Air Conditioner Outdoor Unit Circuit

Reference Guide

RD219-RGUIDE-02

Toshiba Electronic Devices & Storage Corporation

Table of Contents

1. Introduction

This Reference Guide (hereinafter referred to as this guide) describes the specifications and operation procedures of the Air Conditioner Outdoor Unit Circuit (hereinafter referred to as this design).

Recently, low power consumption has been required for outdoor air conditioner units. And brushless motors driven by inverters using high efficiency switching devices have become common for compressors and fans. In addition, sensorless vector control is being increasingly used for motor control, as equipment is required to have low cost, high efficiency, and low motor noise. In addition, the demand for smaller circuit boards in equipment is also increasing.

This design uses a low on-resistance power MOSFET TK20A60W5 for the compressor drive inverter to achieve a highly efficient compressor drive. In addition, a highly efficient and compact fan motor drive is achieved by using an intelligent power device TPD4204F with a built-in gate driver and inverter circuit for the fan motor drive. PFC inductors are also downsized by using IGBT device GT30J65MRB that has low switching losses and can operate at high switching frequencies in a switching PFC power supply circuit. Furthermore, by using the microcontroller TMPM4KLFYAUG equipped with a vector engine, sensorless vector control of the fan motor and the compressor as well as PFC power supply control are realized with a single microcontroller, which simplifies and reduces the size of the outdoor unit circuit.

In addition, a transistor array TBD62003AFG is used as a valve control driver, a photocoupler TLP785 is used as an insulating interface for communication between outdoor units and indoor units, a SiC Schottky barrier diode TRS24N65FB is used as a PFC diode, a TC75W59FU is used as an operational amplifier for signal amplification, and a TA75S393F is used as a comparator for detecting abnormalities.

2. Specifications

Table 2.1 lists the main specifications of the circuit of this design.

Table 2.1 Air Conditioner Outdoor Unit Circuit Specifications

Item	Description
Input Power Supply	AC220 V (Typ.)
Control Power Supply	DC15 V, DC12 V, DC5 V (internally generated)
Compatible Motors and Control Methods	Brushless motor: 2 ch Fan motor (motor ch.0) Compressor (motor ch.1) Sensorless vector control
Rated Output	PFC: 1500 W Fan motor: 200 W Compressor: 1300 W
Switching Frequency (Software Setting)	PFC: 60 kHz Fan motor: 16 kHz Compressor: 6.5 kHz
Hardware Protection Features	AC input overcurrent (fuse 20 A) PFC overcurrent (18 A) Fan motor overcurrent (1.4 A) Compressor overcurrent (17 A) Overheat and power supply voltage drop (driver function of fan motor drive)
Board Size	160 × 220 × 80 mm
Board Configuration	FR-4 Double-sided 1.6 mm Thickness, Copper Foil Thickness 70 μm one-side silk, one-side mounting
Cooling System	(Forced air cooling by an outdoor unit fan)
I/O Interface	Valve control: 5 ch (four-way valve x 1 ch, electric expansion valve x 4 ch) Indoor unit communication: 1 ch Temperature sensor input: 6 ch UART: 1 ch (Host MCU communication) Synchronous communication: 1 ch (for DAC output) SWD input/output: 1 ch (for debugging) LED: 4 pcs. (status display), 1 pc. (power ON display)

2.1. Block Diagram

Figure 2.1 shows the block diagram of this design.

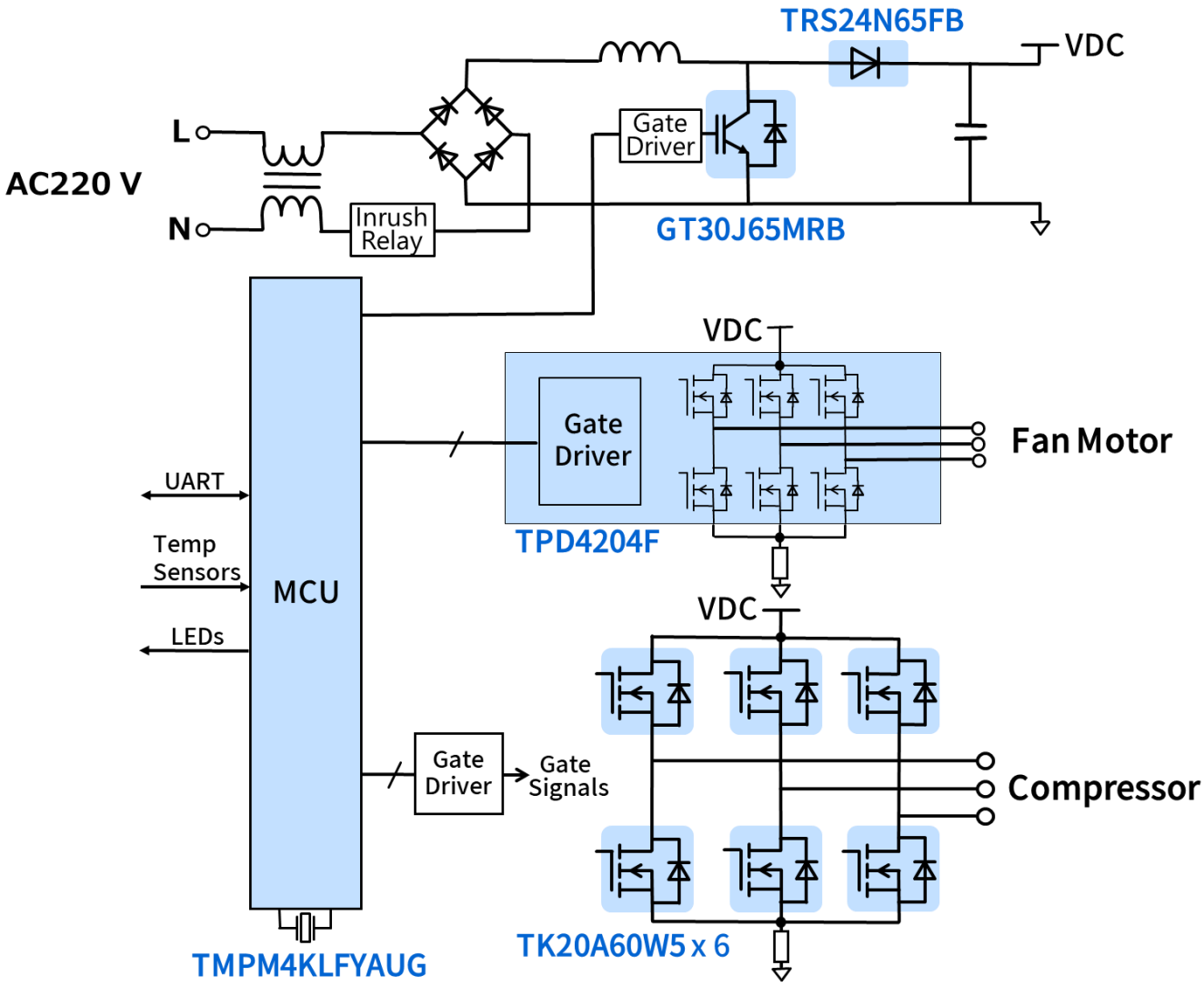


Fig. 2.1 Block Diagram of the Air Conditioner Outdoor Unit Circuit

2.2. Appearance and Component Layout

Figures 2.2, 2.3, and 2.4 show the external appearance of this design, and Figures 2.5 and 2.6 show the PCB layout.

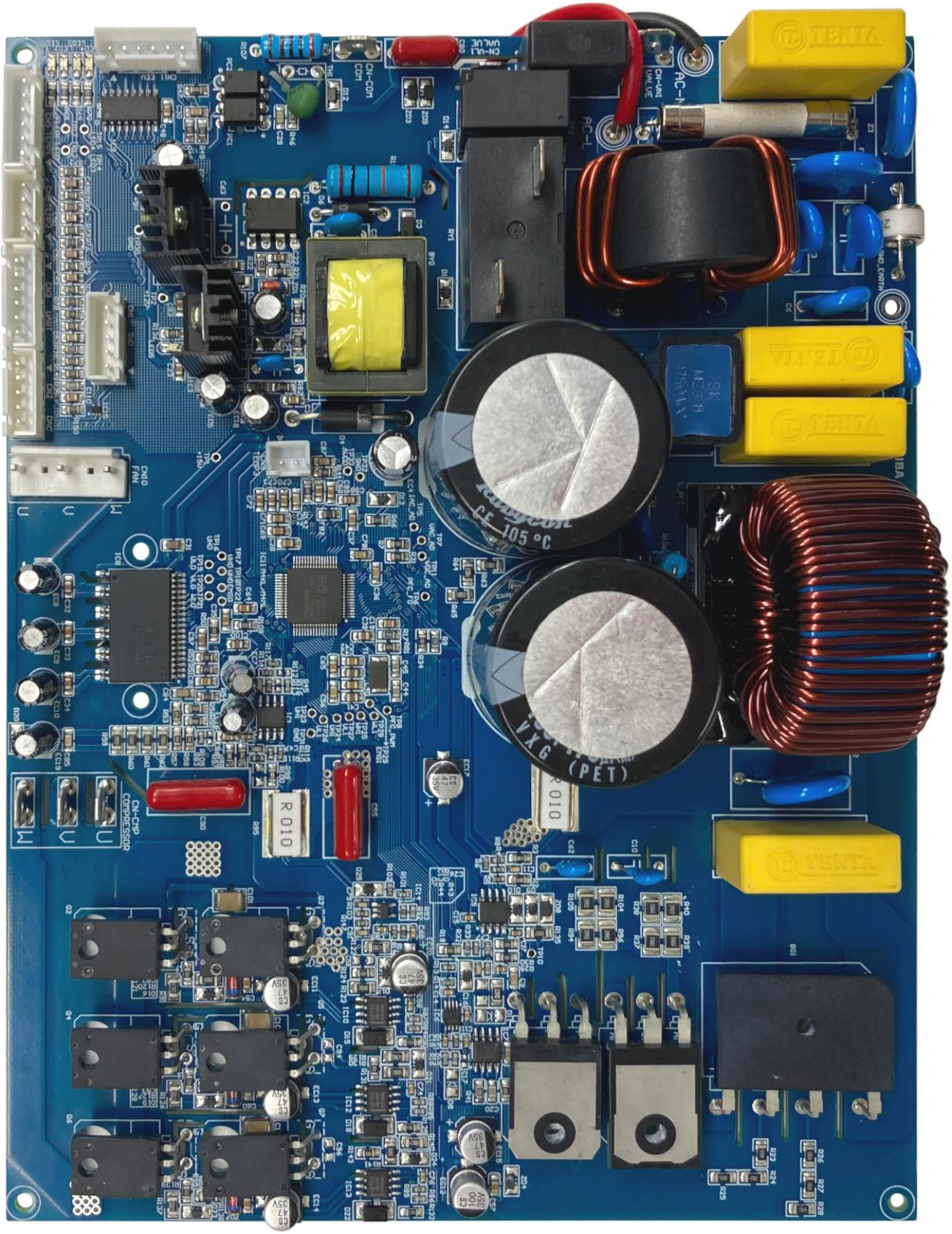


Fig. 2.2 Front View of the Air Conditioner Outdoor Unit Circuit Board

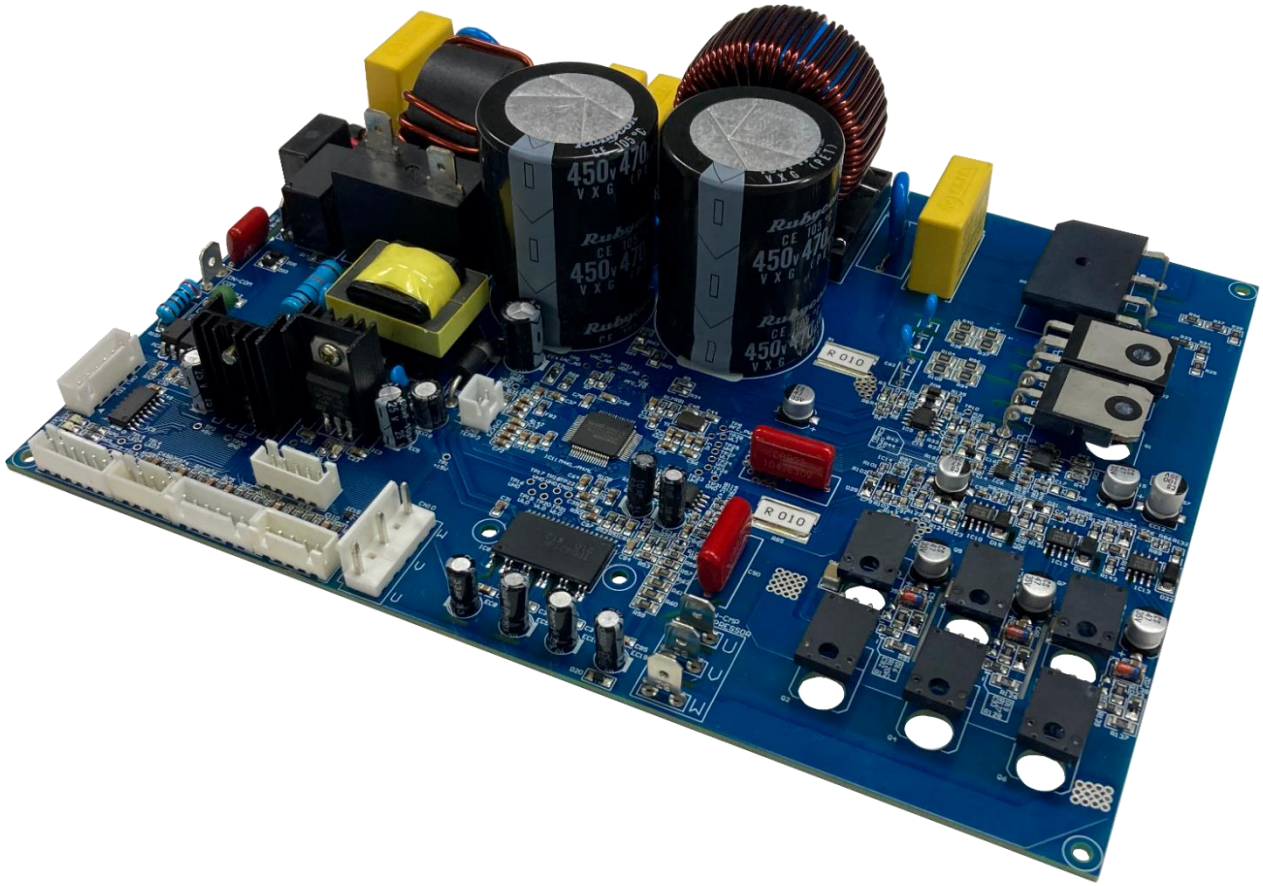


Fig. 2.3 Side View of the Air conditioner Outdoor Unit Circuit Board

Fig. 2.4 Side View of the Air Conditioner Outdoor Unit Circuit Board (with Heat Sink Installed)

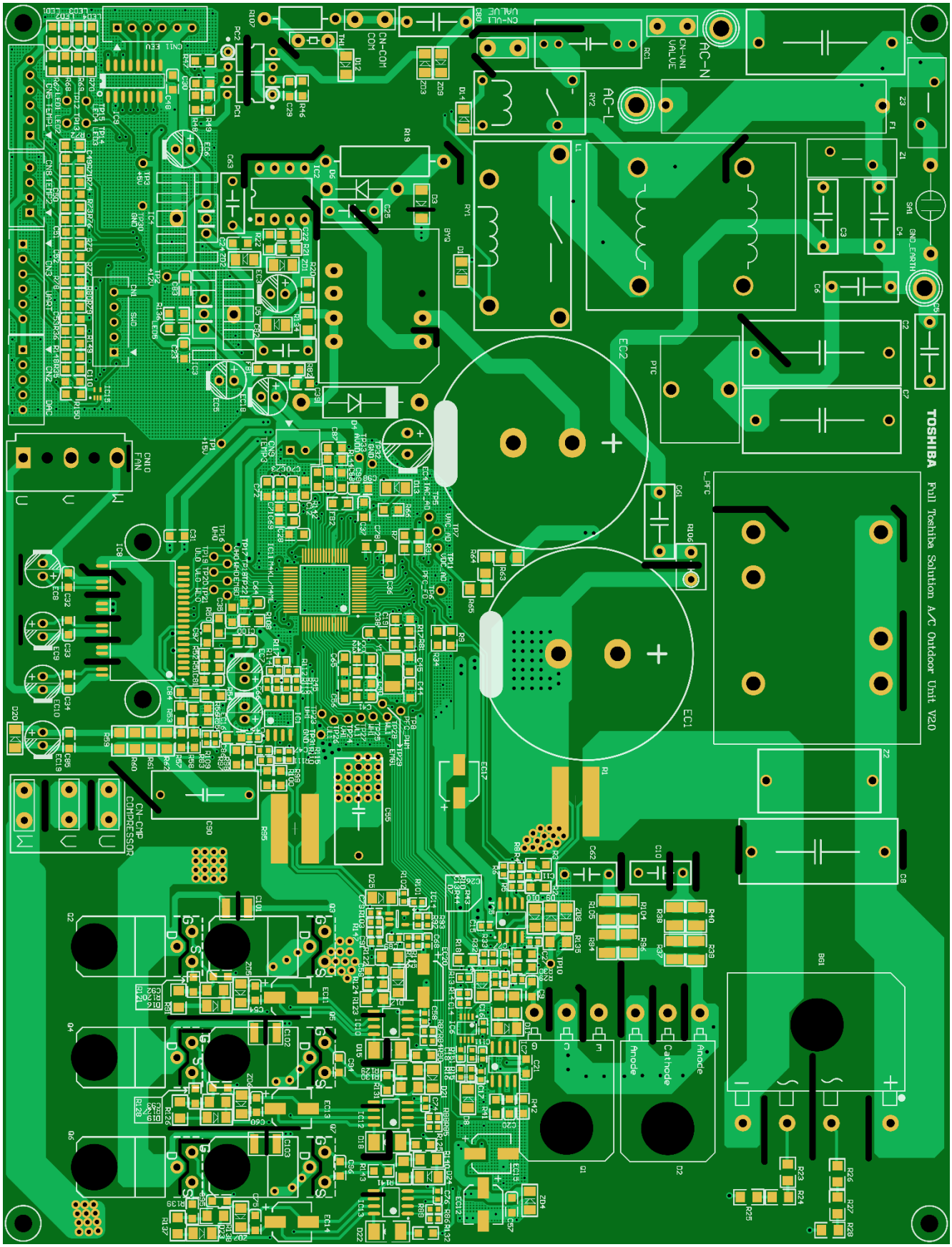


Fig. 2.5 PCB Layout of the Main Components of the Air Conditioner Outdoor Unit Circuit (Top)

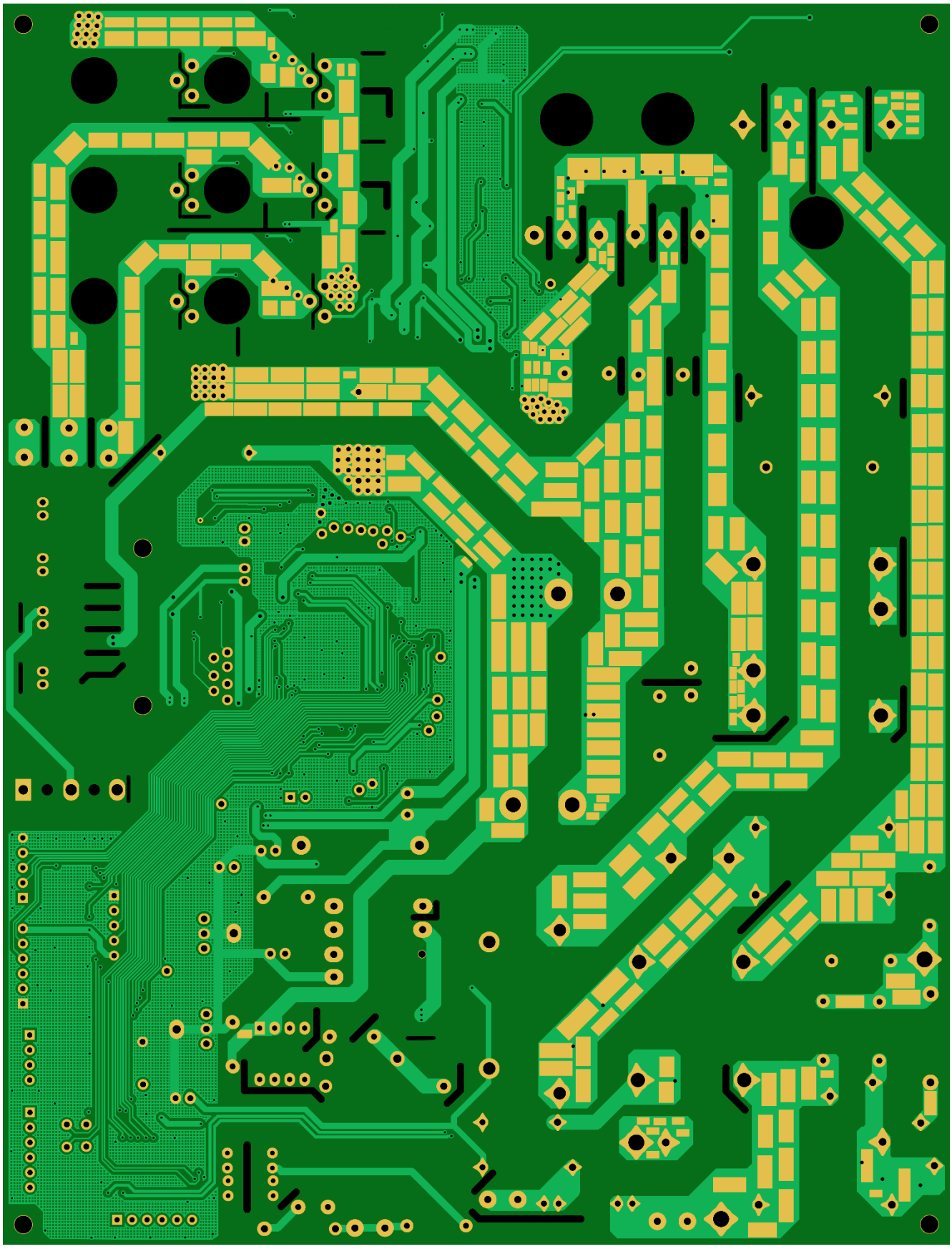


Fig. 2.6 PCB Layout of the Main Components of the Air Conditioner Outdoor Unit Circuit (Bottom)

3. Schematic , Bill of Materials, and PCB Pattern

3.1. Schematic

Refer to the following file.

RD219-SCHEMATIC-xx.pdf

(xx is the revision number.)

3.2. Bill of Materials

Refer to the following file.

RD219-BOM-xx.pdf

(xx is the revision number.)

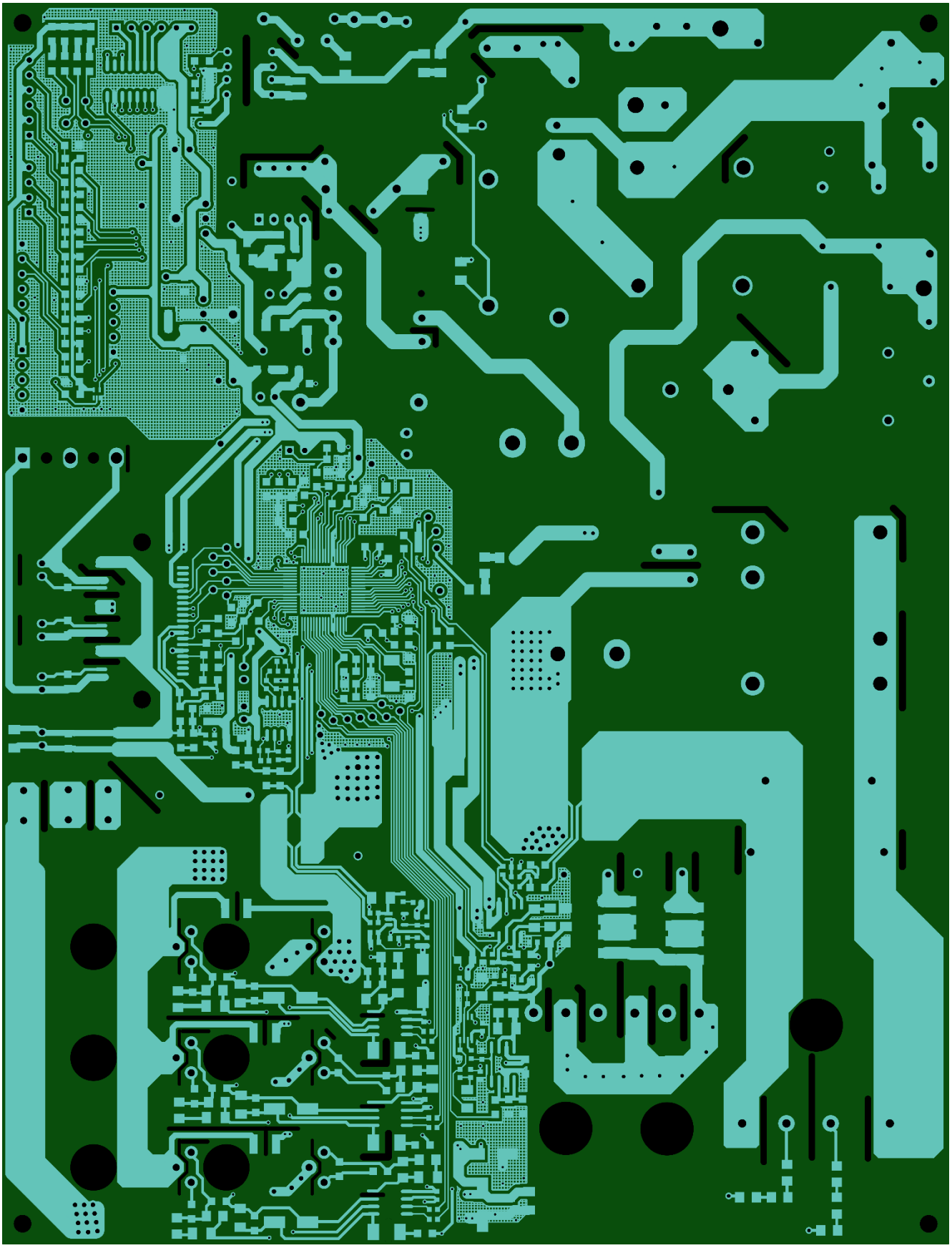
3.3. PCB Pattern

Figure 3.1 shows the PCB pattern of this design.

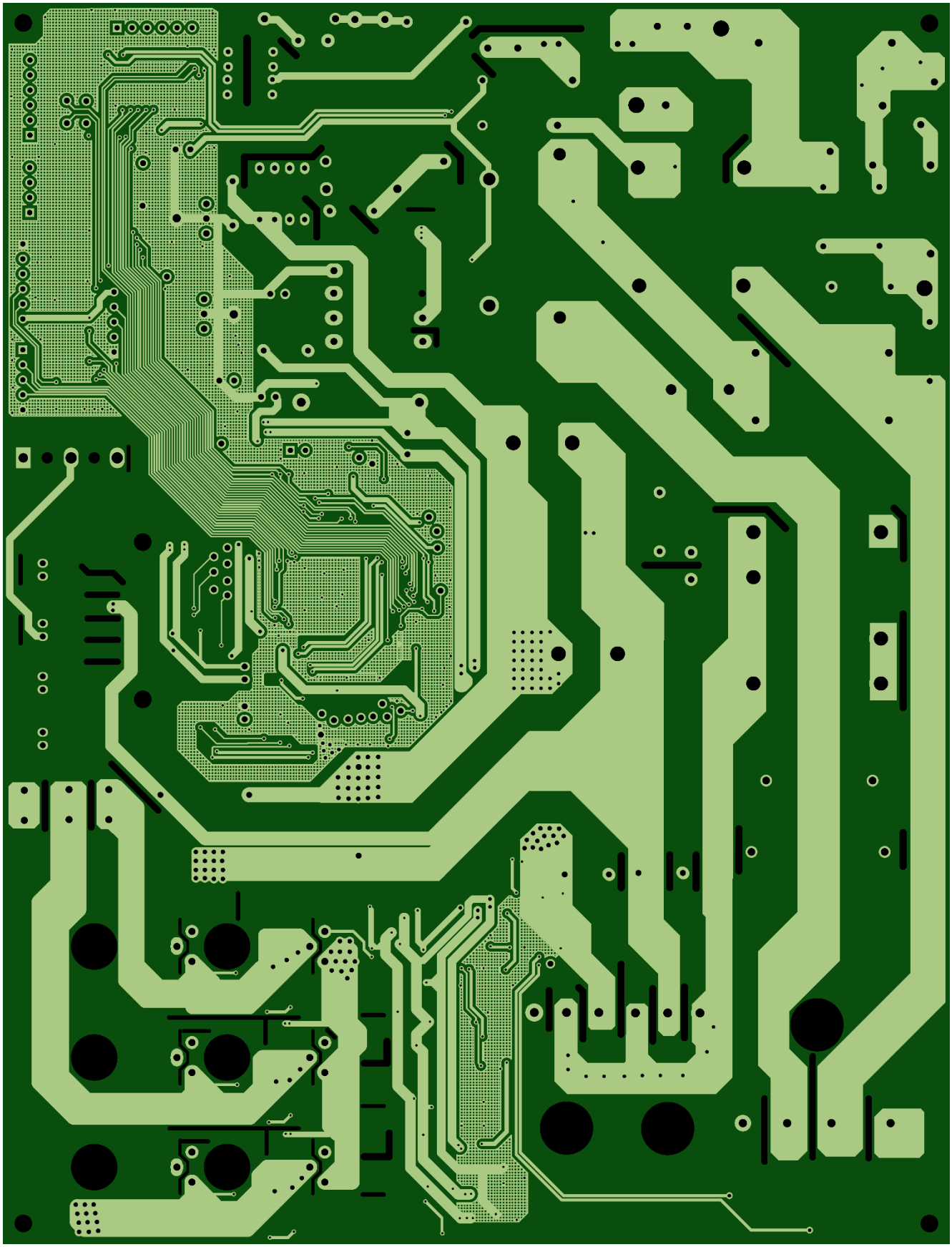
Refer to the following file:

RD219-LAYER-xx.pdf

(xx is the revision number.)



<Layer 1 Front>



<Layer 2 Back>

Fig. 3.1 PCB Pattern Diagram (Top View)

4. Operation

4.1. Names and Functions of Components

4.1.1. Power Supply Input Terminals (AC-L, AC-N, GND_EARTH)

These are the AC power supply input terminals. Connect these to an AC stabilized power supply. Solder the power supply wires to the through hole terminals of 2.7 mm diameter. And, if necessary connect the Earth wire to the frame ground (GND_EARTH) terminal.

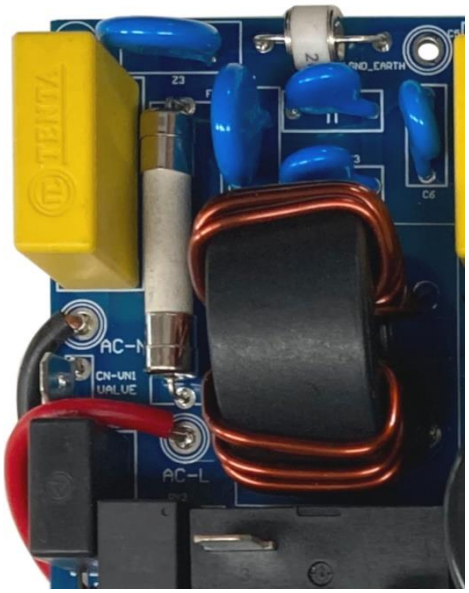


Fig. 4.1 AC Power Supply Input Terminals (AC-L, AC-N, GND_EARTH)

Table 4.1 AC Power Supply Input Terminal Specifications

Terminal Name	Function	Remarks
AC-L	L (Live)	Φ2.7 mm through hole
AC-N	N (Neutral)	Φ2.7 mm through hole
GND_EARTH	Frame Ground	Φ2.7 mm through hole

4.1.2. Fan Motor Connector (CN10)

This is the fan motor (motor ch.0) output connector. Three-phase pins of U/V/W are provided to connect to the three-phase brushless motor. This connector uses B5P5-VH (JST) or a compatible connector.

Fig. 4.2 Fan Motor Connector (CN10)

4.1.3. Compressor Connectors (CN-CMP)

These are the compressor (motor ch.1) connectors (output). Three-phase pins of U/V/W are provided to connect to the three-phase brushless motor. Each of these connectors uses a blade connector DJ6110-6.3x0.8 (Gocel) or a compatible connector.

Fig. 4.3 Compressor Connector (CN-CMP)

4.1.4. Four-Way Valve Connectors (CN-VL1, CN-VN1)

These connectors are used to connect a four-way valve. Software based relay control enables AC line input voltage to be output between CN-VL1 and CN-VN1 when it is ON. CN-VN1 is always connected to AC power input terminal AC-N. Each of these connectors uses a blade connector DJ6110-6.3x0.8 (Gocel) or a compatible connector.

Fig. 4.4 Four-Way Valve Connectors (CN-VL1, CN-VN1)

4.1.5. Electric Expansion Valve Connector (CN11)

This connector is used to connect the electric expansion valve. Four output channels EEV-A, EEV-B, EEV-C and EEV-D are controlled by software operated low-side switches, and the output of each channel is open when the corresponding switch is off and is connected to the GND when the corresponding switch is on. By connecting an electric expansion valve between a channel of EEV output and the 12 V power supply, the 12 V voltage is applied to the electric expansion valve when the switch is on. This connector uses B6B-XH-A (JST) or a compatible connector.

Fig. 4.5 Electric Expansion Valve Connector (CN11)

Table4.2 Electric Expansion Valve Connector (CN11) Specifications

Pin	Function	Description
1	EEV-D control power	Connected to GND when on, open when off
2	EEV-C control power	Connected to GND when on, open when off
3	EEV-B control power	Connected to GND when on, open when off
4	EEV-A control power	Connected to GND when on, open when off
5	Power supply (12 V)	
6	Power supply (12 V)	

4.1.6. Indoor Unit Communication Connector (CN-COM)

This connector is used in conjunction with AC power supply input terminal AC-N to perform serial communication with the indoor unit. Use the product according to the electrical laws and regulations of each country. This connector uses a blade connector DJ6110-6.3x0.8(Gocel) or a compatible connector.

Fig. 4.6 Indoor Unit Communication Connector (CN-COM)

4.1.7. AC Power Supply Fuse (F1)

This is an AC power supply fuse. This fuse has a rating of 250 VAC 20 A.

Fig. 4.7 AC Power Supply Fuse (F1)

4.1.8. Temperature Sensor Connectors (CN5, CN8, CN9)

CN5, CN8, CN9 are the temperature sensor connectors. A total of six channels of temperature sensors can be connected via the three connectors. Connect each NTC thermistor between the power supply (5 V) and the voltage output pin of each connector. The connector CN5 uses B6B-XH-A (JST), CN8 uses B4B-XH-A (JST), CN9 uses B2B-XH-A (JST), or compatible connectors.

Fig. 4.8 Temperature Sensor Connectors (CN5, CN8, CN9)

Table4.3 Temperature Sensor Connector (CN5) Specifications

Pin	Description	Application Examples
1	Temperature sensor ch. 0 voltage input	For measuring temperature in equipment
2	Temperature sensor ch. 0 power supply (5 V)	
3	Temperature sensor ch. 1 voltage input	For measuring temperature in equipment
4	Temperature sensor ch. 1 power supply (5 V)	
5	Temperature sensor ch. 2 voltage input	For measuring temperature in equipment
6	Temperature sensor ch. 2 power supply (5 V)	

Table4.4 Temperature Sensor Connector (CN8) Specifications

Pin	Description	Application Examples
1	Temperature sensor ch. 3 voltage input	For measuring temperature of PFC IGBT
2	Temperature sensor ch. 3 Power (5 V)	
3	Temperature sensor ch. 4 voltage input	For measuring temperature of PFC diode
4	Temperature sensor ch. 4 power supply (5 V)	

Table4.5 Temperature Sensor Connector (CN9) Specifications

Pin	Description	Application Examples
1	Temperature sensor ch. 5 voltage input	For measuring temperature of compressor-drive MOSFET
2	Temperature sensor ch. 5 Power (5 V)	

4.1.9. UART Connector (CN3)

This connector is used to connect to the UART of the MCU included in this design. Connect to the host MCU board when checking the operation. This connector uses B6B-XH-A(JST) or a compatible connector.

Fig. 4.9 UART Connector (CN3)

Table. 4.6 UART Connector (CN3) Specifications

Pin Number	Pin Name	Function	Host MCU Board Connection Destination for Checking Operation
1	DVSS	GND	GND (TB1 - GND)
2	TXD	UART Tx	RXD (HDR1 – pin9)
3	RXD	UART Rx	TXD (HDR1 – pin10)
4	(n.c.)	-	-
5	nRESET	Reset input	HDR1 – pin15
6	DVDD	5 V output	TB1 (VCC-EXT)

4.1.10. SWD Connector (CN1)

This is the SWD (Serial Wire Debug) Connector. MCU used in this design can be debugged by connecting an external debugger. This connector uses B5B-XH-A (JST) or a compatible connector.

Fig. 4.10 SWD Connector (CN1)

Table. 4.7 SWD Connector (CN1) Specifications

Pin Number	Pin Name	Input/Output	Pin Description
1	DVSS	-	GND
2	(n.c.)	-	GPIO port
3	SWCLK	I	SWD clock signal (100 kΩ pull-up recommended)
4	SWDIO	I/O	SWD data signal (100 kΩ pull-up recommended)
5	DVDD	-	5 V power

4.1.11. DAC Output Connector (CN2)

This is a synchronous serial data output connector for an external DAC. The external DAC can be used to monitor the waveform. For example, software settings can be used to output the internal data. This connector uses B5B-XH-A (JST) or a compatible connector.

Fig. 4.11 DAC Output Connector (CN2)

Table. 4.8 DAC Output Connector (CN2) Specifications

Pin Number	Pin Name	Input/Output	Pin Description
1	DVDD	--	5 V voltage
2	SDIN	O	GPIO port
3	SCLK	O	SIO port
4	SYNC	O	SIO port
5	DVSS	--	GND

4.1.12. LEDs (LED1, LED2, LED3, LED4, LED5)

The operation status is displayed on the LED1, LED2, LED3, LED4 by the software. LED5 lights up when 5 V power is supplied.

Fig. 4.12 LEDs (LED1, LED2, LED3, LED4, LED5)

Table 4.9 LED Operation Specifications in Sample Software

Factor Type		LED Status
Fan Motor (Motor ch.0)	Normal operation	LED1 turns off
	Hardware error (overcurrent, etc.)	LED2 blinks 1 time
	Soft overcurrent	LED2 blinks 2 times
Compressor (Motor ch.1)	No error	LED1 turns off
	Hard overcurrent	LED3 blinks 1 time
	Soft overcurrent	LED3 blinks 2 times
PFC	Normal operation	LED1 goes off
	Hard overcurrent	LED4 blinks 1 time
	Soft overcurrent	LED4 blinks 2 times
	AC overvoltage	LED4 blinks 3 times
	AC undervoltage	LED4 blinks 4 times
	DC overvoltage	LED4 blinks 5 times
	DC undervoltage	LED4 blinks 6 times
	AC voltage frequency error	LED4 blinks 7 times
	Zero cross error	LED4 blinks 8 times
Temperature	Normal operation	LED1 goes off
	Sensor is open	LED1 blinks 1 time
	Abnormal temperature	LED1 blinks 2 times

4.1.13. Test Pins (TP)

In this design, the test pins are through holes with 1 mm diameters.

Table 4.10 Test Pin Specifications

Test Pin Name	Signal Name	Description
TP1	+15 V	Control power 15 V
TP2	+12 V	Control power 12 V
TP3	+5 V	Control power 5 V
TP5	IAC_AD	PFC current sense amplifier
TP6	PFC_FO	PFC overcurrent detected
TP7	VAC_AD	AC voltage detection amplifier output
TP8	PFC_PWM	Gate driver input signal for PFC
TP10	IGBT_Drive	IGBT gating for PFC
TP11	VDC_AD	DC voltage detection signal
TP12	LED1	LED1 (L-level when lit)
TP13	LED2	LED2 (L-level when lit)
TP14	LED3	LED3 (L-level when lit)
TP15	LED4	LED4 (L-level when lit)
TP16	PWM_UH0	Motor ch.0 U phase high-side PWM
TP17	PWM_VH0	Motor ch.0 V phase high-side PWM
TP18	PWM_WH0	Motor ch.0 W phase high-side PWM
TP19	PWM_UL0	Motor ch.0 U phase low-side PWM
TP20	PWM_VL0	Motor ch.0 V phase low-side PWM
TP21	PWM_WL0	Motor ch.0 W phase low-side PWM
TP22	EMG0	Motor ch.0 error detection signal
TP23	PWM_UH1	Motor ch.1 U phase high-side PWM
TP24	PWM_VH1	Motor ch.1 V phase high-side PWM
TP25	PWM_WH1	Motor ch.1 W phase high-side PWM
TP26	PWM_UL1	Motor ch.1 U phase low-side PWM
TP27	PWM_VL1	Motor ch.1 V phase low-side PWM
TP28	PWM_WL1	Motor ch.1 W phase low-side PWM
TP29	EMG1	Motor ch.1 Over Current Sensing
TP30	GND	GND
TP31	GND	GND
TP32	GND	GND
TP33	AVDD	Analog voltage 5 V

4.2. Operation

4.2.1. Preparation

MikroElektronika's Clicker 4 for TMPM4K is required as the host MCU board to verify the operation of this design.

Build the reference design sample software for operation verification and the host MCU sample software, and write them to this design and the host MCU board, respectively. The software has been developed and verified in the following environments and versions.

IAR Embedded Workbench for Arm® 9.32.2
Arm Keil MDK 5.38.0

These can be downloaded from the URLs given below.

IAR Embedded Workbench for Arm
https://www.iar.com/products/architectures/arm/iar-embedded-workbench-for-arm/
User registration is required when using the tool for the first time.

Arm Keil MDK
https://www.keil.com/arm/demo/eval/arm.htm
User registration is required for downloading.

Connect the host MCU board to UART connector (CN3) of this design using a cable. Refer to Table. 4.6 UART Connector (CN3) Specifications for more information on connection.

Connect CN1 of the host MCU board to the PC with an USB cable and start the terminal software on PC. The settings for the terminal software are 119200 bps, 8 bit, non parity and 1 stop bit. USB-UART device driver from FTDI must be installed on PC in advance. It can be downloaded from the following site.

https://ftdichip.com/drivers/d2xx-drivers/

4.2.2. Operation Checking Procedure

When AC power is applied to this design, 5 V power is also supplied to the host MCU board. Pressing the reset button on the host MCU board establishes UART communication between the host MCU board and this design.

You can control PFC and motors of this design by operating B1, B2, B3, B4, B5, B6 on the host MCU board. Pressing RST button resets the host MCU board and this design.

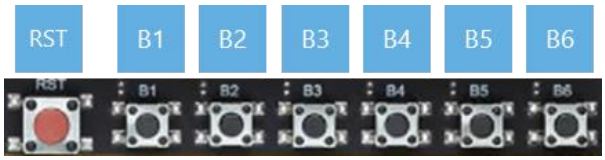


Fig. 4.13 Host MCU Board Operation Switches (RST, B1, B2, B3, B4, B5, B6)

Tab. 4.11 Host MCU Board Switch Function in Sample Software

Switch	Function	Description
RST	Reset	Resets the host MCU board and this design
B1	Motor/PFC Stop	Stops motor drive and PFC operation
B2	PFC operation switching	Switches PFC operation on/off
B3	Motor switching	Switches the motor for controlling the rotation speed.
B4	Motor speed increase	Increases (+10 Hz) the rotational speed. (Higher limit 120 Hz)
B5	Motor speed decrease	Decreases (-10 Hz) the rotational speed. (Lower limit 60 Hz)
B6	Status display (UART output)	Sends the status output to the terminal software on the PC connected via USB-UART. Press and hold (for 3 seconds) to switch the status output type. Fan motor (motor ch.0) → Compressor (motor ch.1)→PFC → fan motor (motor ch.0) →••••

4.2.3. Operation During Abnormality Detection

・UART Communication Error

UART communication error between the host MCU board and this design is judged according to the following conditions.

(1) If the design fails to receive commands from the host MCU board that are sent periodically for two seconds

(2) If the host MCU board fails to send commands ten consecutive times

(3) When there is no answer between 100 ms from this design

(4) When there is a Nack response (no response) from this design

When a communication error occurs, LED(L1) on the host MCU board flashes in 250 ms cycles. To clear a communication error, reset the host MCU board and this design by pressing RST switch on the host MCU board.

・Exception Error

If any of the following factors is detected, this design goes to EMG (Emergency) state, and all the motors and the PFC are stopped. Pressing MCU board B1 switch (Motor/PFC Stop) or RST switch (Reset) releases EMG state.

Table 4.12 Error Detection Operation in Sample Software

Factors		Factor Details	This Design LED Status	Host MCU Board LED Status
Fan Motors (Motor ch.0)	Hardware error	Overcurrent, overheat, etc. are detected by MCU hardware function	LED2 blinks 1 time	L4 flashing
	Soft overcurrent	Overcurrent is detected by software processing	LED2 blinks 2 times	L4 flashing
Compressor (Motor ch1)	Hard overcurrent	Overcurrent is detected by MCU hardware function	LED3 blinks 1 time	L5 flashing
	Soft overcurrent	Overcurrent is detected by software processing	LED3 blinks 2 times	L5 flashing
PFC	Hard overcurrent	Overcurrent is detected by MCU hardware function	LED4 blinks 1 time	L6 flashing
	Soft overcurrent	Overcurrent is detected by software processing	LED4 blinks 2 times	L6 flashing
	AC overvoltage	AC overvoltage is detected by software processing	LED4 blinks 3 times	L6 flashing
	AC undervoltage	AC undervoltage detected by software processing	LED4 blinks 4 times	L6 flashing
	DC overvoltage	DC overvoltage is detected by software processing	LED4 blinks 5 times	L6 flashing
	DC undervoltage	DC undervoltage detected by software processing	LED4 blinks 6 times	L6 flashing
	AC voltage frequency error	A frequency error of AC voltage is detected by software processing	LED4 blinks 7 times	L6 flashing
	Zero cross error	A zero crossing error of AC voltage is detected by the software processing	LED4 blinks 8 times	L6 flashing

4.3. Precautions (To Prevent Electric Shock, Burn Injury, etc.)

Pay special attention to the following when checking the operation.

・Make sure that the equipment is connected properly before turning on the power.

・Connect the connectors and terminals without mistake.

・Do not touch any component of the board while the power is on, as there is a risk of an electric shock.

・It takes time for the smoothing capacitor of the power supply, etc., to completely discharge. Do not touch the circuit board until it is fully discharged after the power is turned off.

・When checking the operation, cover the BOARD with an acrylic case for safety.

・Some components become hot during operation. Be careful not to get burned while handling them.

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