

**Automotive 3kW 48V-12V
Bidirectional DC-DC Converter
Reference Guide**

RD210-RGUIDE-01

Toshiba Electronic Devices & Storage Corporation

Table of Contents

1. Introduction	3
2. Appearance and Specifications	4
2.1. Specifications	4
2.2. Block Diagram	5
2.3. Appearance	6
2.4. PCB Component Layout	9
3. Schematic, Bill of Materials, and PCB Pattern Diagram .	12
3.1. Schematic	12
3.2. Bill of Materials	12
3.3. PCB Pattern Diagram	12
4. Operation Procedure	21
4.1. Connection to External Devices	21
4.2. Starting and Stopping Procedure	22
4.3. Evaluation Precautions (To Prevent Electric Shocks, Burns, etc.)	22
5. Power Supply Characteristics	23
5.1. Efficiency	23

1. Introduction

This reference guide describes the specifications and operation procedure of the Automotive 3kW 48V-12V Bidirectional DC-DC Converter (hereinafter referred to as “this Design”).

As a result of worldwide efforts to reduce greenhouse-gas emissions, the use of hybrid-electric vehicles and battery-powered electric vehicles called xEV is becoming increasingly popular instead of conventional vehicles which use only internal combustion engines as power sources. These xEVs are increasingly being equipped with 48V's Li ion battery to reduce power dissipation. However, 12V batteries must be installed when some existing 12V applications that require lead-acid batteries as power source are used. This design is a bidirectional converter that realizes step-down (buck) operation from 48V to 12V and step-up (boost) operation from 12V to 48V. And such a converter is essential in applications where 48V batteries and 12V batteries coexist.

From our automotive N-channel power MOSFET lineup with low on-resistance and high heat dissipation, 40V rated [XPQR3004PB](#) is used for the high-side MOSFETs, low-side MOSFETs of the switching section and the input/output switches of the 12V line, and 100V rated [XPW4R10ANB](#) is used for the input/output switches of 48V line to achieve high-efficiency operation.

The input/output circuit of 12V line also uses a high-side N-channel power MOSFET gate driver [TPD7106F](#) with a reverse-connection protection function, and by driving MOSFET with a back-to-back connection *, it protects against circuit destruction when the batteries are connected in reverse.

* A configuration in which two MOSFETs are connected in series with their drain or source pins connected. The positive and negative bidirectional currents can be cut off when the switch is off.

2. Appearance and Specifications

2.1. Specifications

Table 2.1 lists the main specifications of this design.

Table 2.1 Specifications of This Design

Item	Conditions	Min.	Typ.	Max.	Unit
During buck operation					
Input voltage		24	48	54	V
Output voltage		11.85	12	12.15	V
Maximum output power	4-phase operation			3	kW
Switching frequency			200		kHz
During boost operation					
Input voltage		5	12	16	V
Output voltage		47.4	48	48.6	V
Maximum output power	Vin = 12V or higher, 4-phase operation			3	kW
Switching frequency			200		kHz
Common items					
Protection function	Input undervoltage protection, input overcurrent protection, input overpower protection, output overvoltage protection, output overcurrent protection, output short-circuit protection, and overheat protection				
Board layer configuration	Main Board: FR-4 6-layer configuration, copper foil thickness of 105μm (surface layer) and 210μm (inner layer) Control Board: FR-4 4-layer configuration, copper foil thickness of 35μm				

2.2. Block Diagram

Fig. 2.1 shows the block diagram of this design.

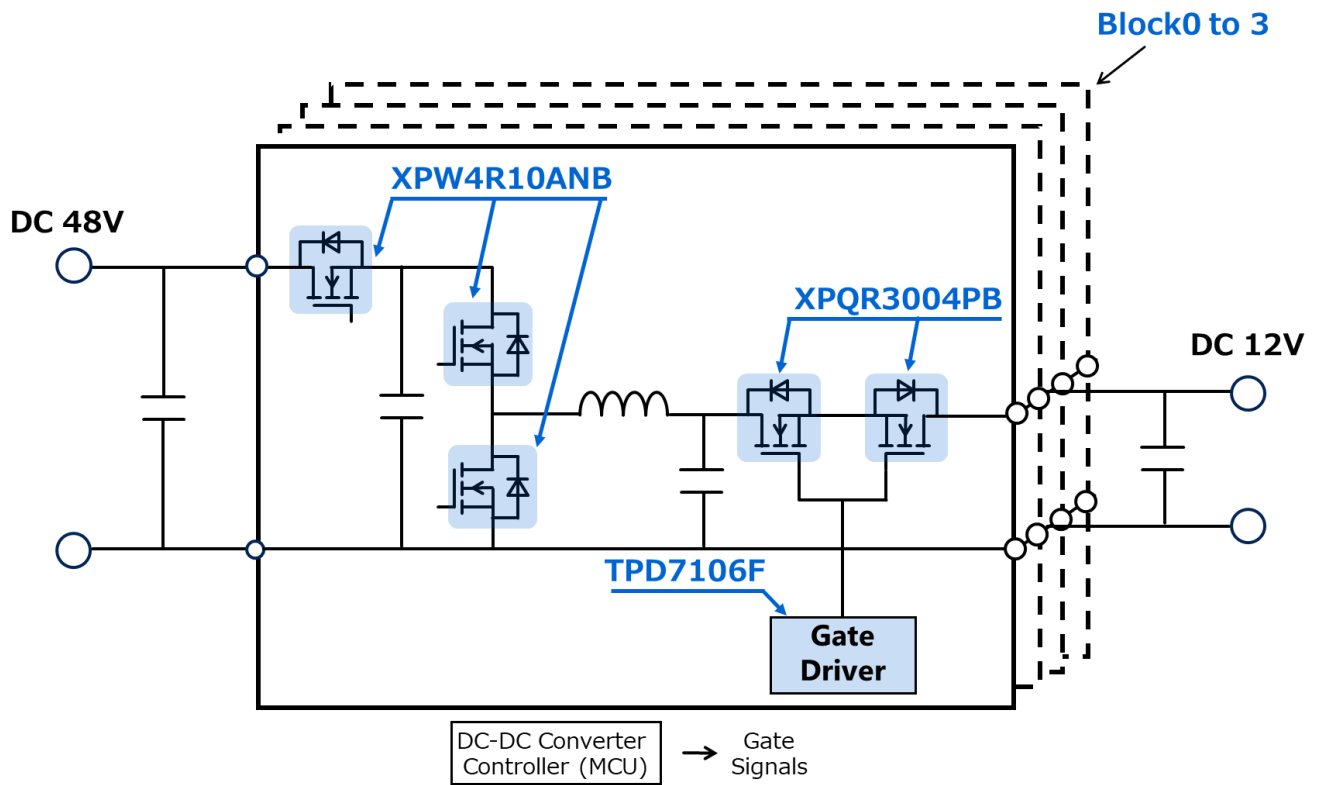


Fig. 2.1 Block Diagram

Four blocks (Block0 to Block3) are connected in parallel with each block consisting of a 48V line input/output circuit, bidirectional DC-DC converter, and a 12V line input/output circuit. The four-phase bi-directional DC-DC converter operates by shifting the switching phase by 90 degrees.

2.3. Appearance

The appearance of this design is shown in Fig. 2.2. This design consists of a main board with input/output circuits and DC-DC converters, and a control board with control MCU placed on top of the main board. Fig. 2.3 and 2.4 show the appearance of the main board, and Fig. 2.5 and 2.6 show the appearance of the control board.

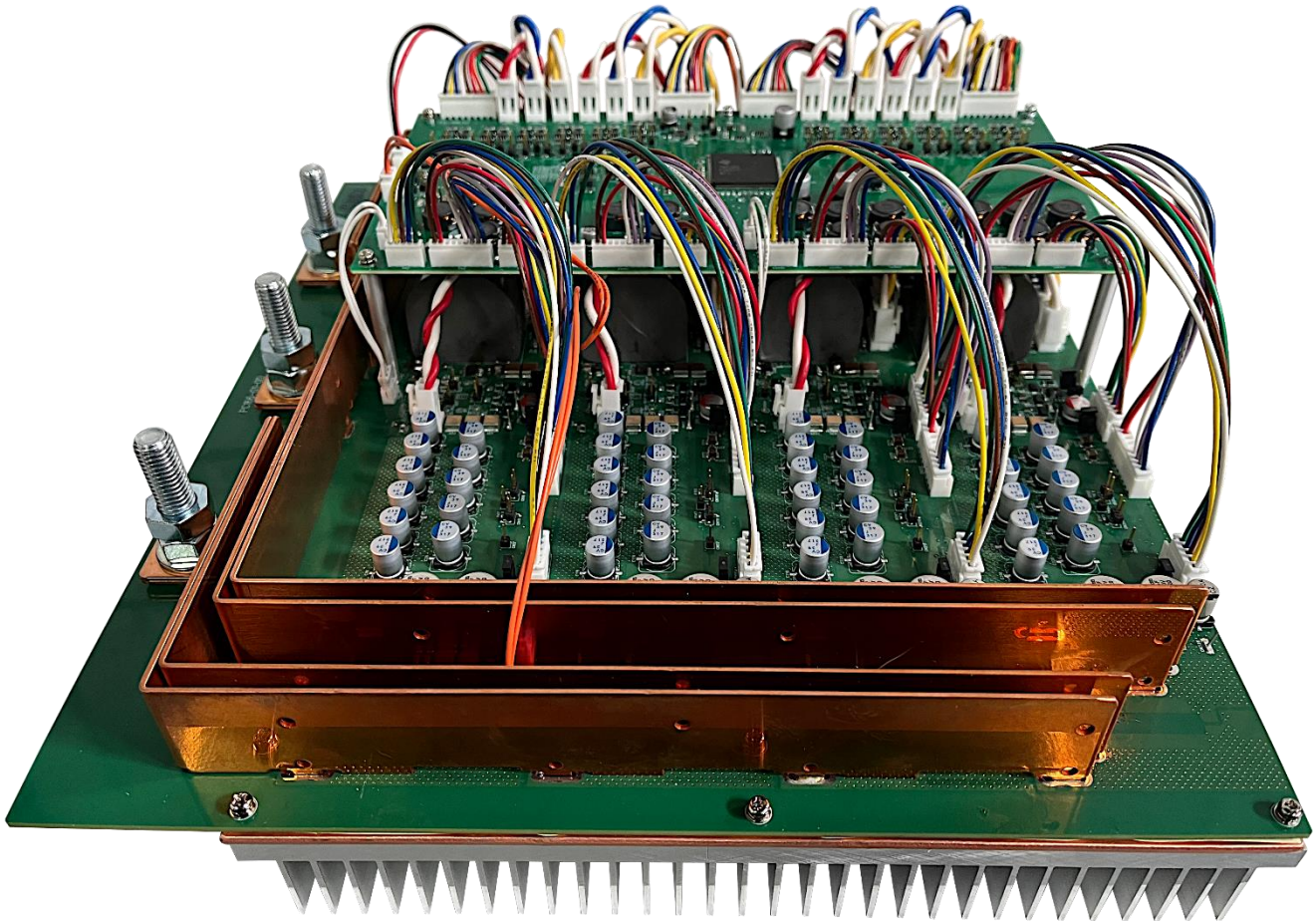


Fig. 2.2 Appearance of This Design

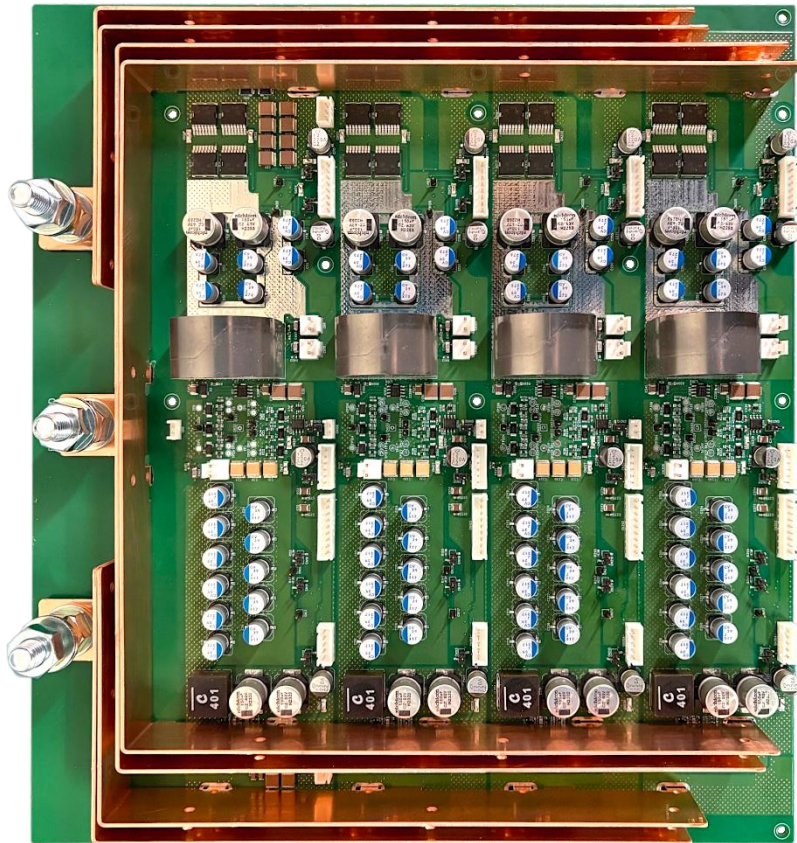


Fig. 2.3 Front View of Main Board

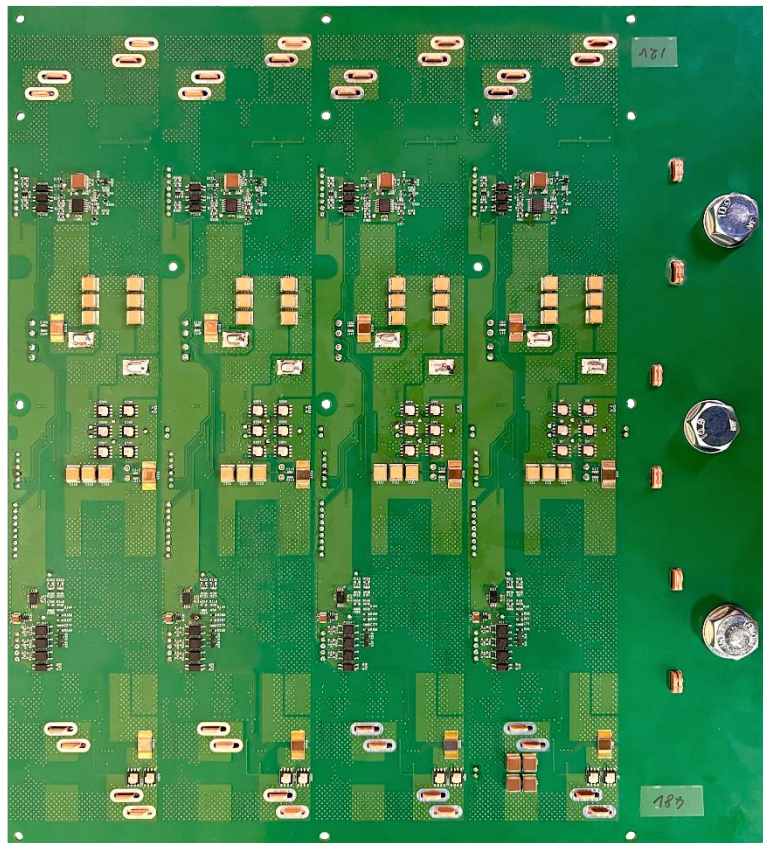


Fig. 2.4 Back View of Main Board

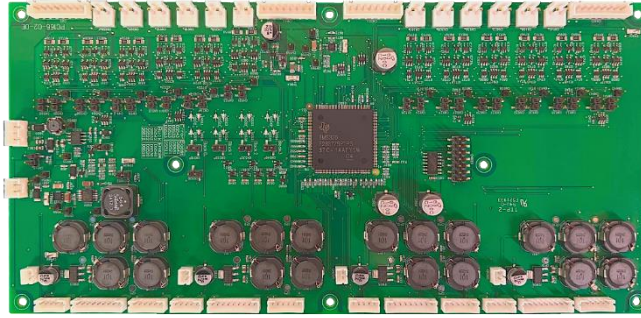


Fig. 2.5 Front View of Control Board

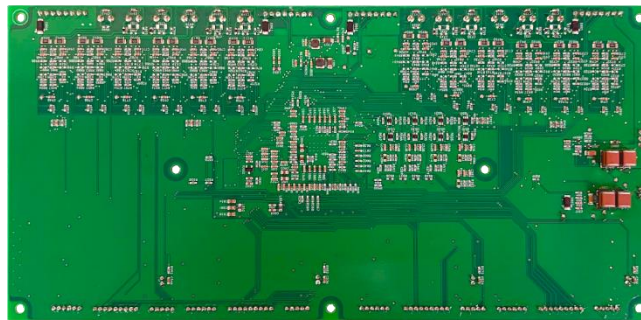
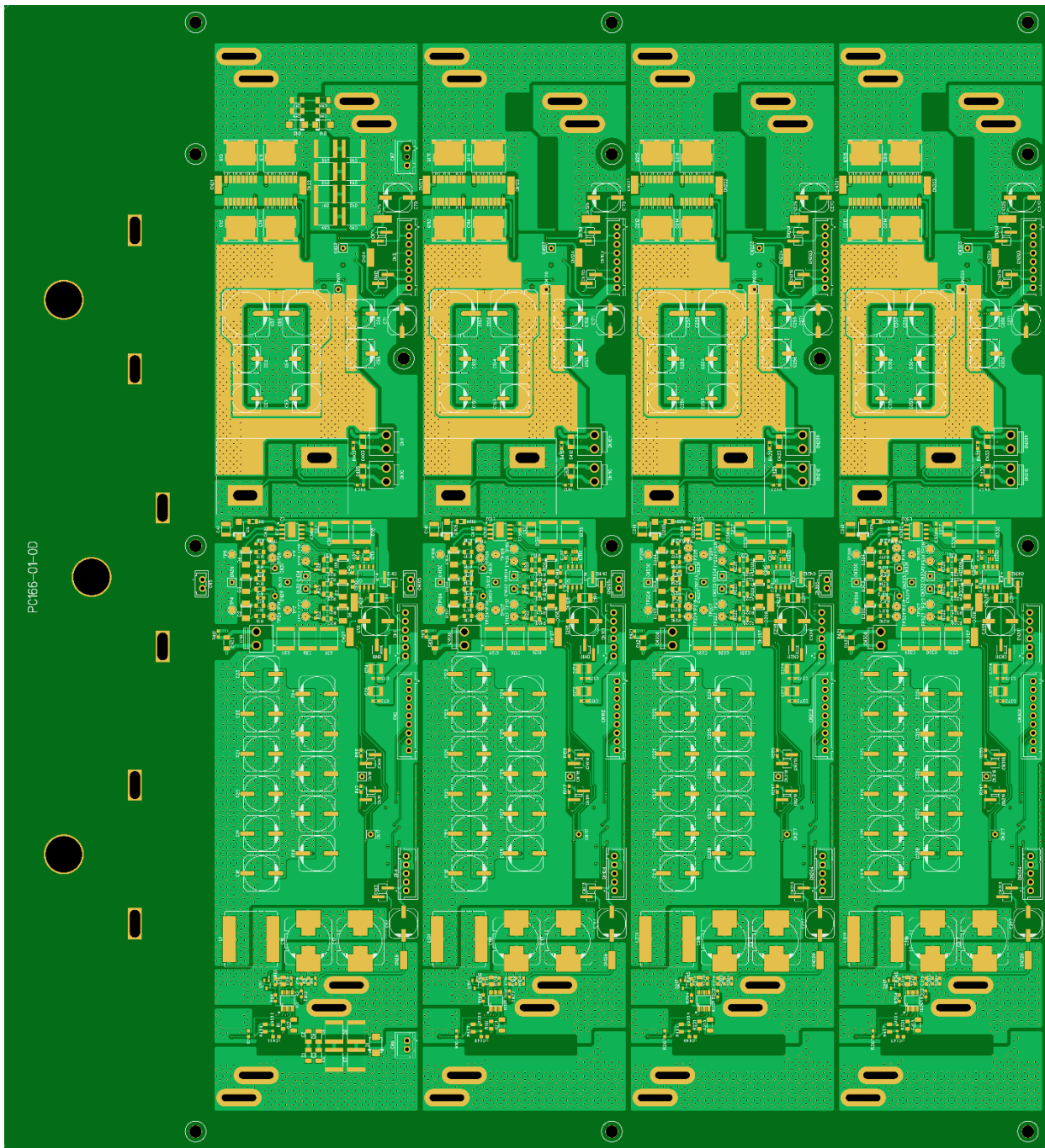


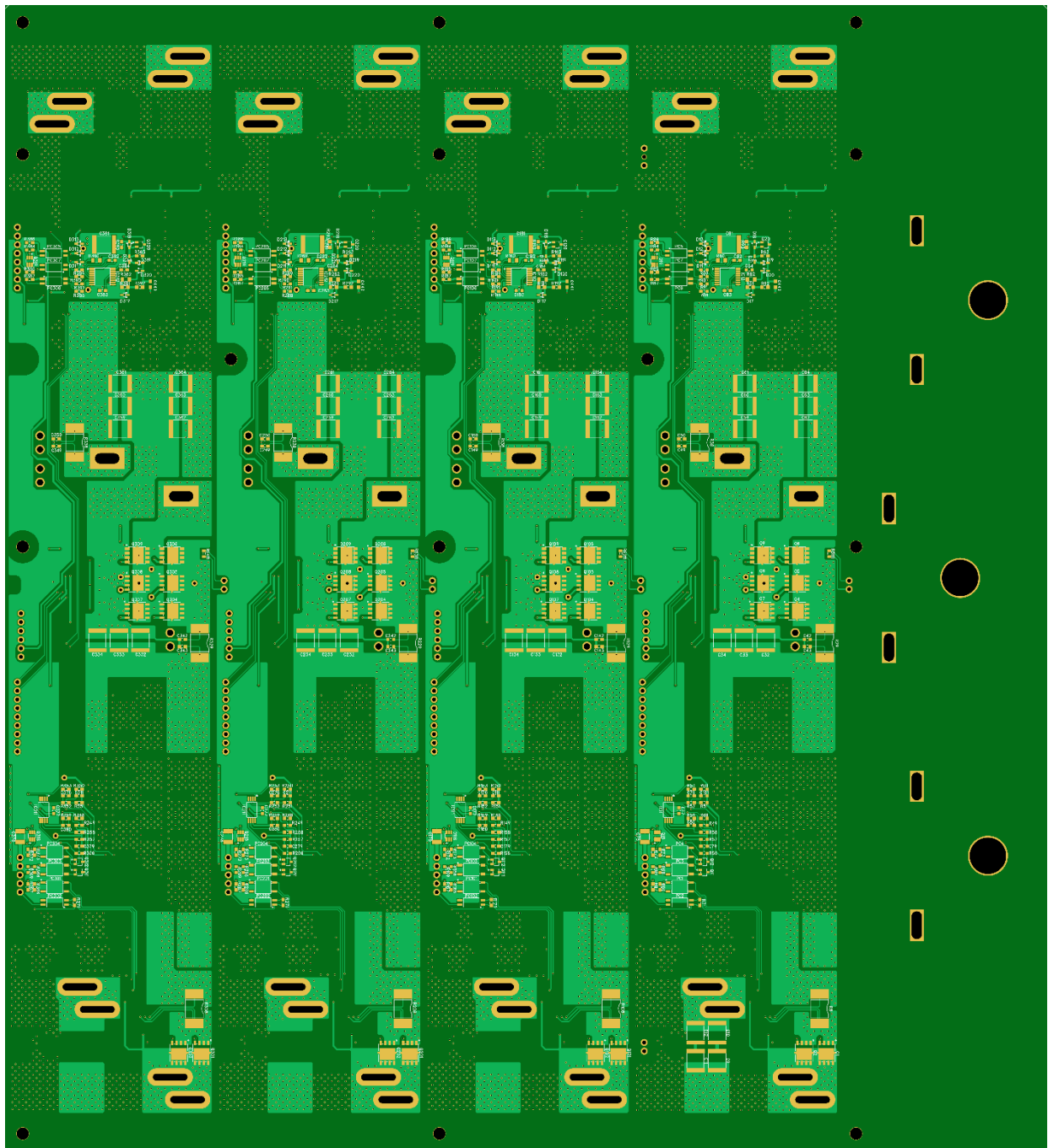
Fig. 2.6 Back View of Control Board

2.4. PCB Component Layout

Fig. 2.7 shows the component layout of the main board, and Fig. 2.8 shows the component layout of the control board.

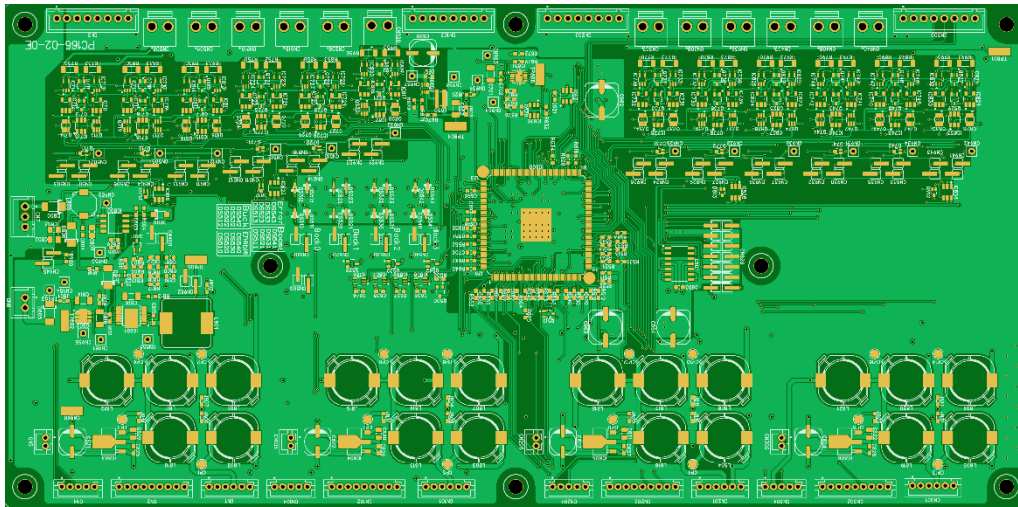


<Front>

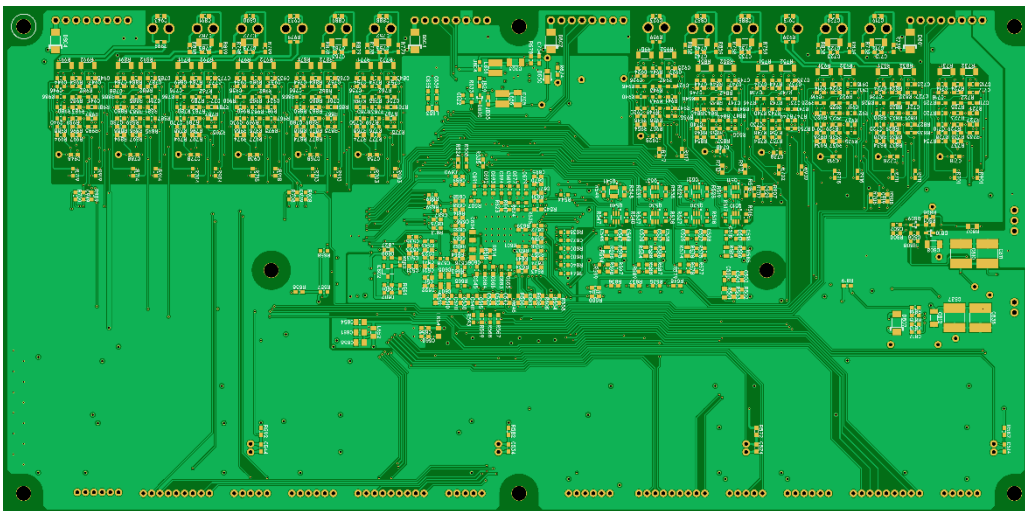


<Back>

Fig. 2.7 Component Layout of Main Board



<Front>



<Back>

Fig. 2.8 Component Layout of Control Board

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

3.1. Schematic

Refer to following files:

Main board: RD210-SCHEMATIC1-xx.pdf

Control board: RD210-SCHEMATIC2-xx.pdf

(xx is the revision number.)

3.2. Bill of Materials

Refer to following files:

Main board: RD210-BOM1-xx.pdf

Control board: RD210-BOM2-xx.pdf

(xx is the revision number.)

3.3. PCB Pattern Diagram

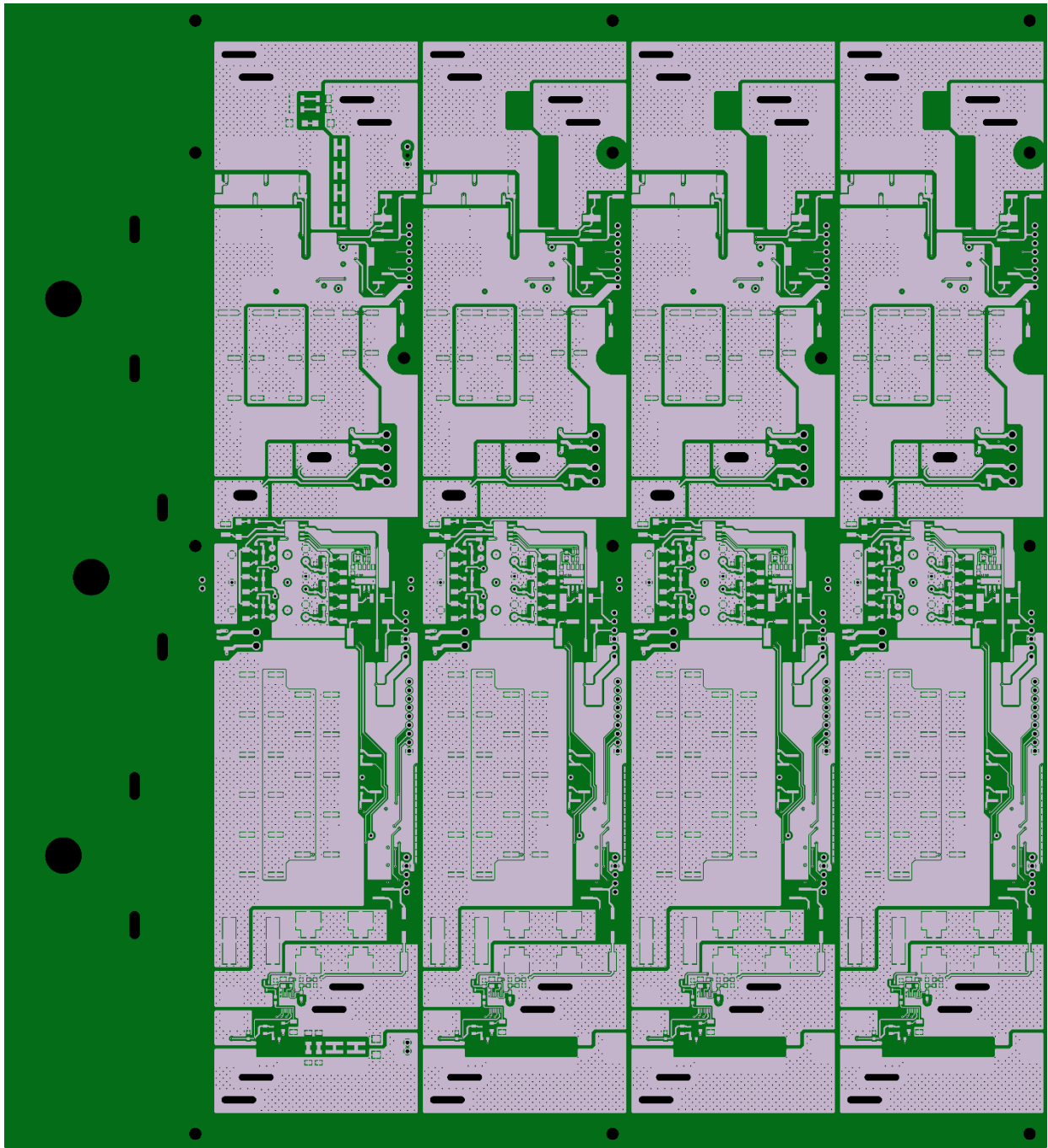
Fig. 3.1 shows PCB pattern diagram of the main board, and Fig. 3.2 shows the pattern diagram of the control board.

Refer to following files:

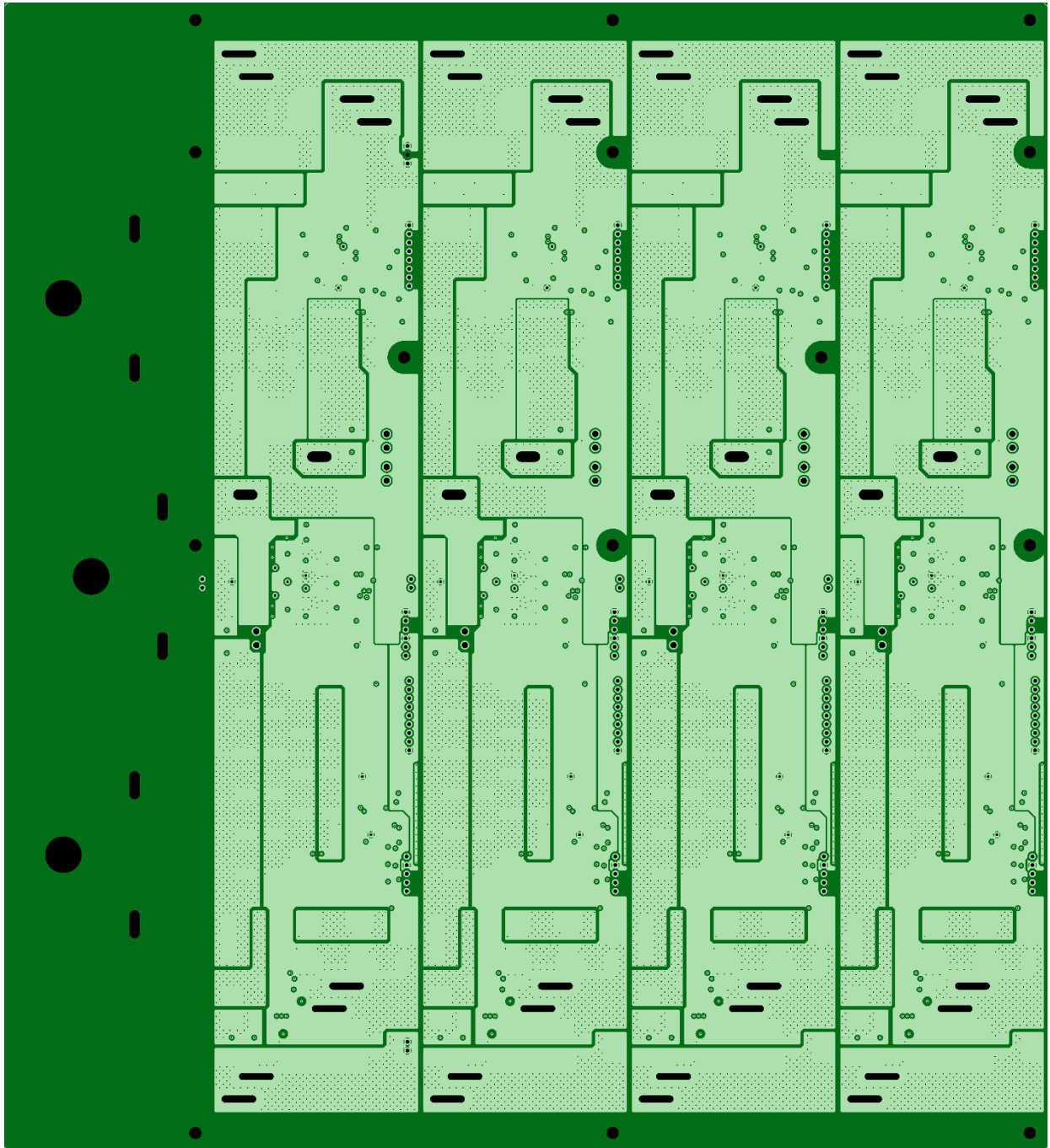
Main board: RD210-LAYER1-xx.pdf

Control board: RD210-LAYER2-xx.pdf

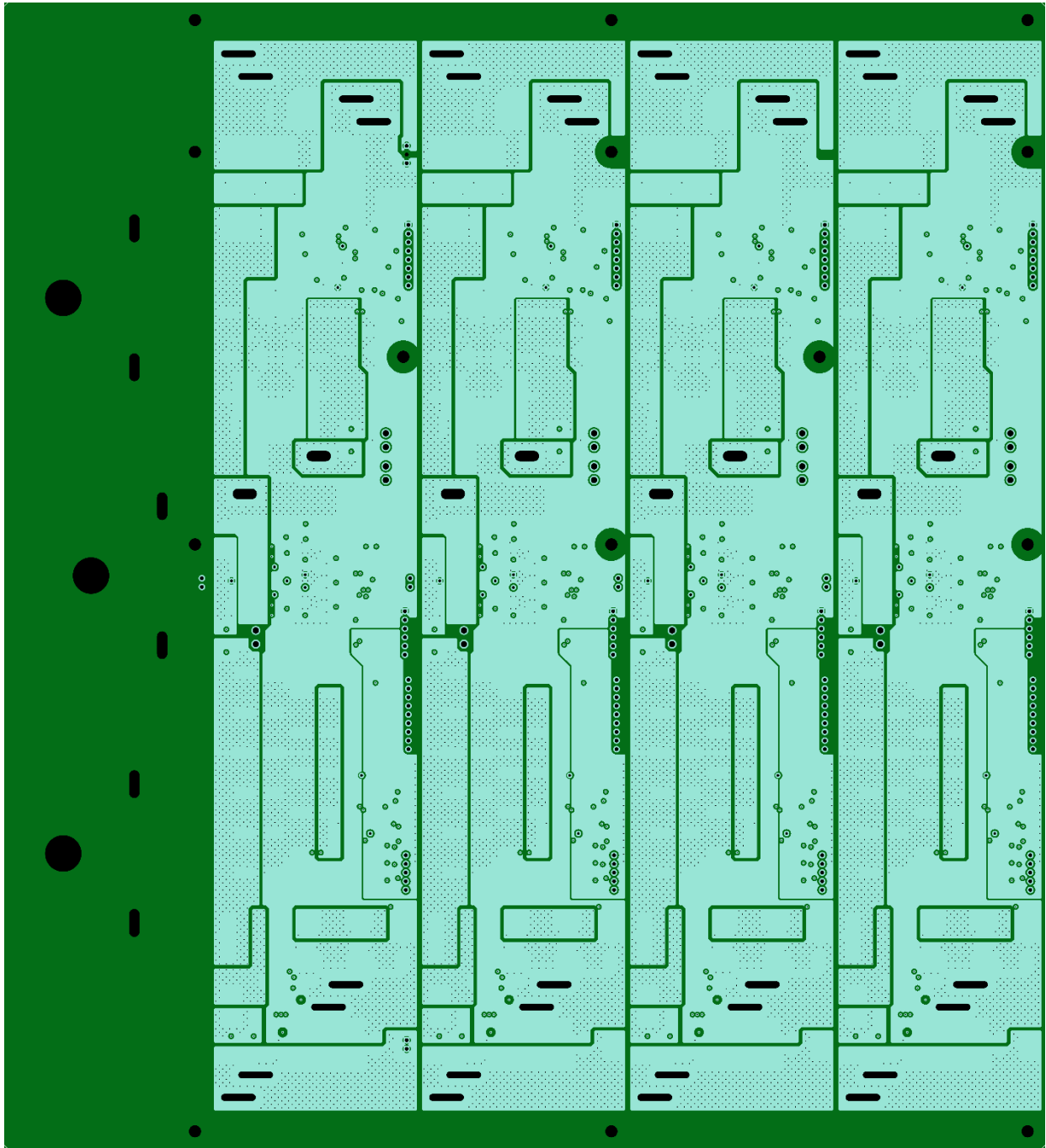
(xx is the revision number.)



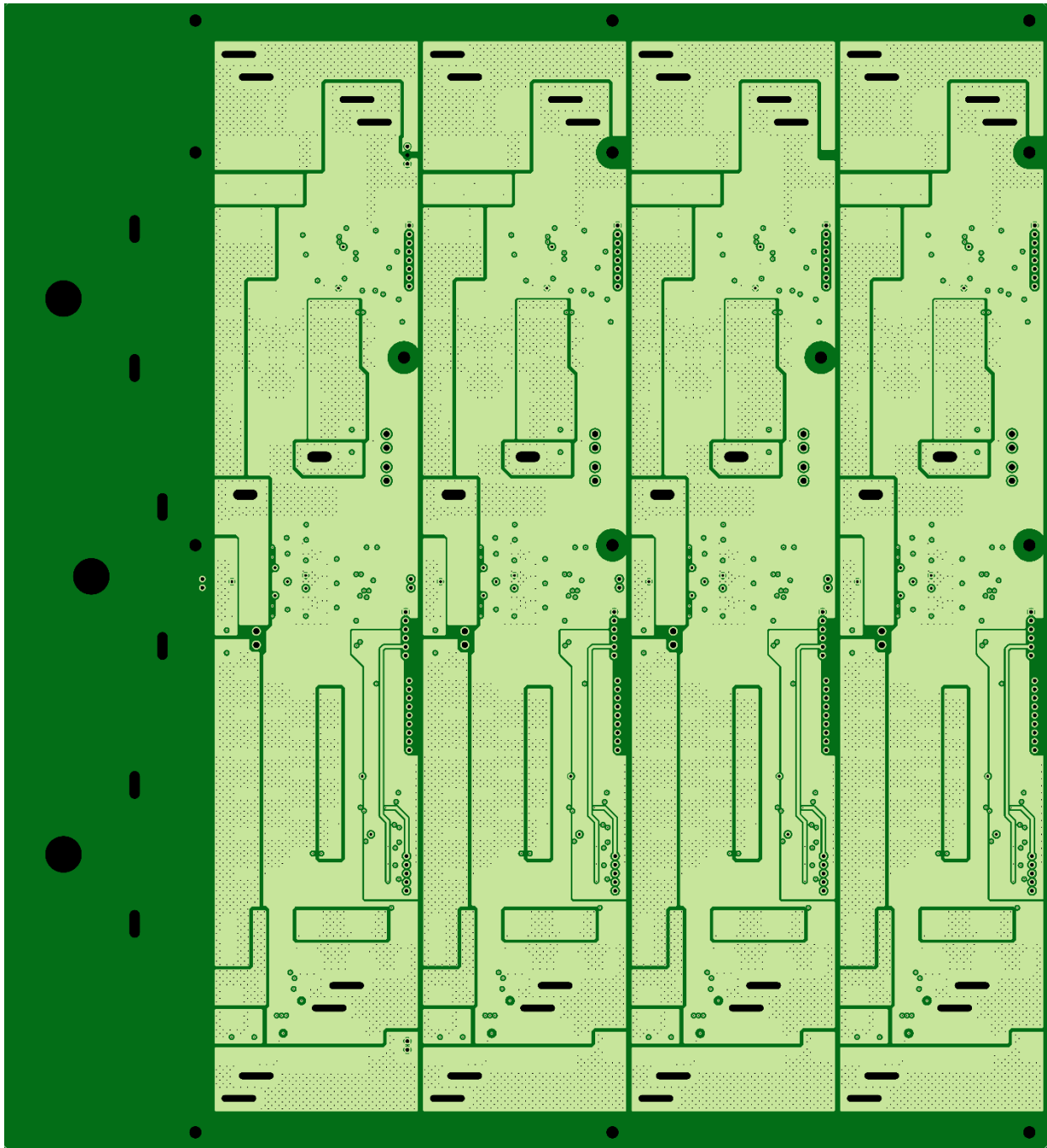
<Layer1, Top>



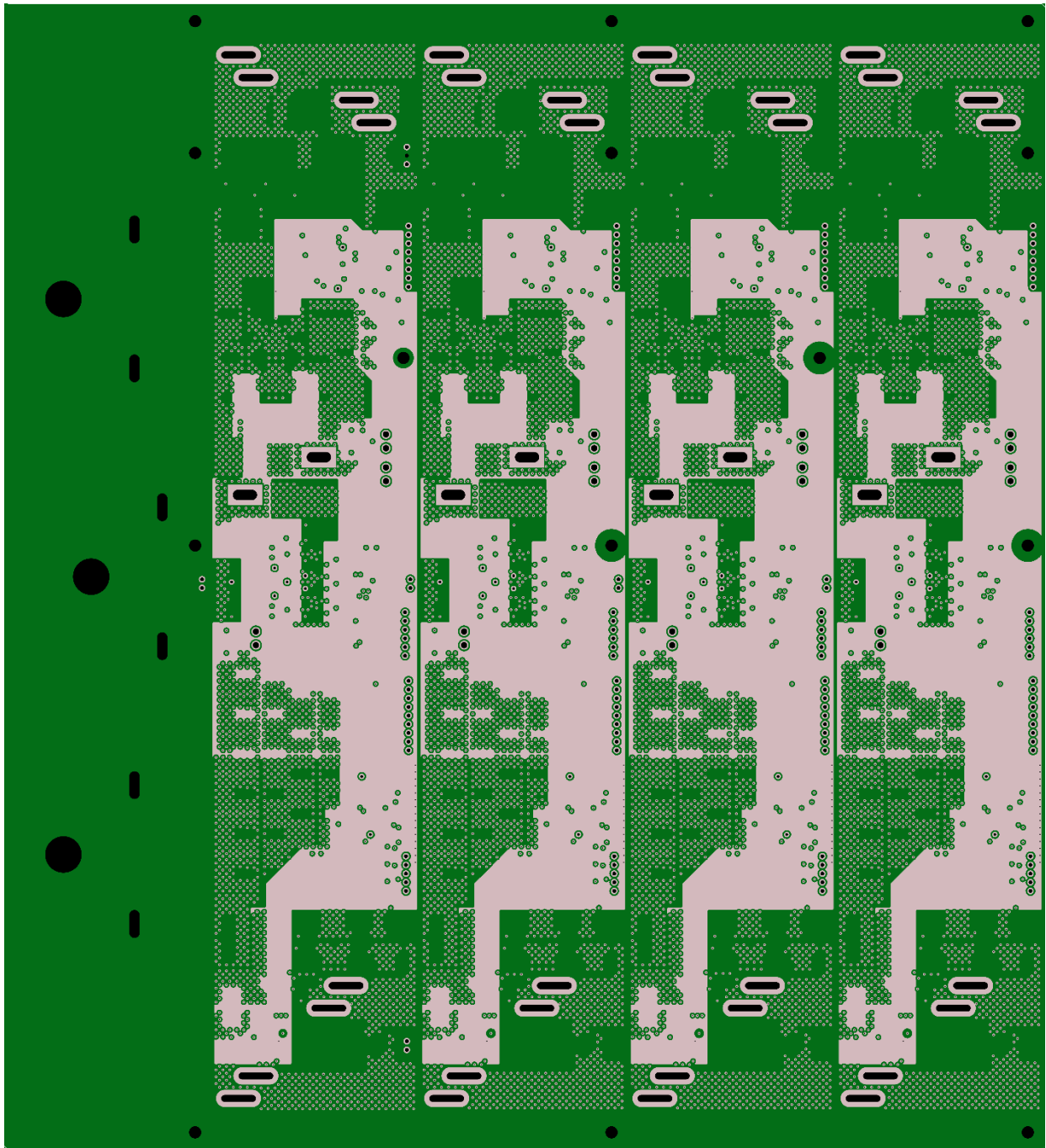
<Layer2>



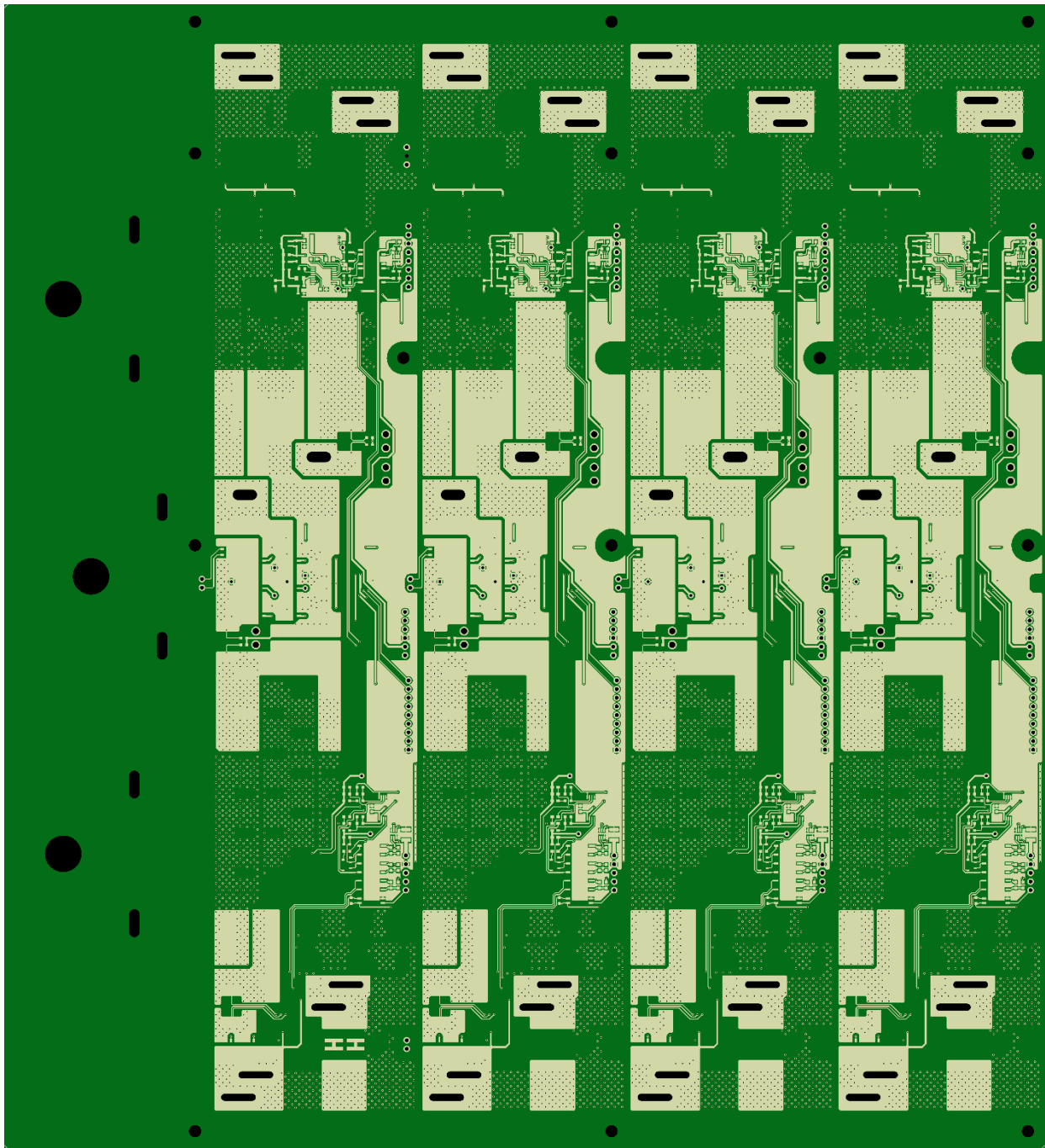
<Layer3>



<Layer4>

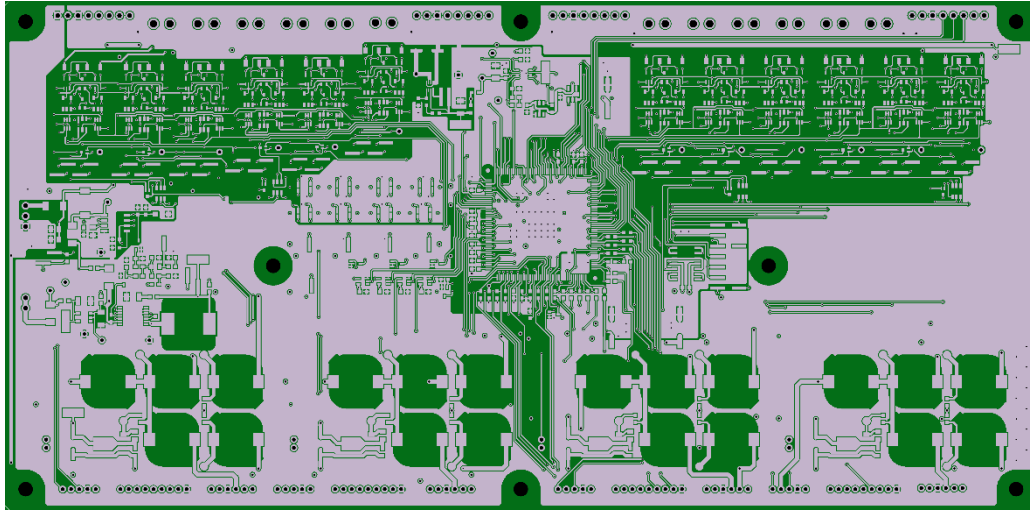


<Layer5>

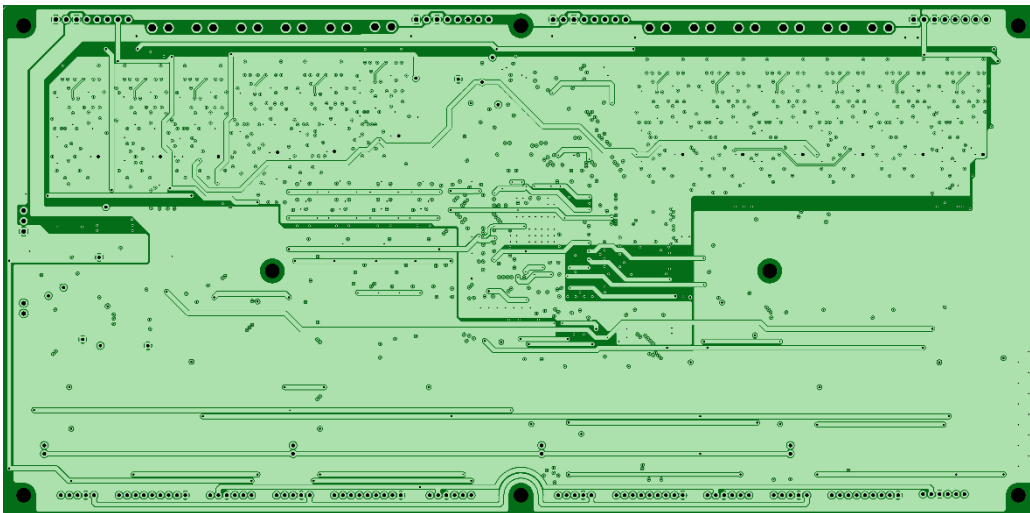


<Layer6, Bottom>

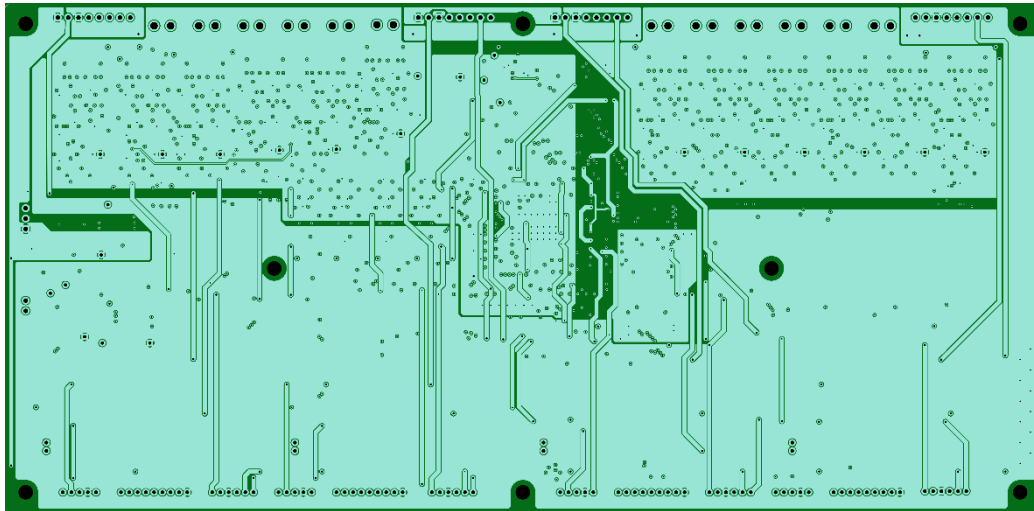
Fig. 3.1 Main Board Pattern Diagram (Top View)



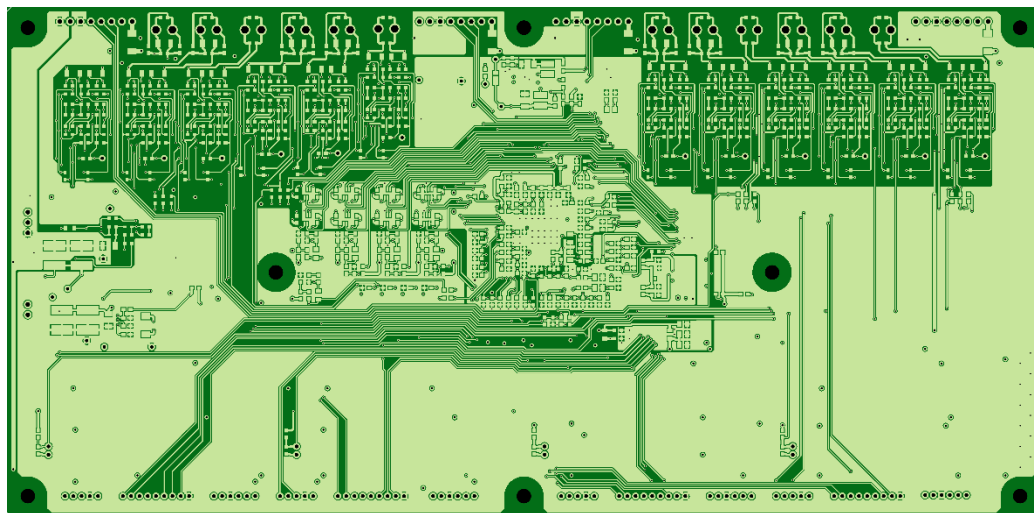
<Layer1, Top>



<Layer2>



<Layer3>



<Layer1, Bottom>

Fig. 3.2 Control Board Pattern Diagram (Top View)

4. Operation Procedure

4.1. Connection to External Devices

Fig. 4.1 shows the external connection terminals and setting jumper terminals of this design. The component enclosed in red is the + terminal of the input/output circuit of 48V line (high-voltage side), the component enclosed in blue is the + terminal of the input/output circuit of 12V line (low-voltage side), and the component enclosed in amber is GND terminal. The components enclosed in white consist of the jumper terminal (CN500) for switching between boost operation and buck operation, and the jumper terminal (CN400) for starting the power supply.

Connect a DC stabilized power supply between the terminal used as input and GND terminal, and connect DC load between the terminal used as output and GND terminal. Use a power supply, a load and cables that satisfy the power specifications.

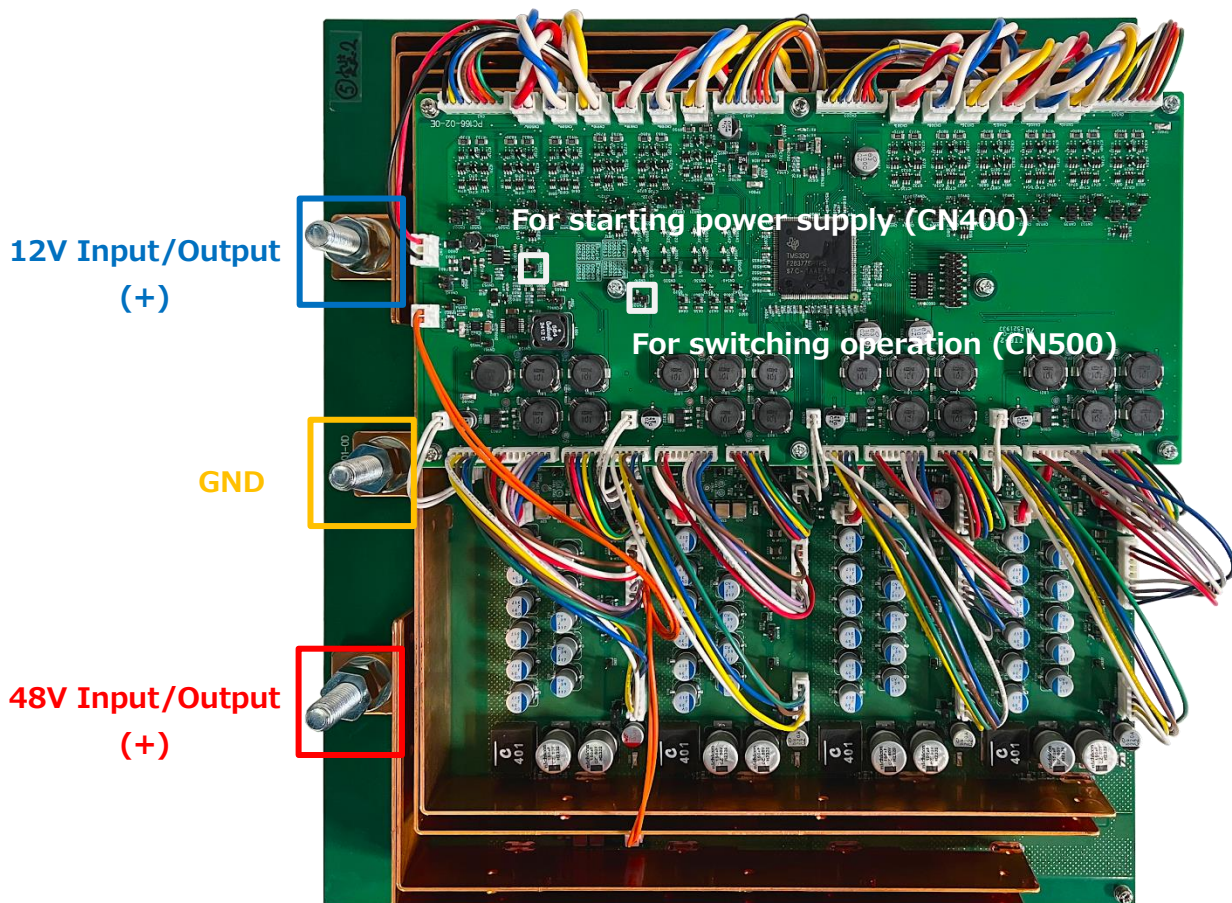


Fig. 4.1 External Connection Terminals

4.2. Starting and Stopping Procedure

Make sure all external terminals are 0V before starting.

[Starting Procedure]

1. Set CN400 to open.
2. Turn on the connected power supply.
3. Set CN500 to open for boost operation (short-circuit CN500 for buck operation).
4. Set CN400 to close to supply power to MCU and start power supply operation.

[Stopping Procedure]

1. Set CN400 to open to cut-off the power supply to MCU and stop power supply operation.
2. Turn off the connected power supply.

4.3. Evaluation Precautions (To Prevent Electric Shocks, Burns, etc.)

Be careful of electric shock when connecting the power supply. Do not touch any component of the power supply directly while it is energized. Be very careful when observing waveforms. Even after this power supply is shut down, there is a danger of electric shock due to residual charge of various capacitors. Make sure that the voltage of each component has dropped sufficiently before touching the BOARD.

In addition, the semiconductor devices and inductors of this power supply may generate heat according to the load current. This power supply assumes forced air cooling. Use an air-cooling device that enables heat-generating components to stay within the rated temperature range under high load. Do not touch any component of the power supply while the power supply is in operation as it may cause burns.

5. Power Supply Characteristics

This section describes the power supply efficiency measurement results of this design. Efficiency was measured up to 3kW of the rated load in both buck operation (input voltage 48V and output voltage 12V) and boost operation (input voltage 12V and output voltage 48V).

5.1. Efficiency

Fig. 5.1 shows the efficiency measurement results in buck operation, and Fig. 5.2 shows the efficiency measurement results in boost operation. The high efficiency of 91.3% is achieved at 3kW output in buck operation and the efficiency of 92.2% is achieved at 3kW output in boost operation.

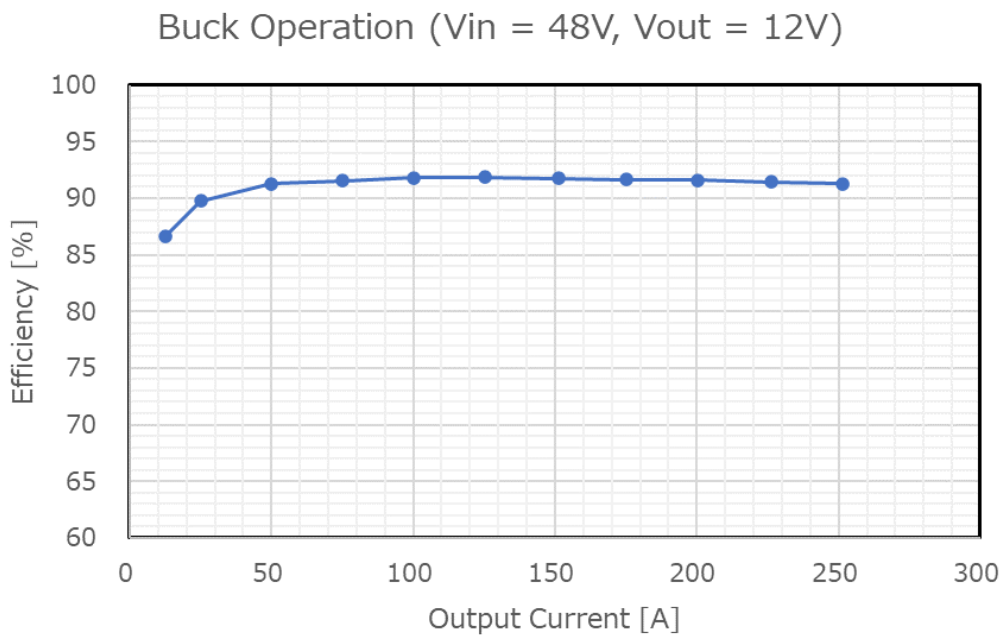


Fig. 5.1 Buck Operation Efficiency

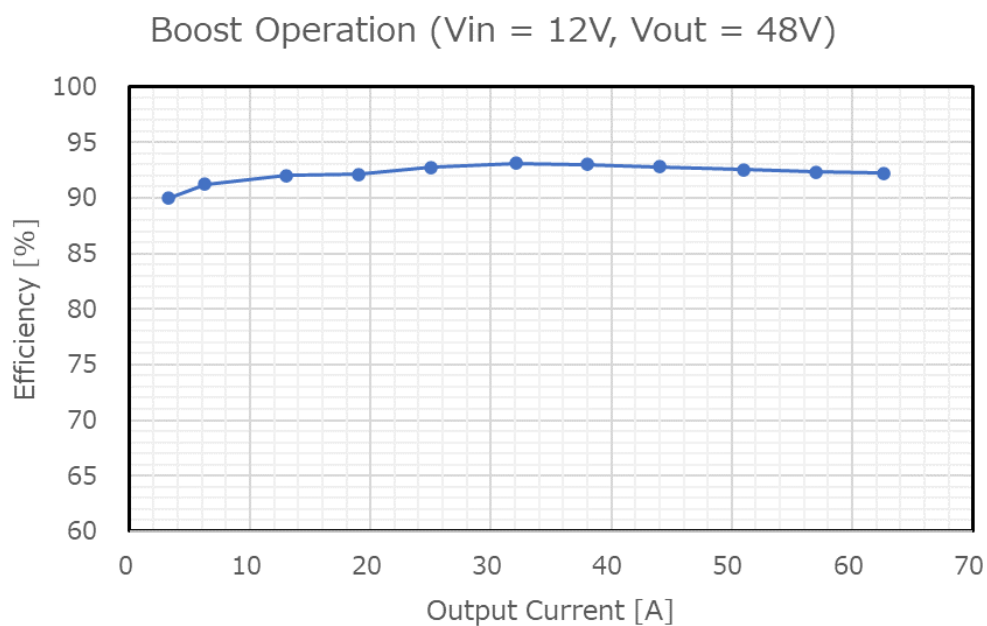


Fig. 5.2 Boost Operation Efficiency

Terms of Use

This terms of use is made between Toshiba Electronic Devices and Storage Corporation ("We") and Customer who downloads or uses this Reference Design. Customer shall comply with this terms of use. This Reference Design means all documents and data in order to design electronics applications on which our semiconductor device is embedded.

Section 1. Restrictions on usage

1. This Reference Design is provided solely as reference data for designing electronics applications. Customer shall not use this Reference Design for any other purpose, including without limitation, verification of reliability.
2. Customer shall not use this Reference Design for sale, lease or other transfer.
3. Customer shall not use this Reference Design for evaluation in high or low temperature, high humidity, or high electromagnetic environments.
4. This Reference Design shall not be used for or incorporated into any product or system whose manufacture, use, or sale is prohibited under any applicable laws or regulations.

Section 2. Limitations

1. We reserve the right to make changes to this Reference Design without notice.
2. This Reference Design should be treated as a reference only. WE ARE NOT RESPONSIBLE FOR ANY INCORRECT OR INCOMPLETE DATA AND INFORMATION.
3. Semiconductor devices can malfunction or fail. When designing electronics applications by referring to this Reference Design, Customer is responsible for complying with safety standards and for providing adequate designs and safeguards for their hardware, software and systems which minimize risk and avoid situations in which a malfunction or failure of semiconductor devices could cause loss of human life, bodily injury or damage to property, including data loss or corruption. Customer must also refer to and comply with the latest versions of all relevant our information, including without limitation, specifications, data sheets and application notes for semiconductor devices, as well as the precautions and conditions set forth in the "Semiconductor Reliability Handbook".
4. Designing electronics applications by referring to this Reference Design, Customer must evaluate the whole system sufficiently. Customer is solely responsible for applying this Reference Design to Customer's own product design or applications. WE ASSUME NO LIABILITY FOR CUSTOMER'S PRODUCT DESIGN OR APPLICATIONS.
5. WE SHALL NOT BE RESPONSIBLE FOR ANY INFRINGEMENT OF PATENTS OR ANY OTHER INTELLECTUAL PROPERTY RIGHTS OF THIRD PARTIES THAT MAY RESULT FROM THE USE OF THIS REFERENCE DESIGN. NO LICENSE TO ANY INTELLECTUAL PROPERTY RIGHT IS GRANTED BY THIS TERMS OF USE, WHETHER EXPRESS OR IMPLIED, BY ESTOPPEL OR OTHERWISE.
6. THIS REFERENCE DESIGN IS PROVIDED "AS IS". WE (a) ASSUME NO LIABILITY WHATSOEVER, INCLUDING WITHOUT LIMITATION, INDIRECT, CONSEQUENTIAL, SPECIAL, OR INCIDENTAL DAMAGES OR LOSS, INCLUDING WITHOUT LIMITATION, LOSS OF PROFITS, LOSS OF OPPORTUNITIES, BUSINESS INTERRUPTION AND LOSS OF DATA, AND (b) DISCLAIM ANY AND ALL EXPRESS OR IMPLIED WARRANTIES AND CONDITIONS RELATED TO THIS REFERENCE DESIGN, INCLUDING WITHOUT LIMITATION, WARRANTIES OR CONDITIONS OF FUNCTION AND WORKING, WARRANTIES OF MERCHANTABILITY, FITNESS FOR A PARTICULAR PURPOSE, ACCURACY OF INFORMATION, OR NONINFRINGEMENT.

Section 3. Terms and Termination

It is assumed that Customer agrees to any and all this terms of use if Customer downloads or uses this Reference Design. We may, at its sole and exclusive discretion, change, alter, modify, add, and/or remove any part of this terms of use at any time without any prior notice. We may terminate this terms of use at any time and without any cause. Upon termination of this terms of use, Customer shall eliminate this Reference Design. Furthermore, upon our request, Customer shall submit to us a written confirmation to prove elimination of this Reference Design.

Section 4. Export Control

Customer shall not use or otherwise make available this Reference Design for any military purposes, including without limitation, for the design, development, use, stockpiling or manufacturing of nuclear, chemical, or biological weapons or missile technology products (mass destruction weapons). This Reference Design may be controlled under the applicable export laws and regulations including, without limitation, the Japanese Foreign Exchange and Foreign Trade Act and the U.S. Export Administration Regulations. Export and re-export of this Reference Design is strictly prohibited except in compliance with all applicable export laws and regulations.

Section 5. Governing Laws

This terms of use shall be governed and construed by laws of Japan, without reference to conflict of law principle.

Section 6. Jurisdiction

Unless otherwise specified, Tokyo District Court in Tokyo, Japan shall be exclusively the court of first jurisdiction for all disputes under this terms of use.