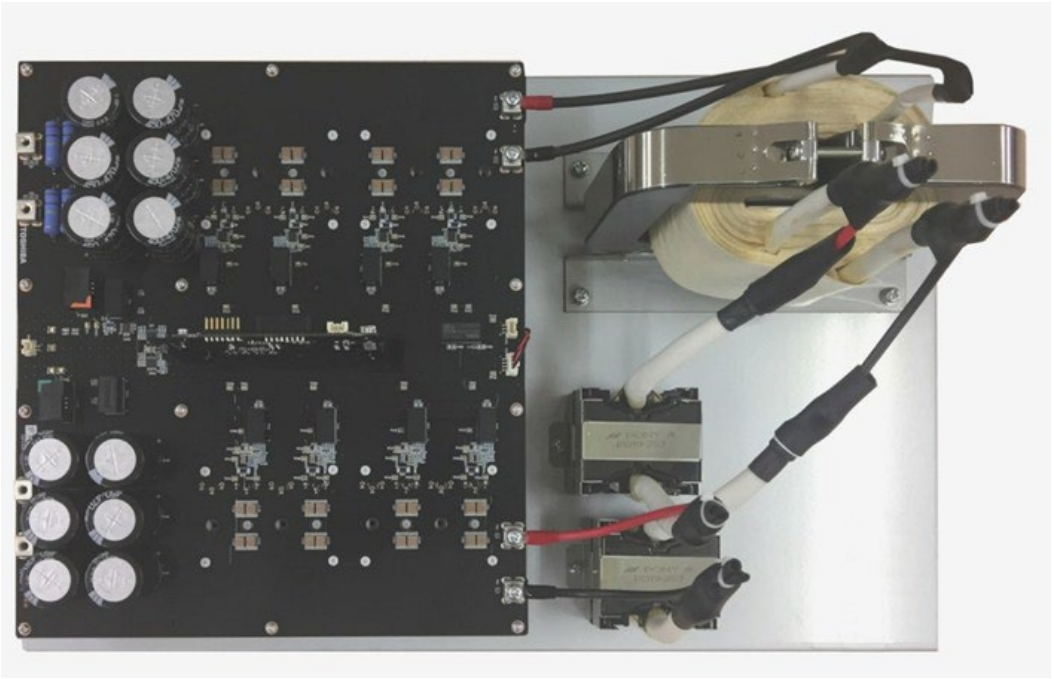
Figure 2.1 Block Diagram

2.3. Appearance

Figure 2.2 shows the appearance of this design.



<Side View>

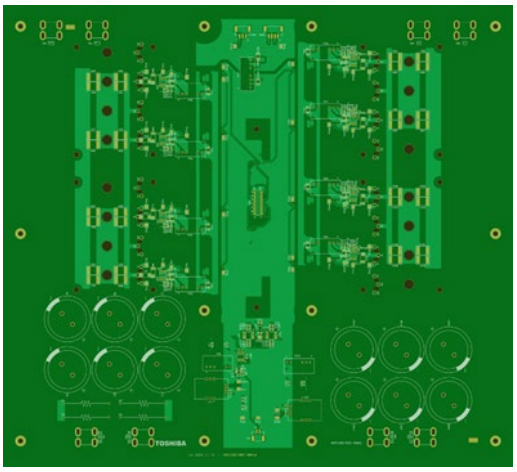


<Top View>

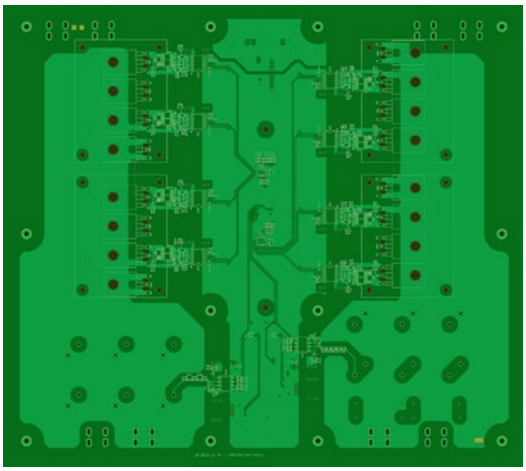
Figure 2.2 External View of This Design

2.4. PCB Component Layout

Figure 2.3 shows the component layout of the main board, and Figure 2.4 shows the component layout of the control board.

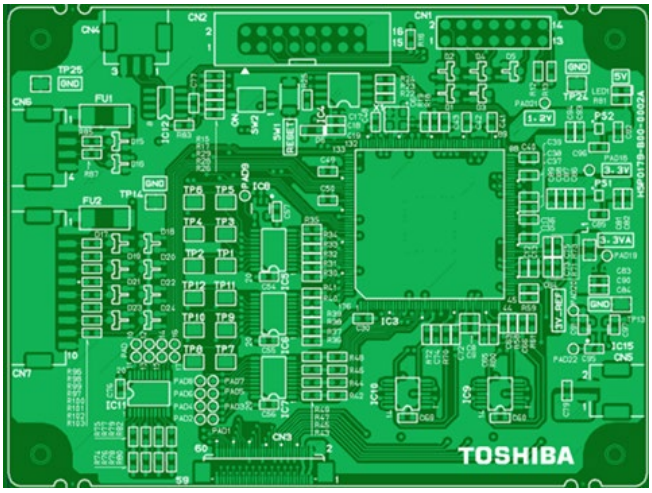


<Front Side>

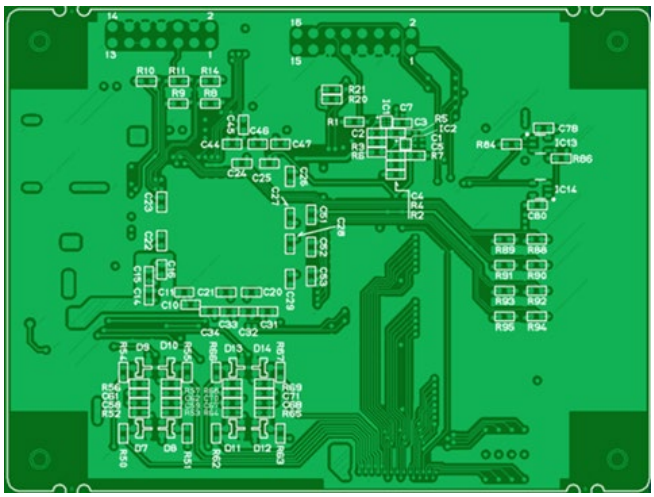


<Back Side>

Figure 2.3 Main Board Component Layout



<Front Side>



<Back Side>

Figure 2.4 Control Board Component Layout

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

3.1. Schematic

Refer to following files:
Main board : RD264-SCHEMATIC1-xx.pdf
Control board : RD044-SCHEMATIC2-xx.pdf
(xx is the revision number.)

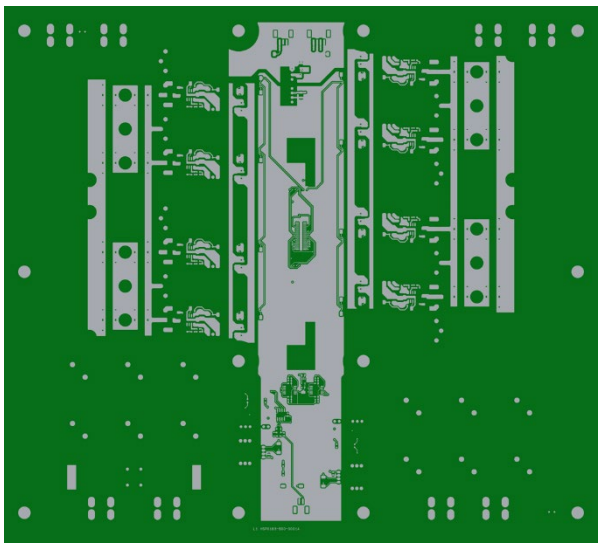
3.2. Bill of Materials

Refer to following files:
Main board : RD264-BOM1-xx.pdf
Control board : RD044-BOM2-xx.pdf
(xx is the revision number.)

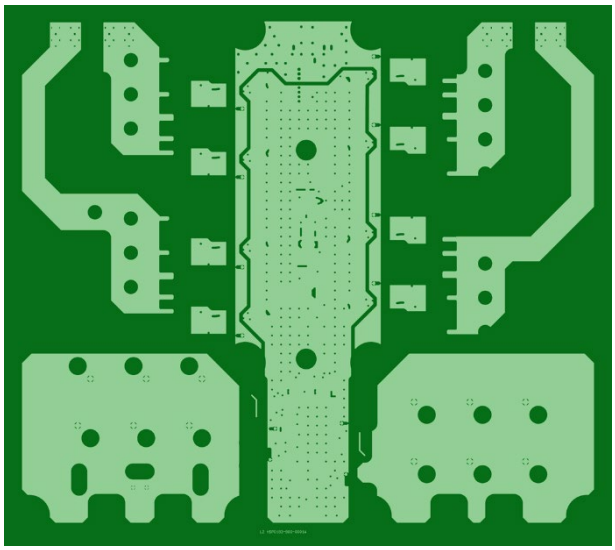
3.3. PCB Pattern Diagram

Figure 3.1 shows the pattern diagram of the main board of this design, and Figure 3.2 shows the pattern diagram of the control board.

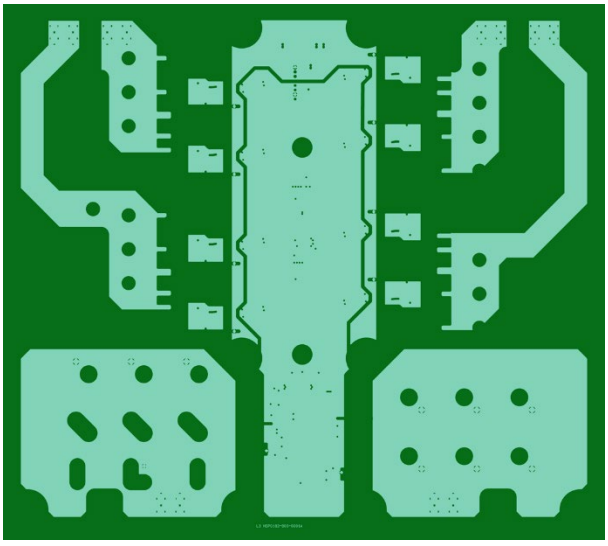
Refer to following files:
Main board : RD264-LAYER1-xx.pdf
Control board : RD044-LAYER2-xx.pdf
(xx is the revision number.)



L1 (Top Layer)



L2



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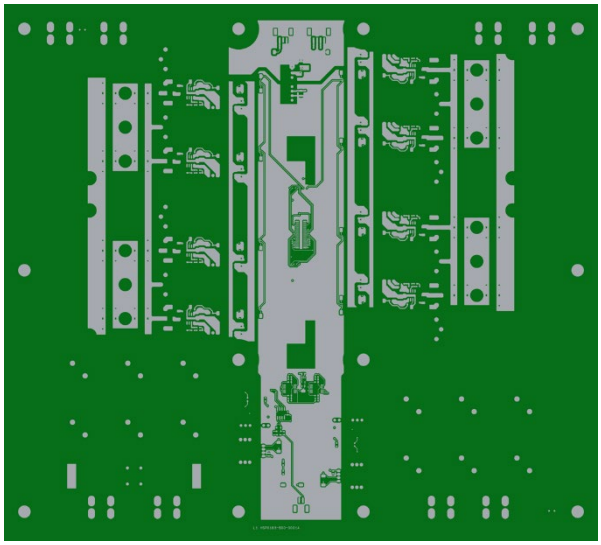

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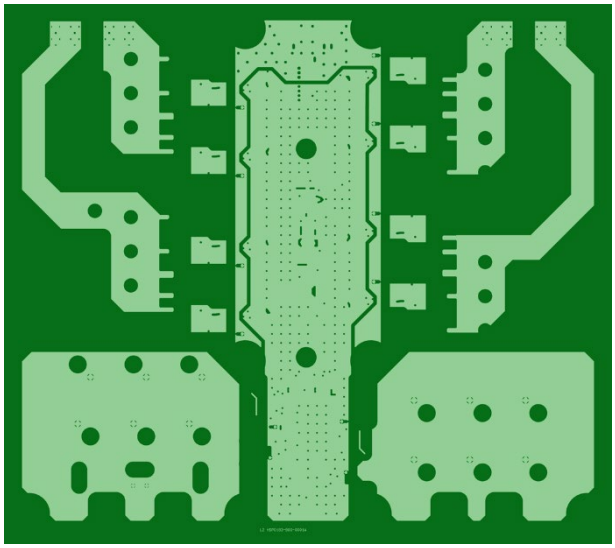
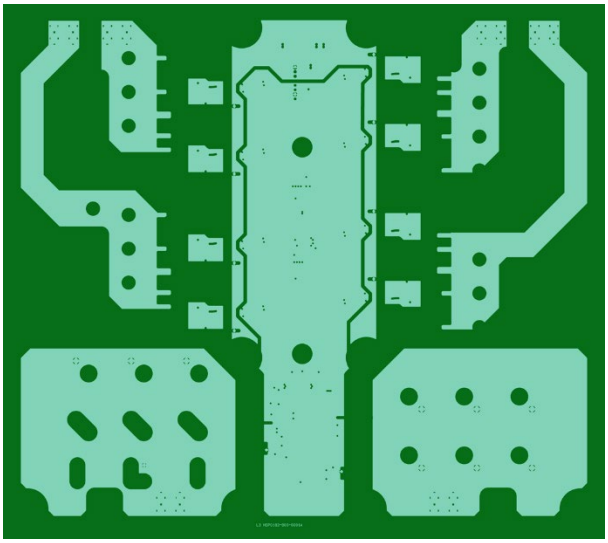
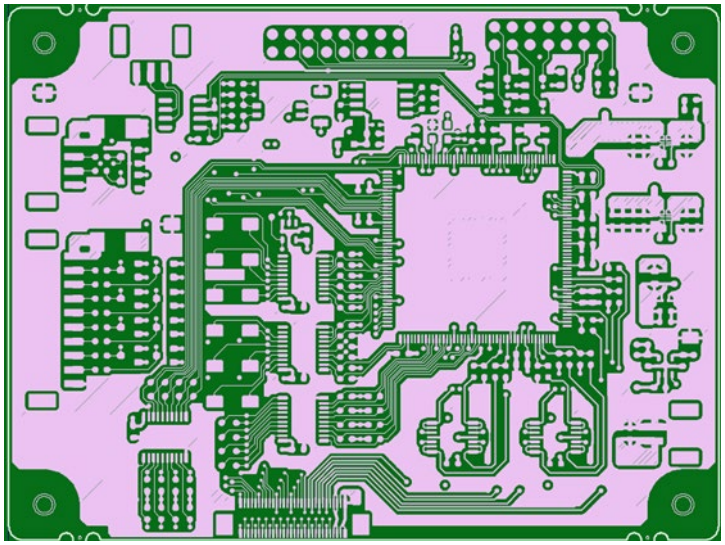


L5

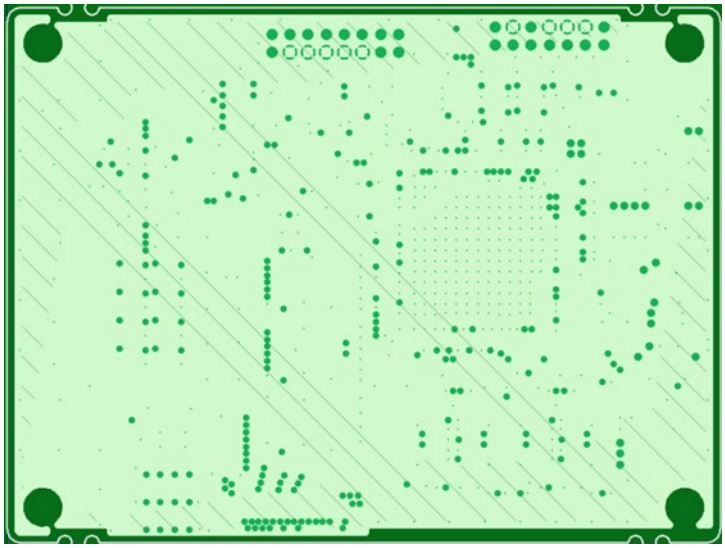


L6 (Bottom Layer)

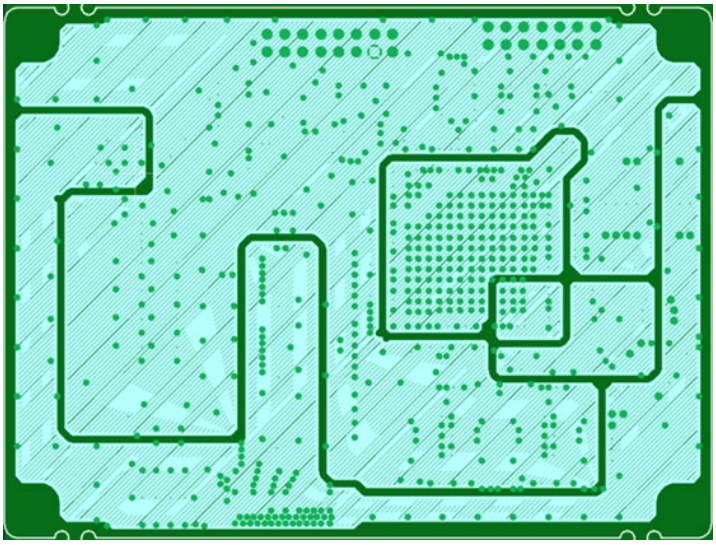
Figure 3.1 Main Board Pattern Diagram (Top View)



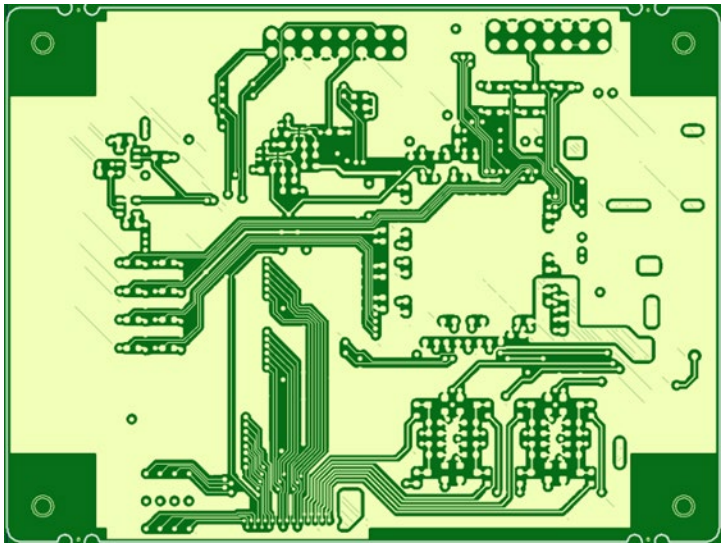
L1 (Top Layer)



L2



L3



L4 (Bottom Layer)

Figure 3.2 Control Board Pattern Diagram (Top View)

4. Operating Procedure

4.1. Wiring Connection

Connect the wiring of this design according to the connection diagram shown in Figure 4.1.

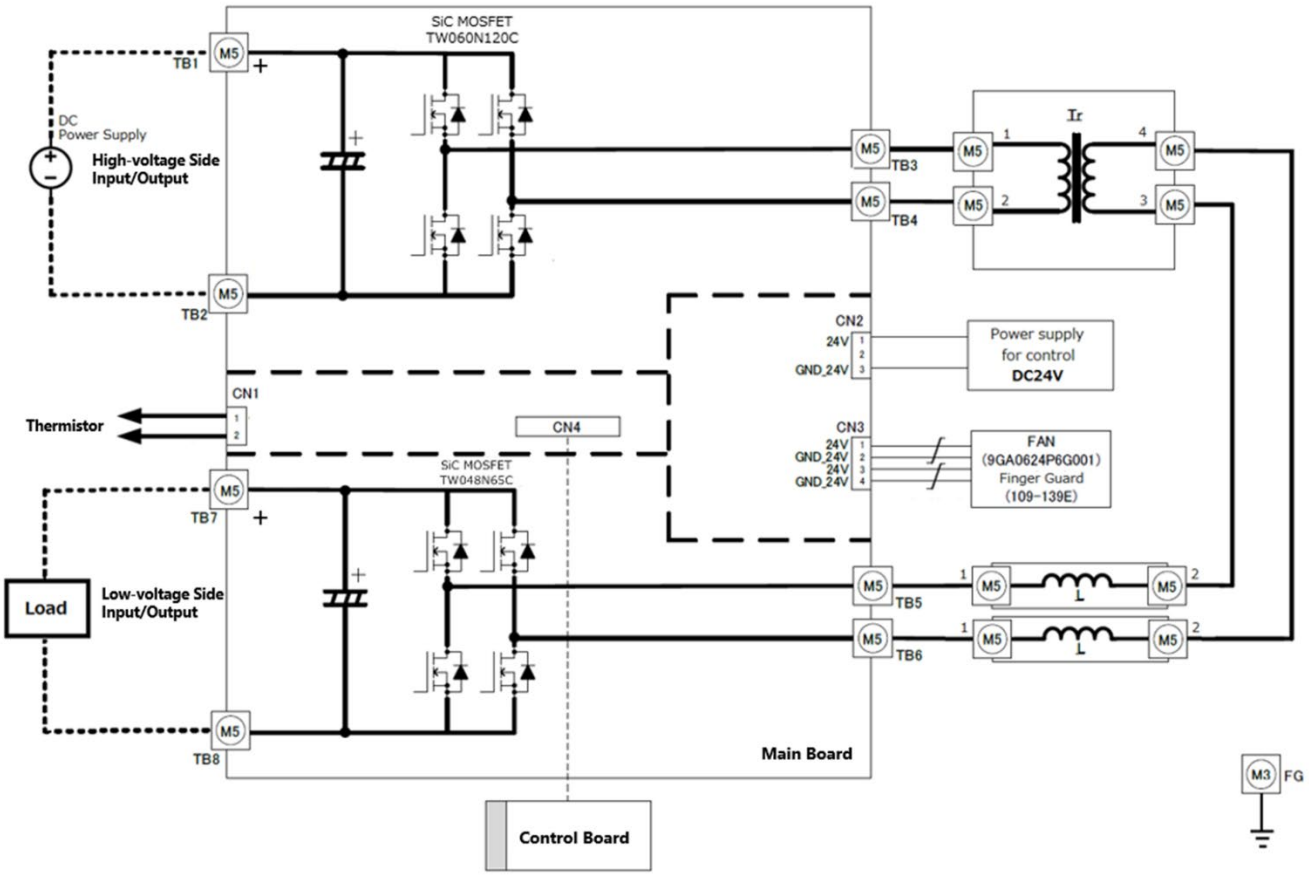


Figure 4.1 Wiring Connection Diagram

4.2. Connection Example with External Device

An example of step-down operation of this design is shown below.
Connect a stabilized power supply (DC750V) to the high-voltage side input/output terminals (TB1 is positive terminal), and connect a load device (TB7 is positive terminal) to the low-voltage side input/output terminals. In addition, connect the DC 24V control power supply to the main circuit board (CN2).

When performing step-up operation, interchange the connections of the stabilized power supply and the load device.

4.3. Start and Stop Procedures

Before starting this design, confirm that the terminal voltages of the high-voltage side input/output terminals and the low-voltage side input/output terminals are all 0V.

[Starting Procedure]

1. Turn on the DC 24V control power supply
2. Turn on the stabilized power supply
3. Turn on the load

[Stopping Procedure]

1. Turn off the load
2. Turn off the stabilized power supply
3. Turn off the DC 24V control power supply

5. Power Characteristics

The power supply efficiency measurement results of this design are described below.

5.1. Efficiency

The efficiency of this design during both step-down and step-up operation is described. Since the DAB topology with full-bridge configurations is used on both the high-voltage side and low-voltage side, high efficiency is achieved over a wide load power range in both operation modes.

Figure 5.1 shows the efficiency measurement results during step-down operation. The efficiency is 97.6% when the input voltage is 750V, the output voltage is 400V, and the load power is 100%.

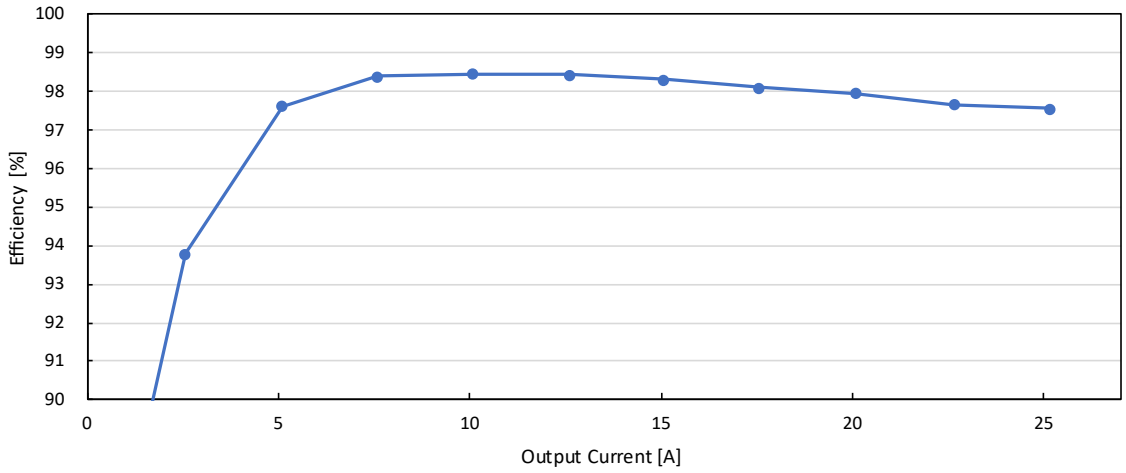


Figure 5.1 Efficiency Measurement Results

Figure 5.2 shows the efficiency measurement results during step-up operation. The efficiency is 97.3% when the input voltage is 400V, the output voltage is 750V, and the load power is 100%.

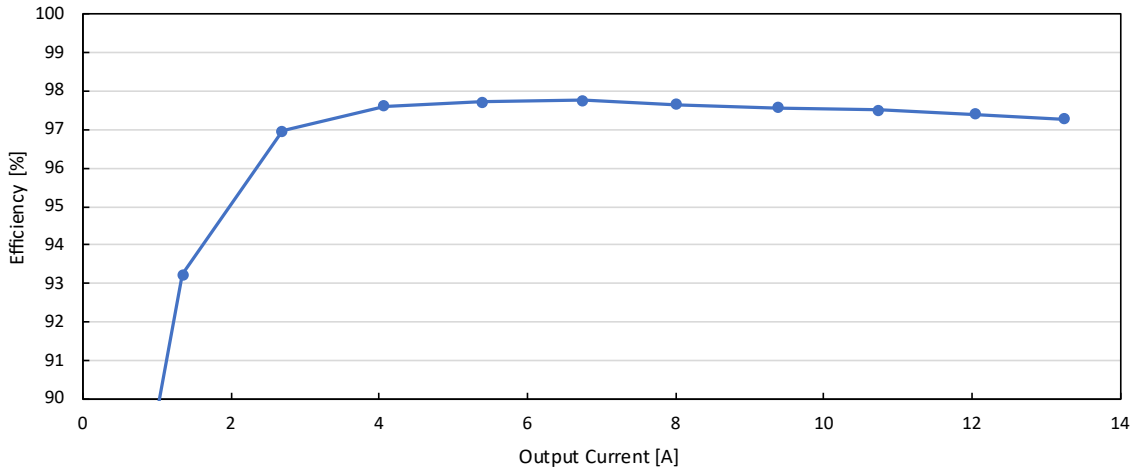


Figure 5.2 Efficiency Measurement Results

5.2. Reference Measurement Results

As reference data, a comparison with our existing similar power supply is shown.

In the existing similar power supply, the circuit configuration is equivalent. An older-generation SiC MOSFET is used as the high-voltage side switching device, and a Si MOSFET is used as the low-voltage side switching device. Table 5.1 shows a comparison of the switching devices used.

Table 5.1 Switching Devices Used in the Existing Similar Power Supply and This Design

	Existing Similar Power Supply		**This Design**		Unit
	Low-voltage Side	High-voltage Side	Low-voltage Side	High-voltage Side	
Using Device	TK49N65W5	**TW070J120B**	TW048N65C	TW060N120C	
	Si MOSFET	2nd Gen. SiC MOSFET	3rd Gen. SiC MOSFET	3rd Gen. SiC MOSFET	
Drain-Source Voltage (Max)	650	1200	650	1200	V
Drain-Source On-resistance (Typ.)	51	70	48	60	mΩ
Total Gate Charge (Typ.)	185	67	41	46	nC

*TW070J120B is discontinued.

Figure 5.3 and Figure 5.4 show the efficiency comparison results during step-down operation and step-up operation, respectively. Thanks to using full SiC MOSFETs, high efficiency can be achieved.

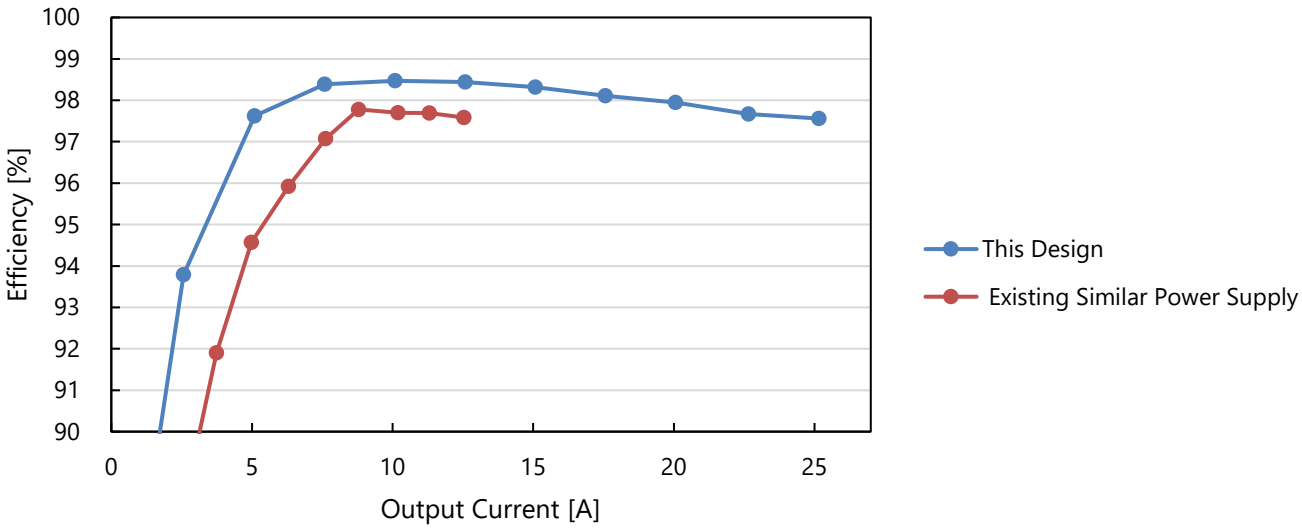


Figure 5.3 Efficiency Comparison Results

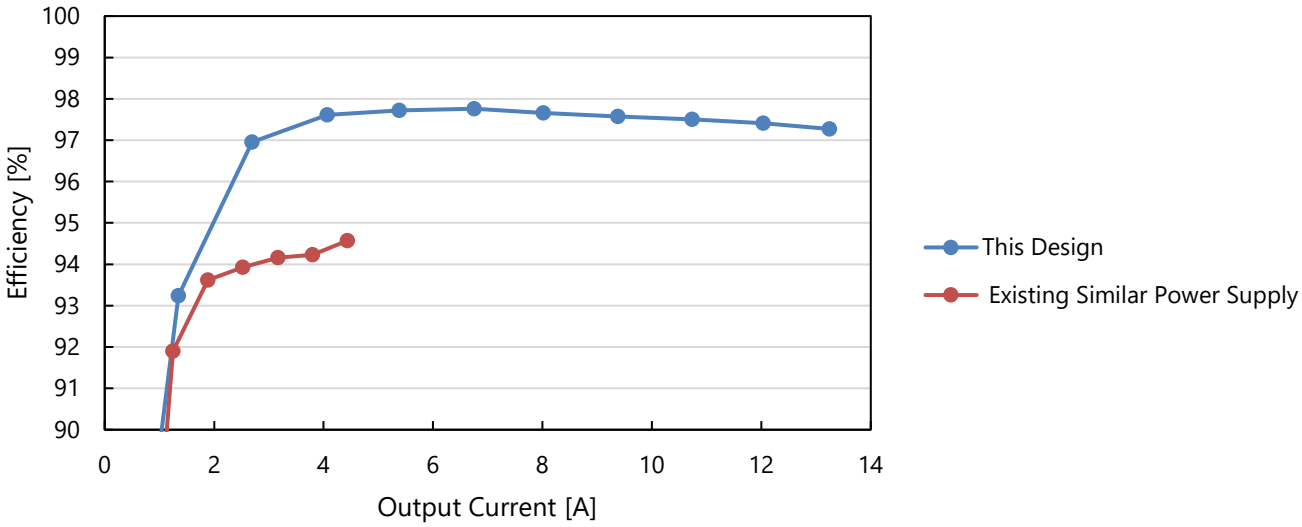


Figure 5.4 Efficiency Comparison Results

Common Precautions for Evaluation

Please read and follow the precautions below to ensure safe evaluation work.

- **Precautions for Electric Shock Prevention**
  - Before applying power, **confirm that the polarity of connectors, terminals, and wiring is correct**.
  - Some parts of the board may be exposed to high voltage. **Do not touch the board or components while power is applied**.
  - Even after the power is turned off, capacitors may retain residual charge. **Ensure that all capacitors are fully discharged before touching the board**.
  - When measuring voltage or current waveforms, **take sufficient precautions to avoid electric shock and maintain a safe distance**.

- **Precautions for Burn Prevention (High-Temperature Components)**
  - MOSFETs, diodes, inductors, coils, and semiconductor devices may become **very hot during operation**. Handle them carefully to avoid burns.
  - Under high load conditions, heat generation increases. **Use appropriate cooling (such as fans)**.
  - Component temperatures may remain high immediately after power-off. **Allow sufficient cooling time before touching**.

- **Precautions for the Evaluation Environment**
  - During operation checks, implement safety measures such as **covering the board with a non-conductive enclosure** if necessary **(e.g., acrylic case)**.
  - When using motors or other moving parts, **take measures to prevent contact during operation**.
  - For designs with shunt or jumper settings, **verify that the settings are correct before operation**.

- **Other Precautions**
  - Loads connected to output terminals may generate heat. **Pay attention to load temperature rise**.
  - Keep flammable and conductive materials away during evaluation to **avoid short circuits and accidents**.

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