User's Manual

RL78/G24 Interleaved PFC + LLC Board 400W Kit Manual

Renesas Electronics
www.renesas.com

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General Precautions in the Handling of Microprocessing Unit and Microcontroller Unit Products

The following usage notes are applicable to all Microprocessing unit and Microcontroller unit products from Renesas. For detailed usage notes on the products covered by this document, refer to the relevant sections of the document as well as any technical updates that have been issued for the products.

1. Precaution against Electrostatic Discharge (ESD)

   A strong electrical field, when exposed to a CMOS device, can cause destruction of the gate oxide and ultimately degrade the device operation. Steps must be taken to stop the generation of static electricity as much as possible, and quickly dissipate it when it occurs. Environmental control must be adequate. When it is dry, a humidifier should be used. This is recommended to avoid using insulators that can easily build up static electricity. Semiconductor devices must be stored and transported in an anti-static container, static shielding bag or conductive material. All test and measurement tools including work benches and floors must be grounded. The operator must also be grounded using a wrist strap. Semiconductor devices must not be touched with bare hands. Similar precautions must be taken for printed circuit boards with mounted semiconductor devices.
2. Processing at power-on

   The state of the product is undefined at the time when power is supplied. The states of internal circuits in the LSI are indeterminate and the states of register settings and pins are undefined at the time when power is supplied. In a finished product where the reset signal is applied to the external reset pin, the states of pins are not guaranteed from the time when power is supplied until the reset process is completed. In a similar way, the states of pins in a product that is reset by an on-chip power-on reset function are not guaranteed from the time when power is supplied until the power reaches the level at which resetting is specified.
3. Input of signal during power-off state

   Do not input signals or an I/O pull-up power supply while the device is powered off. The current injection that results from input of such a signal or I/O pull-up power supply may cause malfunction and the abnormal current that passes in the device at this time may cause degradation of internal elements. Follow the guideline for input signal during power-off state as described in your product documentation.
4. Handling of unused pins

   Handle unused pins in accordance with the directions given under handling of unused pins in the manual. The input pins of CMOS products are generally in the high-impedance state. In operation with an unused pin in the open-circuit state, extra electromagnetic noise is induced in the vicinity of the LSI, an associated shoot-through current flows internally, and malfunctions occur due to the false recognition of the pin state as an input signal become possible.
5. Clock signals

   After applying a reset, only release the reset line after the operating clock signal becomes stable. When switching the clock signal during program execution, wait until the target clock signal is stabilized. When the clock signal is generated with an external resonator or from an external oscillator during a reset, ensure that the reset line is only released after full stabilization of the clock signal. Additionally, when switching to a clock signal produced with an external resonator or by an external oscillator while program execution is in progress, wait until the target clock signal is stable.
6. Voltage application waveform at input pin

   Waveform distortion due to input noise or a reflected wave may cause malfunction. If the input of the CMOS device stays in the area between V_{IL} (Max.) and V_{IH} (Min.) due to noise, for example, the device may malfunction. Take care to prevent chattering noise from entering the device when the input level is fixed, and also in the transition period when the input level passes through the area between V_{IL} (Max.) and V_{IH} (Min.).
7. Prohibition of access to reserved addresses

   Access to reserved addresses is prohibited. The reserved addresses are provided for possible future expansion of functions. Do not access these addresses as the correct operation of the LSI is not guaranteed.
8. Differences between products

   Before changing from one product to another, for example to a product with a different part number, confirm that the change will not lead to problems. The characteristics of a microprocessing unit or microcontroller unit products in the same group but having a different part number might differ in terms of internal memory capacity, layout pattern, and other factors, which can affect the ranges of electrical characteristics, such as characteristic values, operating margins, immunity to noise, and amount of radiated noise. When changing to a product with a different part number, implement a system-evaluation test for the given product.

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For Your Safety
Be sure to read the precautions and instructions in this manual before using this product.

Meaning of Notations

In this manual, items related to the safe use of the product are indicated as described below. The degree of injury to persons or damage to property that could result if the designated content in this manual is not followed is indicated as follows.

⚠ Danger	Indicates content that, if not followed, could result in death or serious injury to the user, and which is highly urgent.
⚠ Warning	Indicates content that, if not followed, could result in death or serious injury to the user.
⚠ Caution	Indicates content that, if not followed, could result in injury to persons or physical damage.

Warnings Regarding Use of the Product

■ Danger Items

⚠ Danger
• This product is intended for use only for research purposes within a properly equipped research and development (R&D) facility by persons (hereinafter referred to as “users”) who are trained and qualified in handling power supply equipment and who are familiar with electrical and mechanical components, systems, and the risks associated with their operation. Please carefully read the precautions described in this manual and restrict both the users and the place of use accordingly. • The product contains high-temperature components that could be dangerous. Do not touch the product or cables while power is being supplied. • Carefully check to make sure that there are no pieces of conductive materials or dust adhering to the board, connectors, and cables. • Do not touch the motor while power is being supplied. • Ensure that the motor is insulated and placed in a stable location before supplying power.

■ Warning Items

	Warning
	High voltage is applied to the terminals during operation and for 30 seconds after power shutdown. Do not touch the terminals or the product during this period.
	Always insert plugs, connectors, and cables securely, and confirm that they are fully inserted. Incomplete connections could cause fire, burns, electric shock, or injury. Always use screws that meet the specified standards.
	Use the power supply apparatus specified in the manual. Failure to do so could cause fire, burns, electric shock, injury, or malfunction.
	Disconnect the power supply and unplug all cables when the system will not be used for a period of time or when moving the system. Failure to do so could cause fire, burns, electric shock, or malfunction. This will protect the system against damage due to lightning.
	Use a mechanism (switch, outlet, etc.) located within reach to turn off (disconnect) the power supply. In case of emergency, it may be necessary to cut off the power supply quickly.
	In this product, the ground of the main power supply circuit is connected to the ground of the CPU board. When the user evaluates the product, be aware that the product and the measuring instruments may be damaged depending on the connection method of the measuring instruments.
	Turn off the power supply immediately if you notice abnormal odor, smoke, abnormal sound, or overheating. Continuing to use the system in an abnormal condition could cause fire, burns, or electric shock.
	Do Not Disassemble, Modify, or Repair! Doing so could cause fire, burns, electric shock, injury, or malfunction.
	Do not use this product for purposes other than power supply evaluation within a research and development (R&D) facility. In addition, do not incorporate this product or any part of it into other equipment. Do not connect or disconnect cables or connectors while the product is powered on. The product has no safety case. The user must cover the product for safety protection. Failure to observe the above could cause fire, electric shock, burns, or malfunction. The product may not perform as expected if used for other than its intended purpose.

■ Caution Items

	Caution
	Caution – Hot! The motor gets hot. Touching it could cause high-temperature burns.
	Follow the procedure specified in the manual when powering the system on or off. Failure to do so could cause overheating or malfunction.
	Caution – Static Electricity Use the antistatic band. Failure to do so could cause malfunction or unstable motion.

Contents

1. Overview

The RL78/G24 Interleaved PFC+LLC Board 400W is an evaluation kit for digital power supply. It allows users to easily evaluate digital power systems.

1.1 Presupposition and Precautions of This Document

1. Experience of MCU tool chains: This document assumes that the user have prior experience with integrated development environments (IDEs) such as e2 studio and on-chip debuggers.
2. Software knowledge: This document assumes that the user has a basic knowledge to run or modify the sample project written in C or assembly language for MCU and embedded system.
3. Before using this product, wear an antistatic wrist strap. If you touch this product with static charge on your body, a device failure may occur, or operation may become unstable.
4. This product is intended to be used in research laboratory environments by engineers who have knowledge of power-supply control and high-voltage equipment handling.
5. When using this product, be sure to follow the safety precautions described in this document (see Chapter 6). Failure to implement appropriate safety measures may result in electric shock or burns.

1.2 Features of the RL78/G24 for Digital Power

The RL78/G24-based digital power solution enables both high efficiency and low power consumption during light-load and standby operation by optimizing PWM control patterns and flexibly switching operating modes through software.

Control sequences and fine PWM tuning that are difficult to realize with conventional analog control can be easily implemented using digital control with the RL78/G24, which incorporates dedicated hardware.

This flexibility and improved power efficiency simplify compliance with energy regulations and reduce heat dissipation, allowing smaller cooling components such as heat sinks and contributing to overall power system cost reduction.

More specific features are described below.

- The RL78/G24 integrates advanced dedicated peripherals optimized for digital power applications. For instance, the PWM output capability of the 16-bit Timer KBn and the timer restart function using an external interrupt or comparator provide hardware-level support for CrM PFC control and LLC converter control, enabling basic converter operation.
  With feedback control performed by the CPU or FAA, this microcontroller can achieve high-efficiency and high power-factor PFC and LLC control.
- The RL78/G24 also provides functions for power supply protection. The forced output shutdown function of Timer KBn, operating in conjunction with a high-speed comparator or external interrupt, enables immediate and asynchronous shutdown upon detection of overcurrent or overvoltage in the PFC or LLC circuit, without intervention by the CPU or FAA, thereby protecting the device and surrounding components.
  Since this function is implemented in hardware, it guarantees fast and reliable shutdown with no software-induced latency. Furthermore, recovery from an emergency shutdown can be managed by software, allowing flexible design of restart sequences and protection release conditions to meet system requirements.
- The RL78/G24 incorporates a 32-bit independently operating coprocessor known as the Flexible Application Accelerator (FAA). Operating separately from the CPU, the FAA can rapidly execute power control feedback calculations, allowing real-time control loops to be processed without CPU involvement.
  This improves feedback response and reduces CPU load, enabling the CPU to dedicate resources to communication tasks and higher-level system control, thereby achieving high overall control performance and system stability.
- The RL78/G24 integrates peripheral functions supporting commonly used communication interfaces, including UART, SPI, PMBus/SMBus, and infrared (IR).
  For instance, remote control signal reception can be implemented using the pulse interval

measurement function of the 16-bit Timer Array Unit, thereby reducing CPU load during data reception.

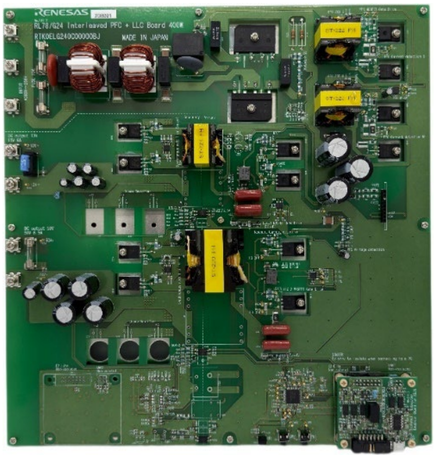
1.3 Product Contents

This product consists of the following parts.

1. Main board (Model: RTK0ELG240C00000BJ)
2. IPD circuit board (Model: RTK0ELPB00B00000BJ)
3. Debug board (Model: RTK0ELDB00B00000BJ)

Items to be prepared separately:

4. E2 Emulator Lite (hereafter referred to as “E2 Lite”)
5. USB Mini-B cable (included with the E2 Lite)
6. User-interface cable (included with the E2 Lite)
7. Ferrite clamp equivalent to RFC-H13 (Kitagawa Industries) — to be installed with one turn on the input side



1. Main board

2. IPD circuit board

3. Debug board

4. E2 Emulator Lite

5. USB Mini-B cable

6. User-interface cable

7. Ferrite clamp

Figure 1.1 Product contents

2. Hardware Configuration

2.1 Detailed Specifications

Table 2.1 Overview

Item	Specification
Product Name	RL78/G24 Interleaved PFC+LLC Board 400W Kit
Board Model	RTK0EL0006D00000BJ
Product Dimensions	325 mm(W) x 315 mm(L) x 80 mm(H)
Withstand Voltage	Between Input–FG and Input–Output: 300 V_{AC} for 1 minute
Insulation Resistance	Between Input–FG and Input–Output: 30 MΩ or higher / 500 V_{DC}
Operating Environment	Indoor use only Temperature: 0–40°C Humidity: 20–85% RH Overvoltage Category II Pollution Degree 2
EMC Standards	• EN61326-1:2021 • EMI : Class A EMS : Industrial Electromagnetic Environment

Note: This product is optimized for use in evaluation and development phases. Therefore, conformity assessment and certification in accordance with the EU Low Voltage Directive (LVD: 2014/35/EU) have not been performed.

Table 2.2 Input/Output Specifications

Item			Specification	Remarks
Input		Voltage	90 V_{AC} – 264 V_{AC}	This specifies the hardware design range. Since it depends on the combined software, please refer to the application note for details.
		Frequency	50/60 Hz	
		Maximum Power	400 W	
Output	PFC	Rated Voltage	386 V_{DC}	LLC input voltage
		Maximum Voltage	1.044 A	
	LLC1 (Output 1)	Rated Voltage	13 V_{DC} ± 5%	
		Maximum Voltage	6.0 A	
		Maximum Power	78 W	
	LLC2 (Output 2)	Rated Voltage	50 V_{DC} ±5%	
		Maximum Voltage	6.5 A	
		Maximum Power	325 W	
	Others	Power Factor	0.96 or higher	
		Overall Efficiency	95% or higher	
		Standby Power	0.3 W or lower	Standby mode, Output 1 = 0.15 W load

2.2 Protection Functions

This board provides both hardware-based protection functions implemented using the comparators and timers integrated in the microcontroller, and software-based protection functions implemented through program operation.

2.2.1 Hardware-Based Protection Functions

The following hardware-based protection functions detect abnormalities and stop operation rapidly without software intervention.

2.2.1.1 PFC OCP

The circuit is configured so that the PFC MOSFET source current is converted into a voltage and applied to the comparator of the RL78/G24. The output of the RL78/G24 D/A converter is used as the reference voltage, and when the detected voltage exceeds this threshold, the forced output shutdown function of the 16-bit Timer TMKB in the RL78/G24 is used to immediately stop the PFC PWM output. function is defined as OCP (Overcurrent Protection) for the PFC.

2.2.1.2 LLC OCP

The resonant current of the LLC stage is converted into a voltage and applied to the comparator of the RL78/G24. When the input voltage exceeds the reference voltage generated by the RL78/G24 D/A converter, the output of the corresponding LLC stage is forcibly stopped. This function is defined as the LLC OCP (Over-Current Protection).

2.2.2 Software-Based Protection Functions

Software-based protection functions are described in this section. For specific threshold values and related parameters, refer to Section 3.3.1 of the application note “RL78/G24 Constant Voltage Control Using PFC+LLC Converter (R01AN8175EJ0100)”.

2.3 Functional Block Diagram

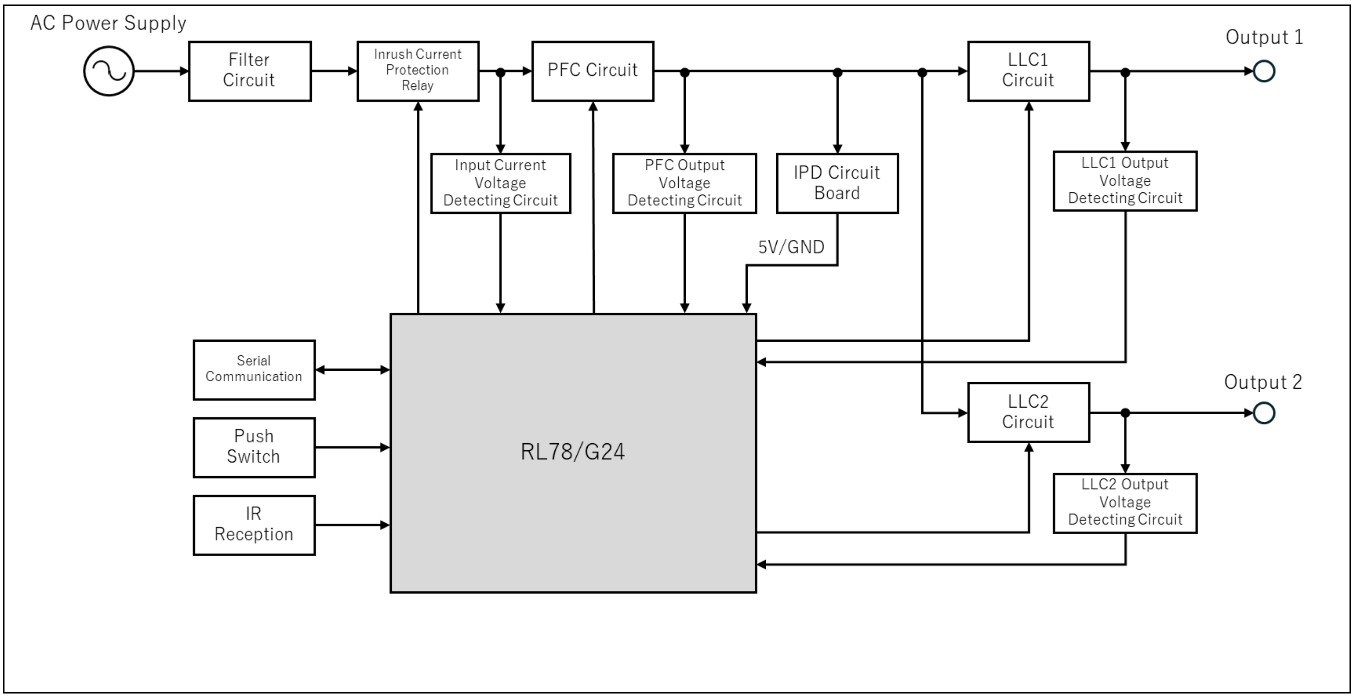


Figure 2.1 Functional Block Diagram

2.4 Board Appearance

2.4.1 Main Board

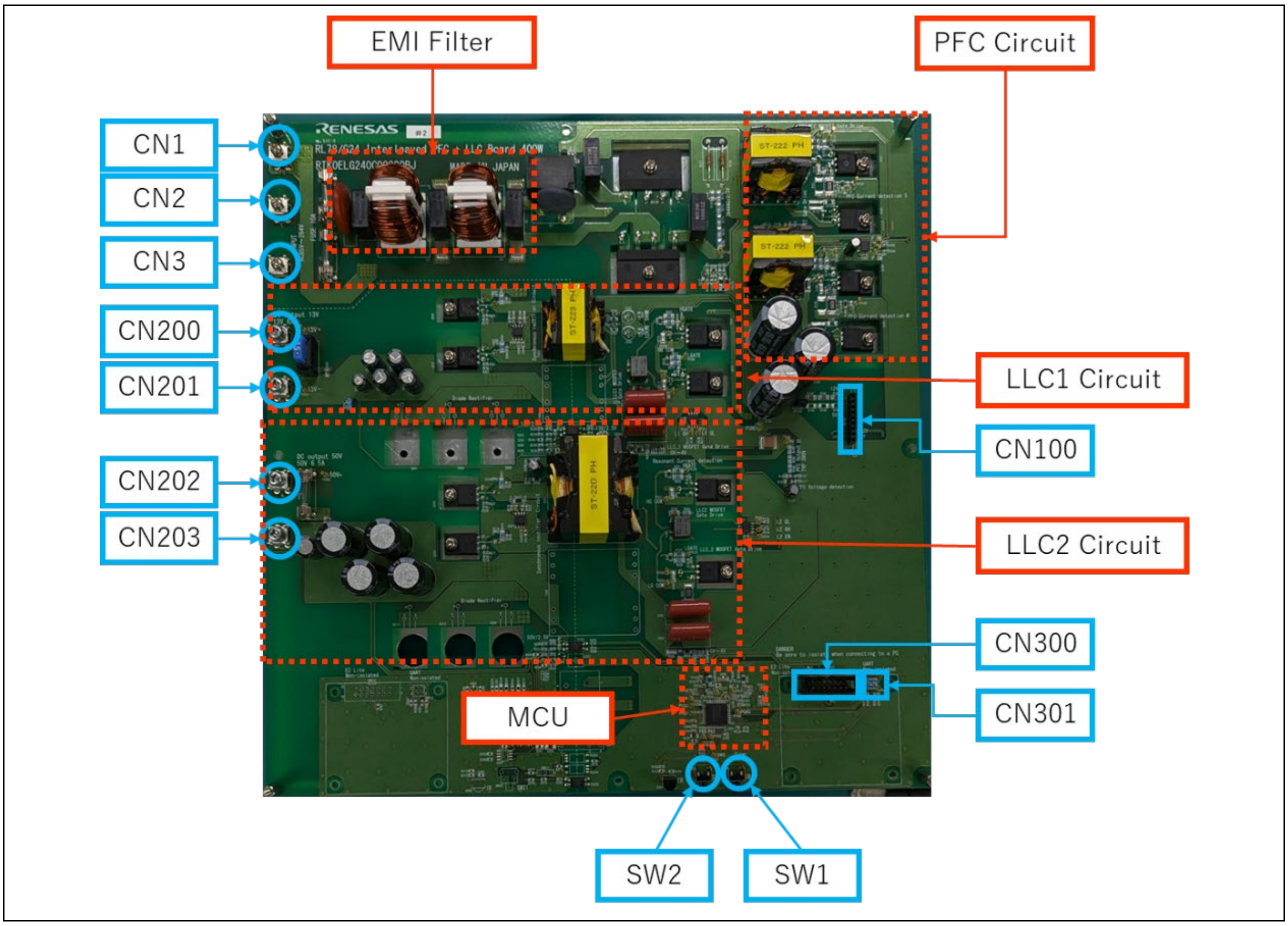


Figure 2.2 Main Board Appearance Photo

The main board's input/output pins are listed in Table 2.3.

Table 2.3 Main Board Input/Output Pin List

Terminal	I/O	Function	Remarks
CN1	-	FG	
CN2	I	AC (L) Input	90-264VAC
CN3	I	AC (N) Input	
CN200	O	Output 1 (+)	6.0 A Max
CN201	O	Output 1 (-)	
CN202	O	Output 2 (+)	6.5 A Max
CN203	O	Output 2 (-)	
CN100	I/O	IPD Board	
CN300	I/O	Debug Board	
CN301	I/O	Debug Board	

2.4.2 IPD Circuit Board

Figure 2.3 IPD Board Appearance Photo

The IPD board's input/output pins are listed in Table 2.4.

Table 2.4 IPD Board Input/Output Pin List

Terminal	I/O	Function	Remarks
C	I	Vin	
2	-	N/A	
3	-	N/A	
4	-	N/A	
5	-	N/A	
6	-	N/A	
7	O	12 V out	
8	O	5 V out	
9	I	GND	

2.4.3 Debug Board

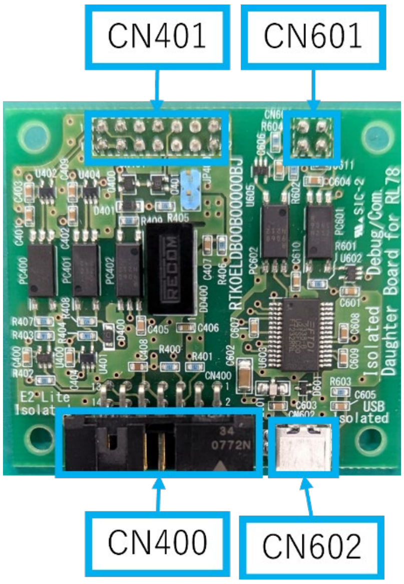


Figure 2.4 Debug Board Appearance Photo

The debug board's input/output pins are listed in Table 2.5.

Table 2.5 Debug Board Input/Output Pin List

Terminal	I/O	Function	Remarks
CN400	I/O	E2 lite connection pin	
CN401	I/O	Connected to main board CN300	
CN601	I/O	Connected to main board CN301	
CN602	I/O	USB pin (Mini-B)	

2.5 Jumper Settings

The debug board is equipped with an isolated DC/DC converter, allowing power to be supplied from the E2 Lite to the MCU on the main board via the converter. The power supply path can be selected by opening or shorting the jumper pin (JP400).
When this jumper is set to the short position, do not connect the AC power supply.

Table 2.6 Initial Settings and Functions of the Jumper Pin

Jumper Pin	Initial Setting	Function
JP400	Open	**Open:** No power supply from E2 Lite to the main board MCU. **Short:** Supplies 3.3 V power from the E2 Lite to the MCU on the main board.

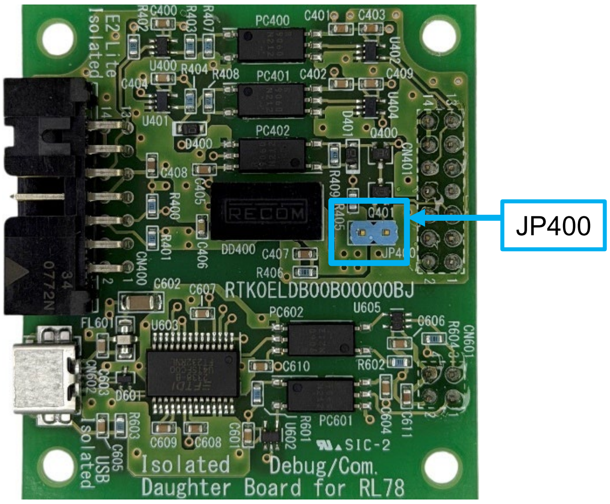


Figure 2.5 Jumper Pin Location

2.6 Connector Pin Assignment

2.6.1 Main Board

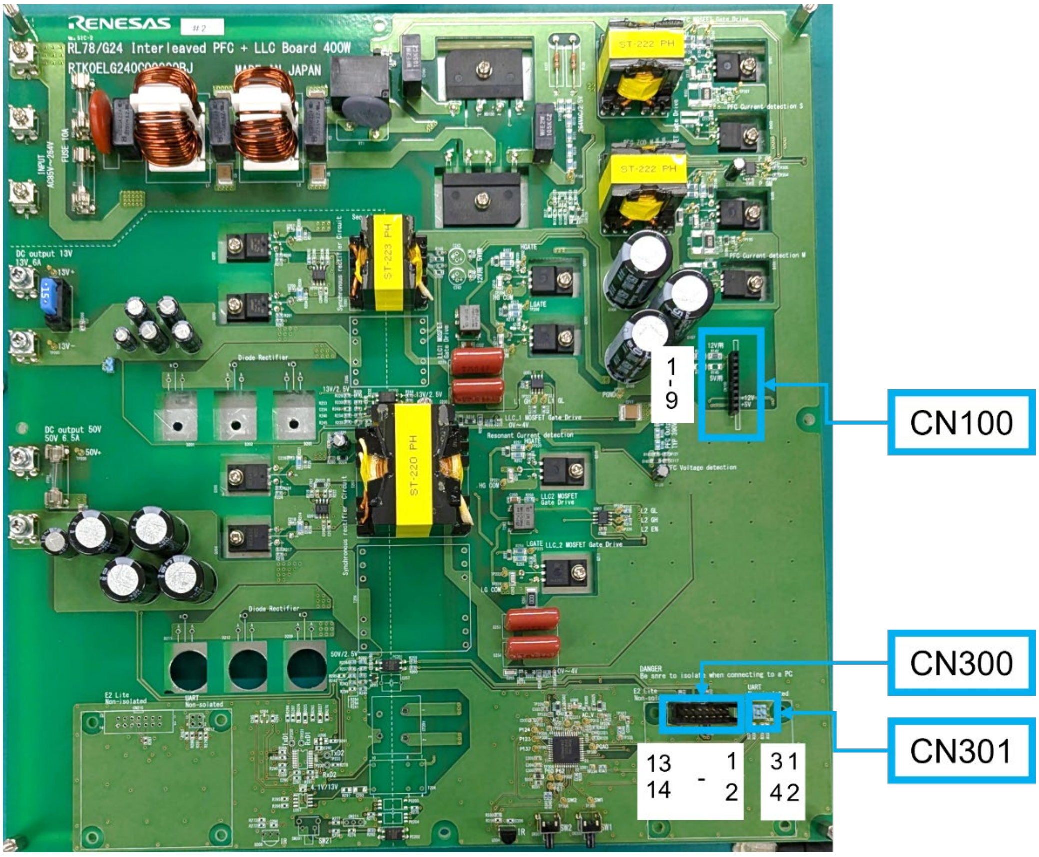


Figure 2.6 Connector Location and Pin Numbers

Table 2.7 CN100 Connector Pin Assignment

Pin No.	Signal Name	Function
1	V_Start_1	Vin
2	-	N/A
3	-	N/A
4	-	N/A
5	-	N/A
6	-	N/A
7	+12 V	12 V out
8	+5 V	5 V out
9	PGND	GND

Table 2.8 CN300 Connector Pin Assignment

Pin No.	Signal Name	Function
2, 12, 14	GND	PGND
5	TOOL0	I/O
6	RESET_IN	Reset Input
8	VDD	+5 V
9	EMVDD	+5 V
10,13	RESET_OUT	Reset Output
1,3,4,7,11	NC	-

Table 2.9 CN301 Connector Pin Assignment

Pin No.	Signal Name	Function
1	RXDin	I
2	+5 V	+5 V in
3	TXDout	O
4	GND	PGND

3. Setup Guide

Before using this product, prepare the equipment specified in the following chapters and perform the setup according to the procedures described.
Do not apply power to the board until the setup is completed and the settings have been confirmed.

3.1 Items Required from the User

To develop and evaluate software using this product, the following software is required:

(1) Smart Configurator for RL78 (V1.12.0 or later)

(2) Renesas Flash Programmer (V3.11.02 or later)

(3) CS+ for CC (V8.09.01 or later)

or IAR Embedded Workbench for RL78 (V5.10.3 or later)

or e2 studio (2025-10 or later)

If QE tools are used for evaluation, the following software is additionally required:

(4) Renesas QE for Lighting & Power (V200_20251107)

In addition, the following hardware is required:

(5) A PC capable of running the above software (Supported OS: Windows 11)

(6) USB Mini-B cable (one additional cable, separate from the one included with the E2 Lite)

(7) E2 Lite

(8) AC power supply (100 V–240 V)

3.2 Software Installation

3.2.1 When Not Using the QE for Lighting & Power Tool

If debugging and evaluation are performed without using QE for Lighting & Power, download the required software individually from each vendor's website according to their instructions, and install them in any desired location.

URL: https://www.renesas.com/en/design-support/development-tools

3.2.2 Using QE for Lighting & Power

3.2.2.1 Installing Renesas QE for Lighting & Power

(1) Extract the downloaded zip file "RenesasQE_Lighting_Power_V200_20251107.zip" to any desired location.

Note: Do not place the tool under the OS program folder (e.g., C:\Program Files).

(2) Extract the zip file "\com.renesas.qe.lighting.power_download.zip" located inside the extracted folder, and copy the extracted contents to the following directory: "C:\Users\<username>\.eclipse"

(3) Open the folder "RenesasQE_Lighting_Power_V200_20251107 \QE-Lighting-Power\eclipse" and run "qe-lighting-power.exe".

(4) When launching the tool for the first time, a license agreement dialog will be displayed. After reviewing the contents, select either "Agree" or "Disagree." If "Agree" is selected, the product will start and become available for use. If "Disagree" is selected, the product will not start. q q

3.2.2.2 Installation of Other Software

(1) In the QE for Lighting & Power window, click “Open Preferences Settings” (Figure 3.1).

(2) The installation locations for “CS+” or “IAR” or“e2 studio”, “Renesas Flash Programmer (RFP)”, and “Smart Configurator” will be displayed (Figure 3.2).

(3) If these software packages are already installed, the paths to their respective installation folders will be entered automatically.

(4) If any software is not installed, or if an item is marked with a yellow “!”, click “Download” for that software. Follow the instructions on the vendor’s website to download and install the required software.

(5) After all software installations are completed, click “Apply and Close.”

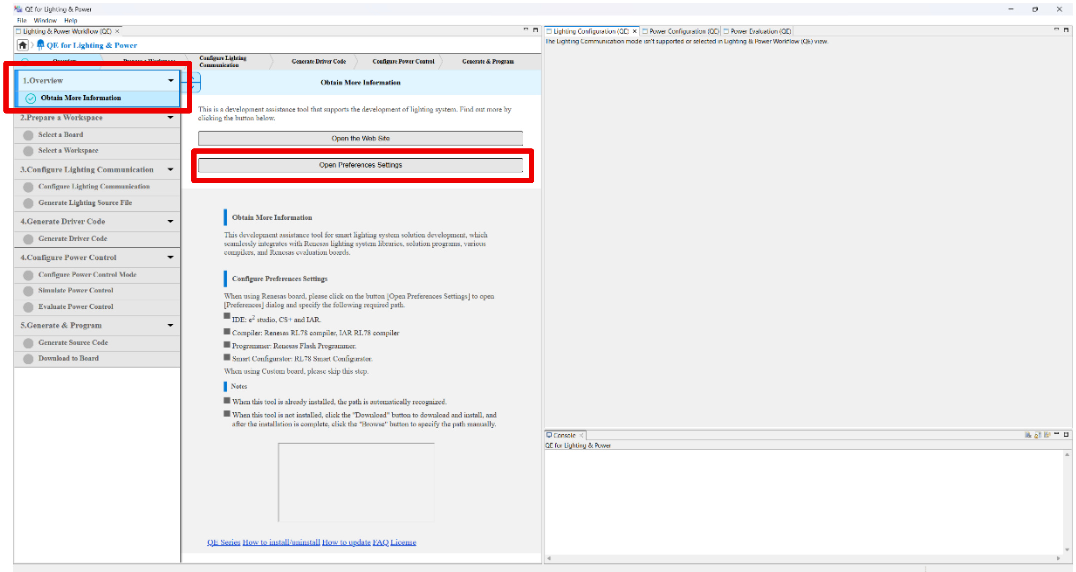


Figure 3.1 QE for Lightning & Power

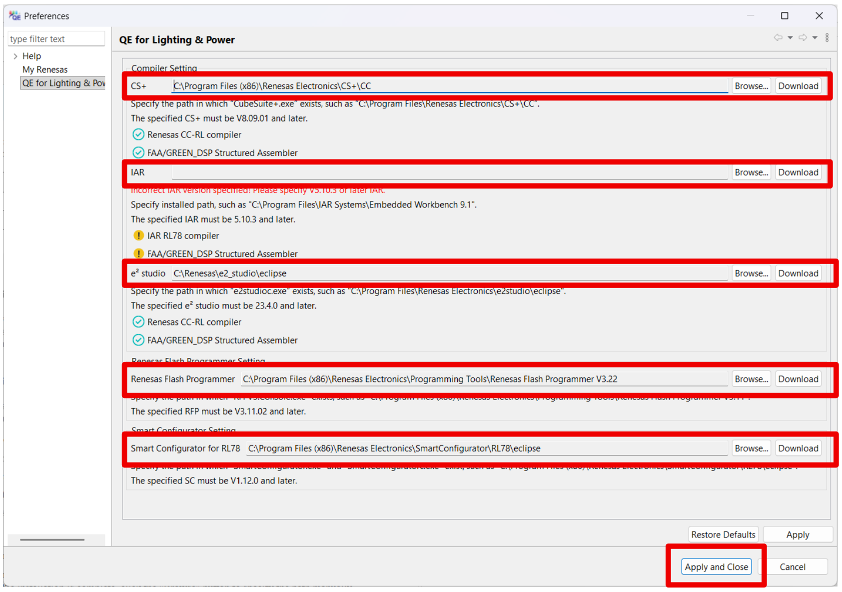


Figure 3.2 Preferences Settings

3.2.2.3 Preparing the Workspace

(1) Click “Select a Board” under “2. Prepare a Workspace” (Figure 3.3).

(2) Select the “Renesas Board” radio button, then choose “[R01AN8175EJ0100] RL78/G24 TV Application Model” from “Select a Target Program.”

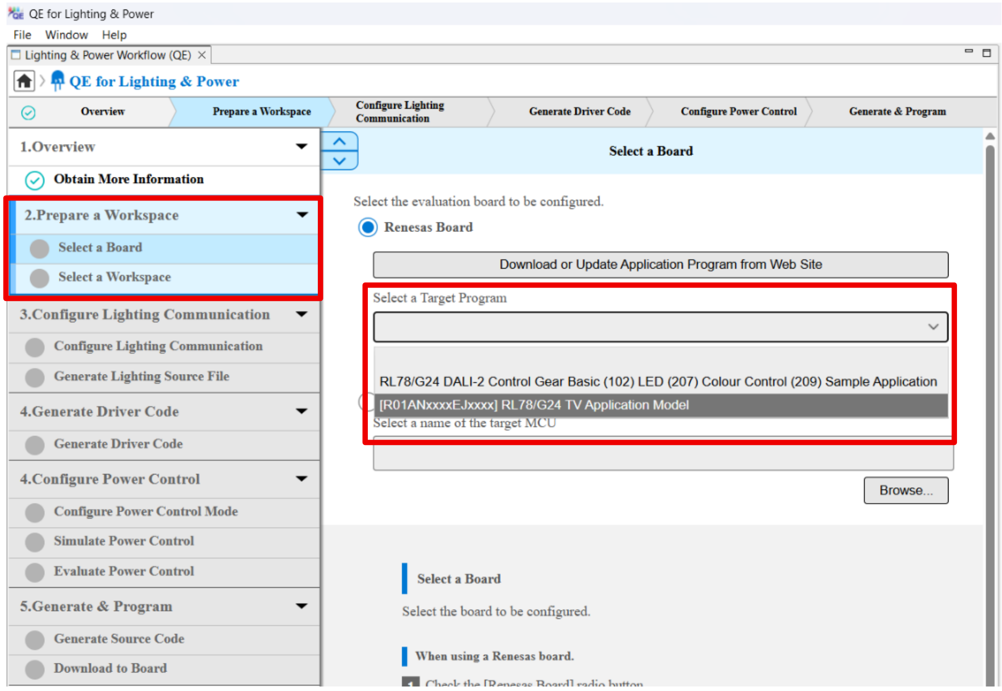


Figure 3.3 Select a Board

(3) Click “Select a Workspace” and specify the folder to be used as the workspace. The folder name must be an absolute path and may contain only alphabetic characters, numbers, underscores, and spaces.

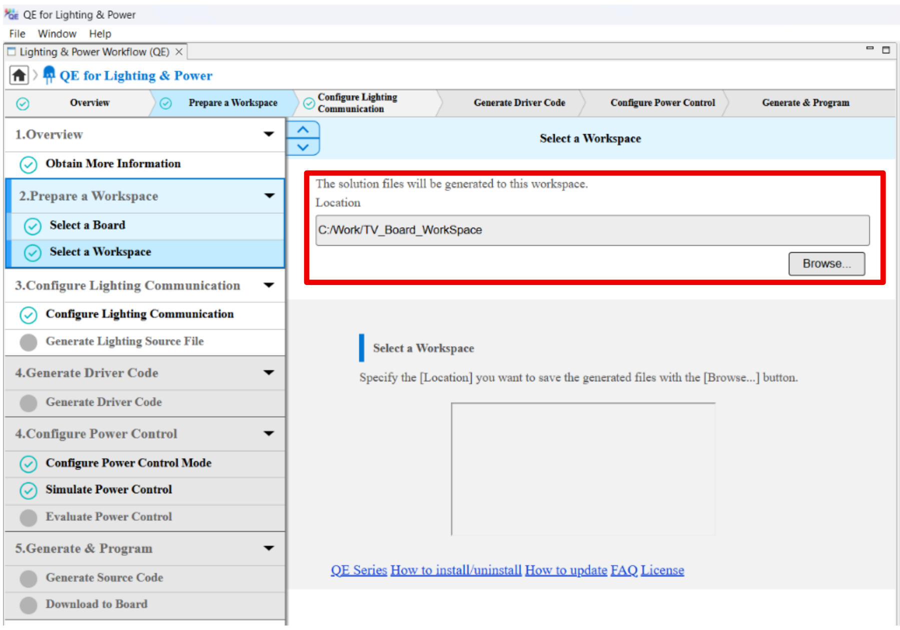


Figure 3.4 Select a Workspace

3.3 Installation and Board Connections

After installing the main board, insert the IPD circuit board's CN500 into the main board's CN100, and insert CN401 and CN601 into the main board's CN300 and CN301, respectively.

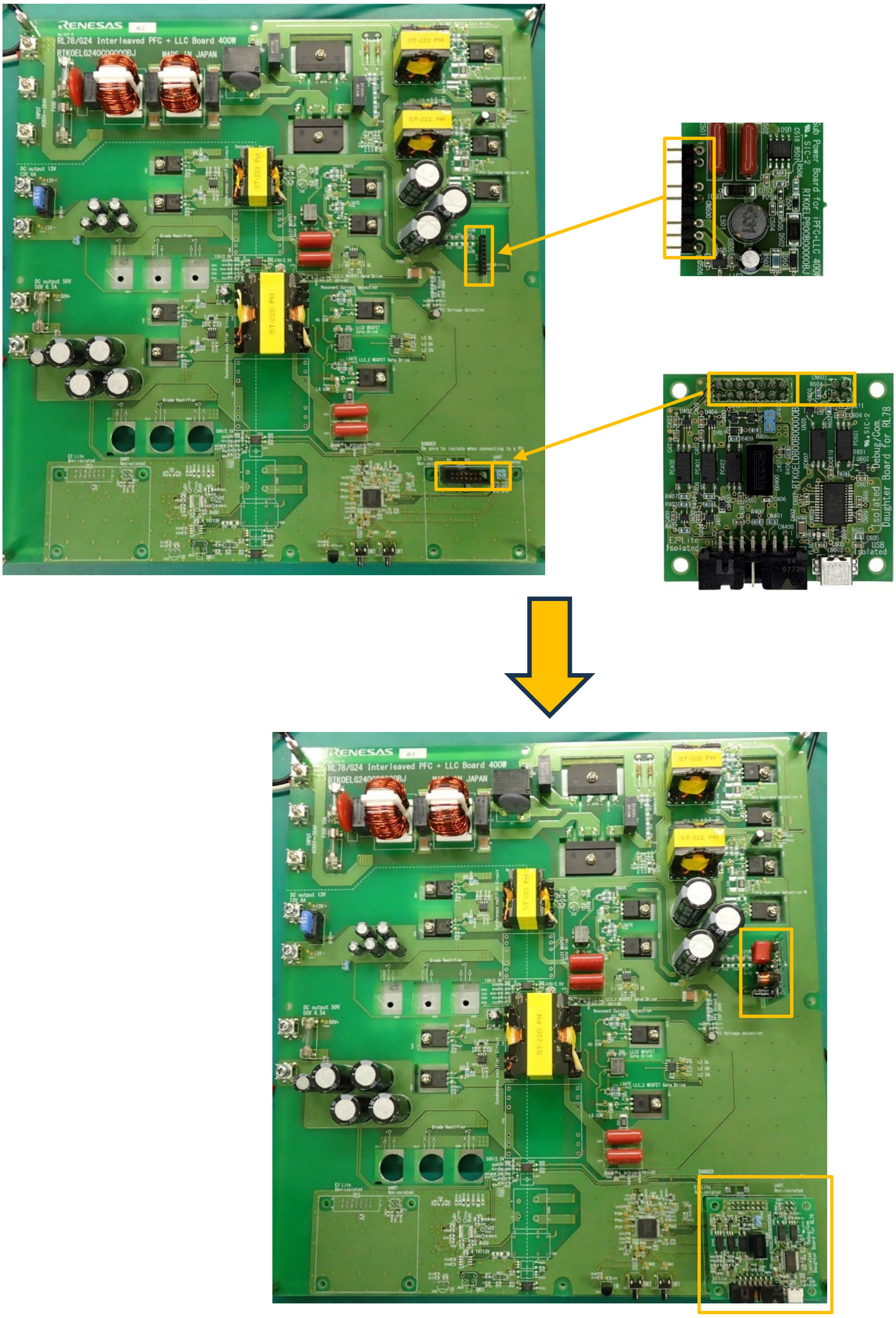


Figure 3.5 Connection Overview of Each Board

3.4 Debugging or Programming (AC Power Supply Required)

3.4.1 Operating Procedure

1. Confirm that JP400 on the debug board is in the open state.

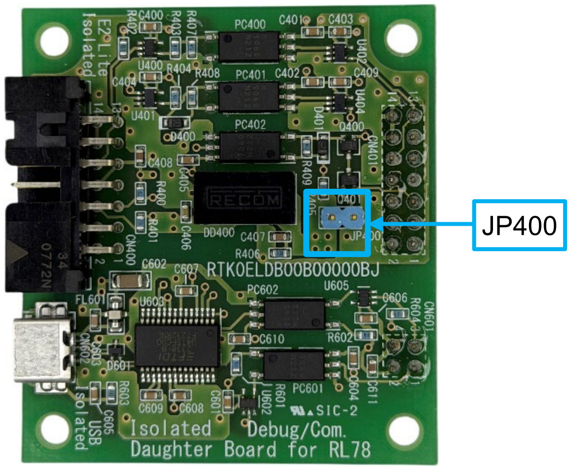


Figure 3.6 Position of the jumper pin

2. Connect CN400 on the debug board to the E2 Lite using the user interface cable.

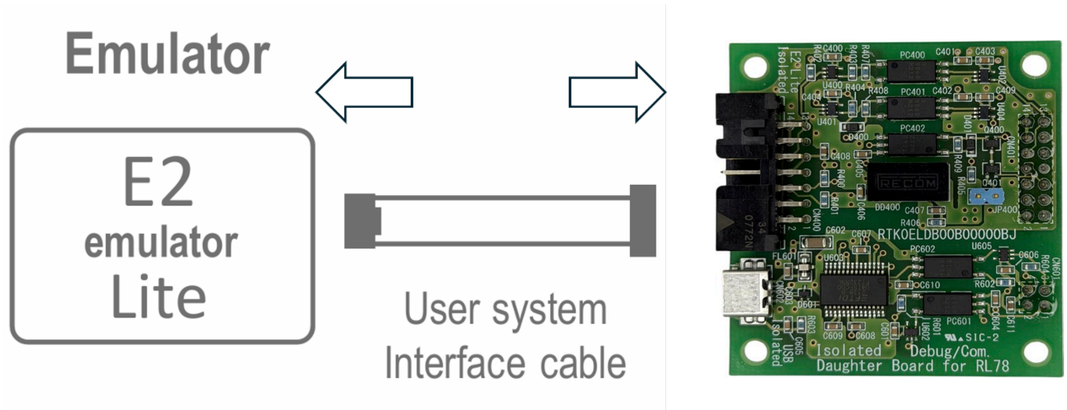


Figure 3.7 Connection between the E2 Lite and the debug board

3. Connect an AC regulated power supply to CN2 (L) and CN3 (N) on the main board, and supply power to the board.

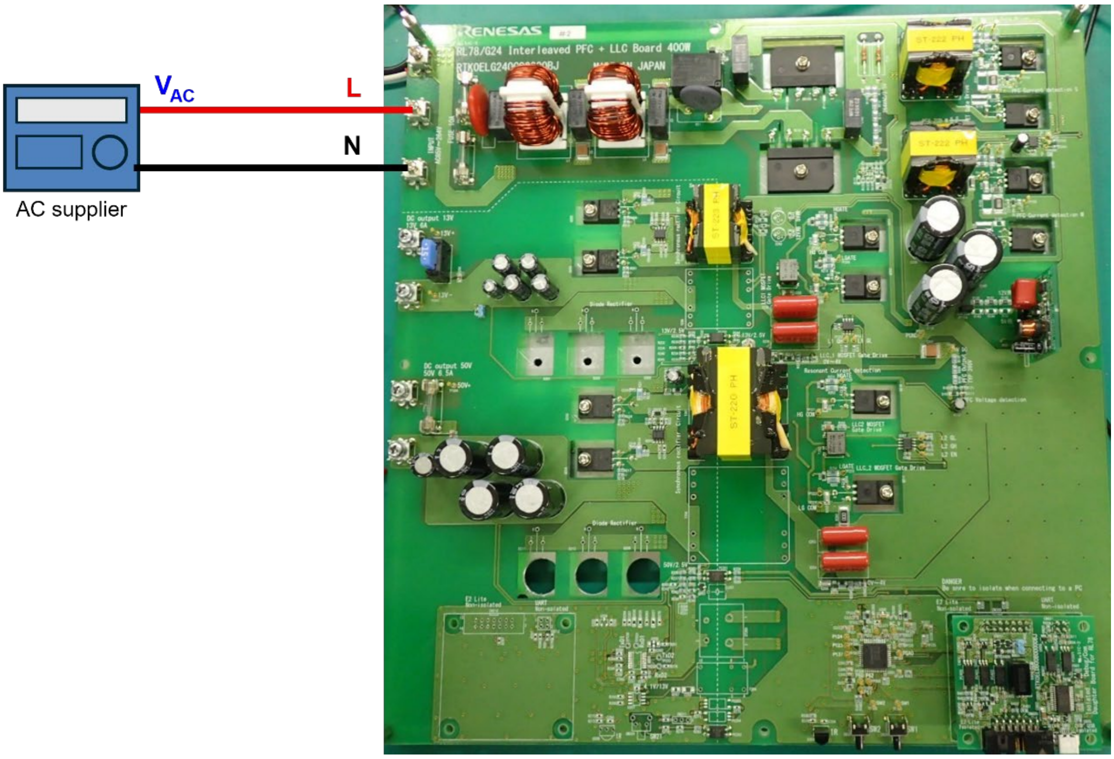


Figure 3.8 AC power connection

4. Connect the E2 Lite to the PC using a USB Mini-B cable.

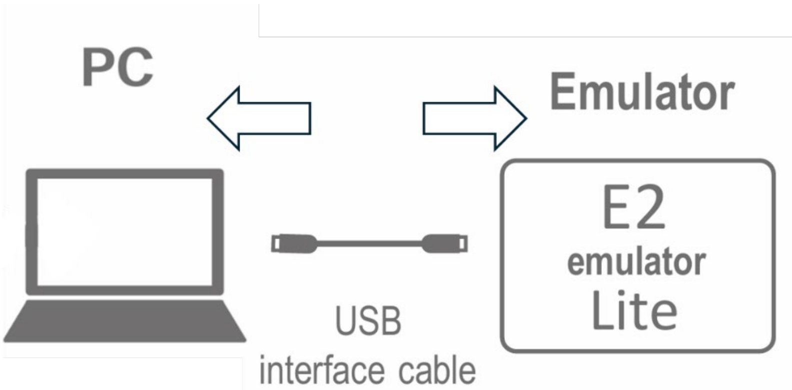


Figure 3.9 Connection between the PC and the E2 Lite

5. Perform debugging or firmware programming using any of the following tools: QE Tool, RFP, Integrated Development Environment (IDE). In the software settings, ensure that 3.3 V power is supplied to the debug board via the E2 Lite.

6. When continuing debugging, press the switch on the main board after RUN to proceed with the startup sequence (this applies only to the current firmware).

   SW2: Standby / Normal mode switching

   SW1 (short press): Start/stop LLC2

   SW1 (long press): Maximum frequency limit function ON/OFF

   Short press: less than 2 seconds / Long press: 3 seconds or more

   Note: When operating the system in standalone mode to measure standby power consumption, please remove the debug board to avoid the influence of the debug board's current consumption.

   Always turn off the power before attaching or removing the debug board.

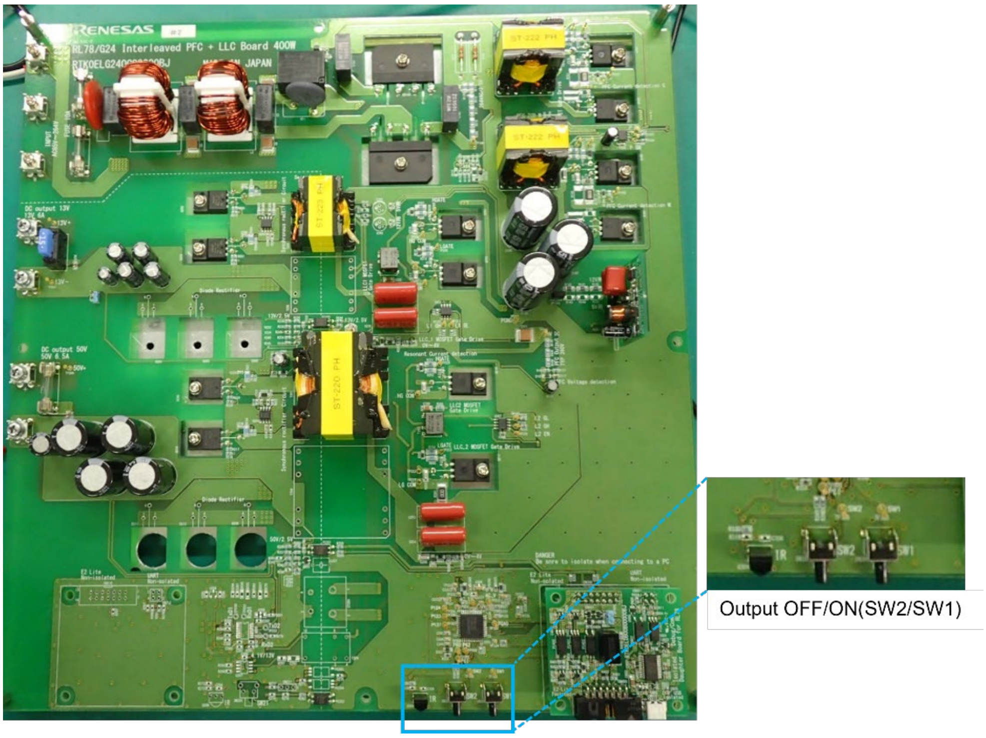


Figure 3.10 Position of the switches on the main board

7. After debugging or firmware programming is completed, first stop the AC regulated power supply, and then disconnect the E2 Lite.

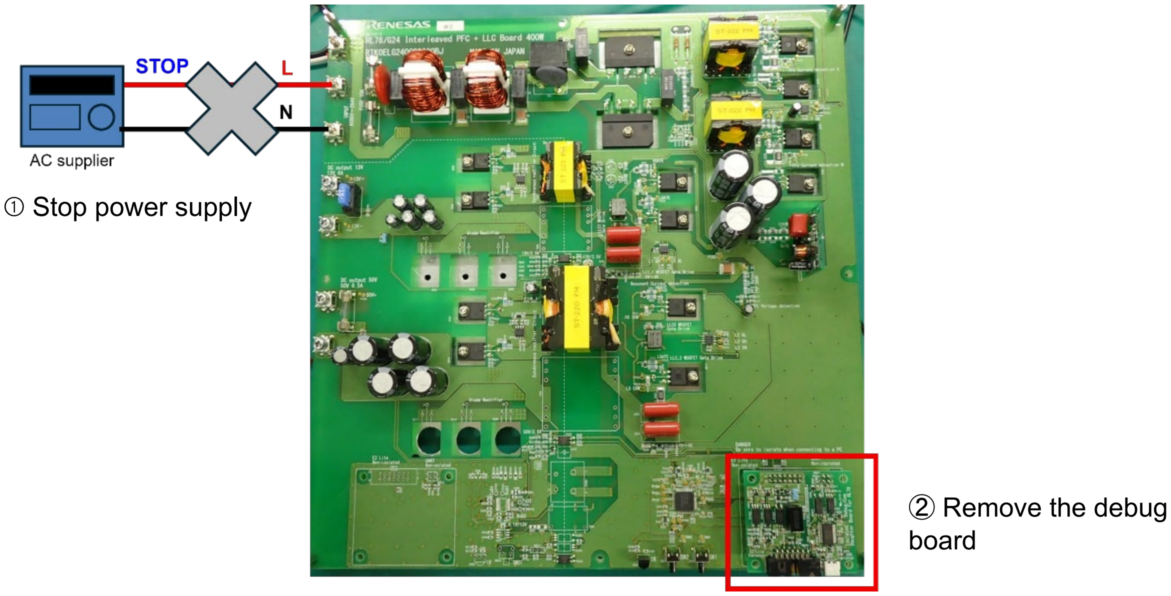


Figure 3.11 Removal of the Debug Board

3.4.2 Power Supply Route

The power supply route is as shown in the figure below.

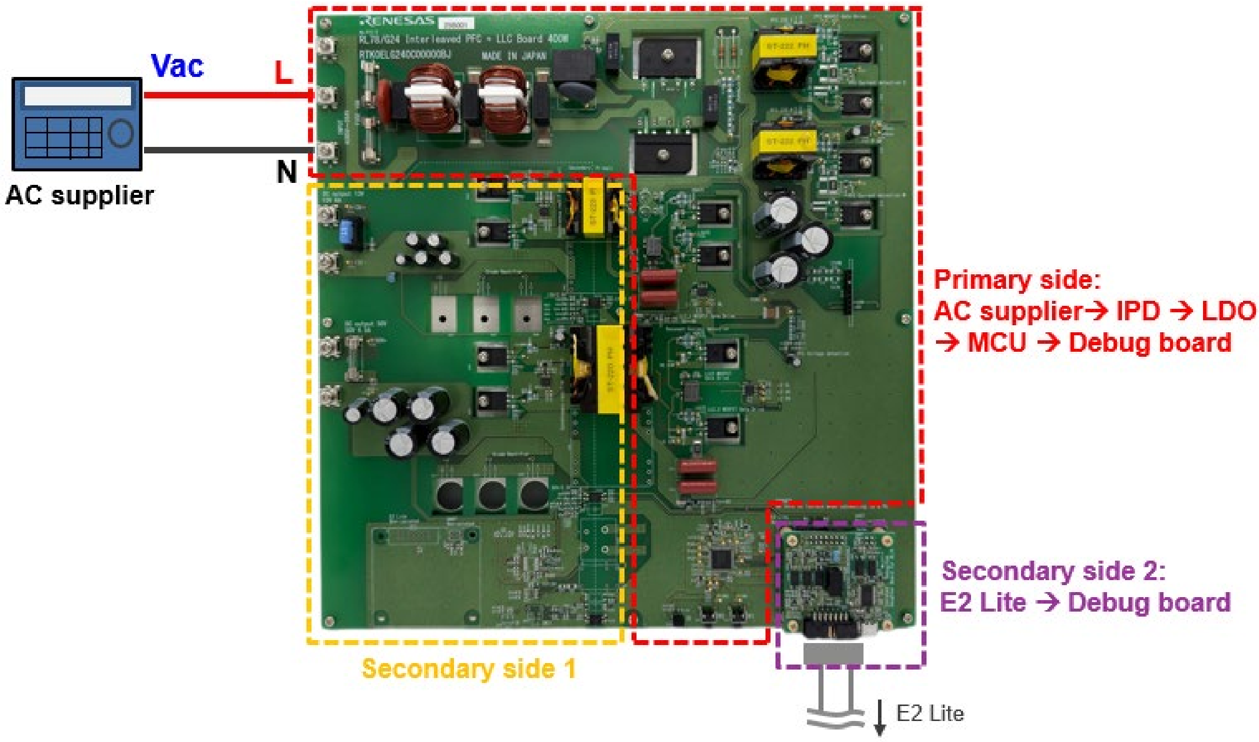


Figure 3.12 Power Supply Route

3.5 Programming Only (No AC Power Supply Required)

3.5.1 Operating Procedure

1. Confirm that no AC regulated power is being supplied.

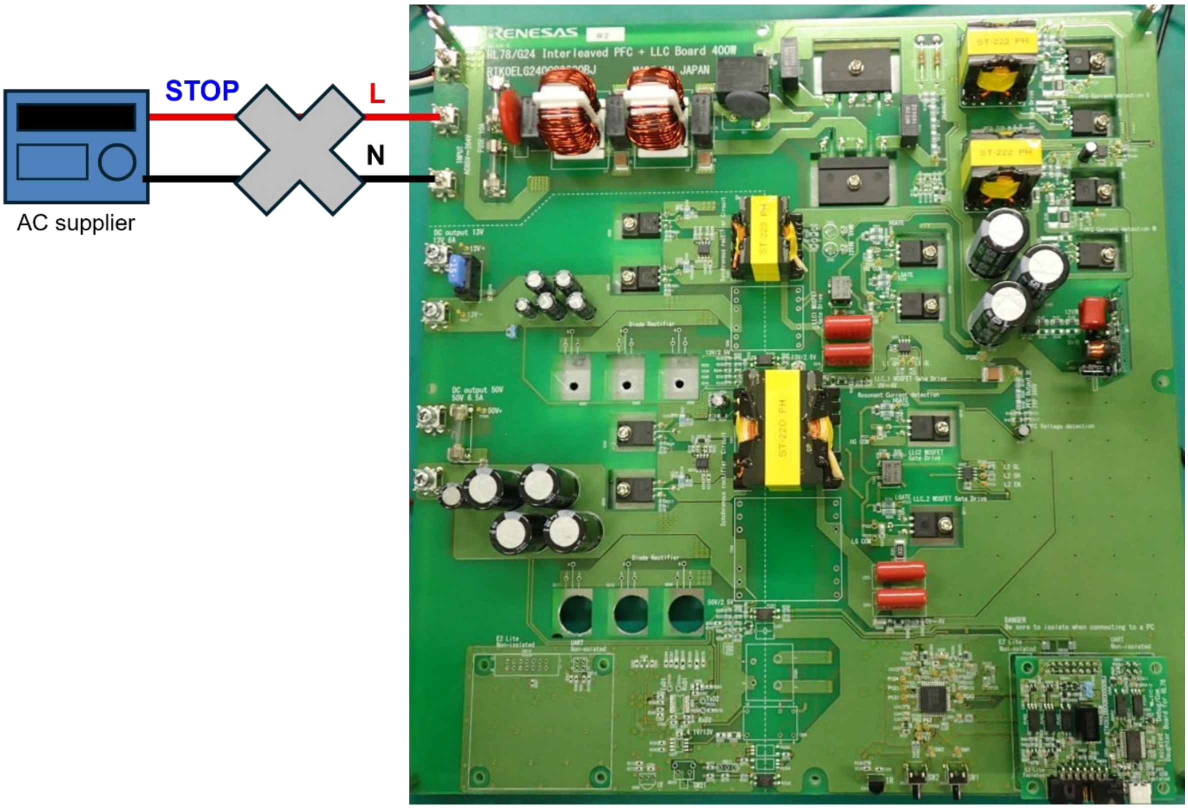


Figure 3.13 Checking that no AC power is being supplied

2. Short JP400 on the debug board using a jumper.

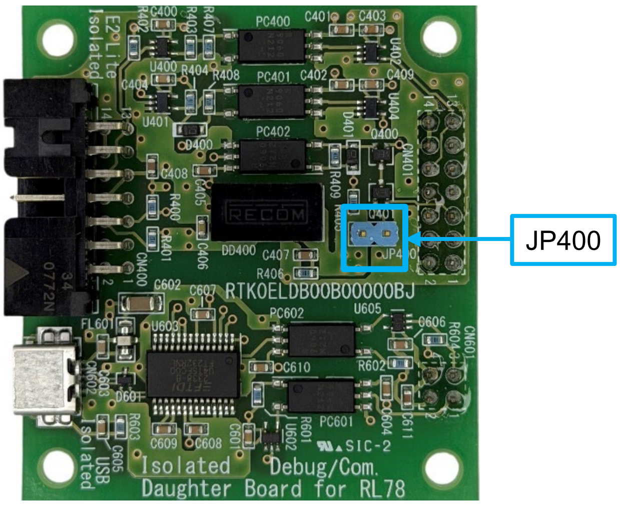


Figure 3.14 Position of the jumper pin

3. Connect CN400 on the debug board to the E2 Lite using the user interface cable.

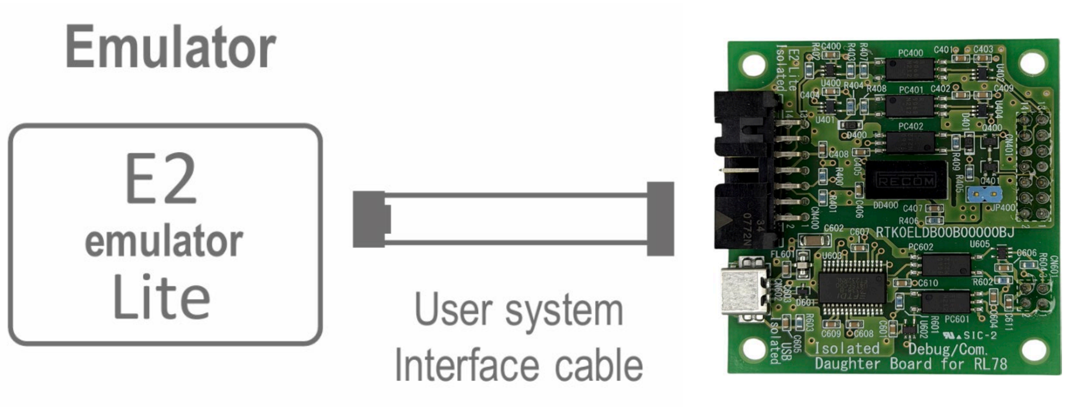


Figure 3.15 Connection between the E2 Emulator Lite and the debug board

4. Connect the E2 Lite to the PC using a USB cable, and program the firmware using RFP. In the software settings, ensure that 3.3 V power is supplied to the debug board via the E2 Lite.

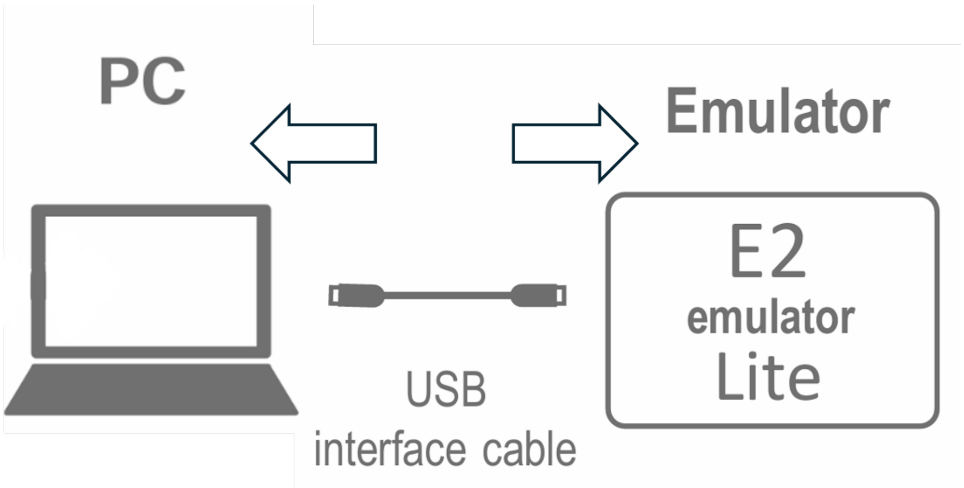


Figure 3.16 Connection between the PC and the E2 Lite

5. After programming is completed, disconnect the E2 Lite from the debug board.
6. Remove the debug board from the main board.

7. Connect an AC regulated power supply to CN2 (L) and CN3 (N) on the main board, and supply power to the board.

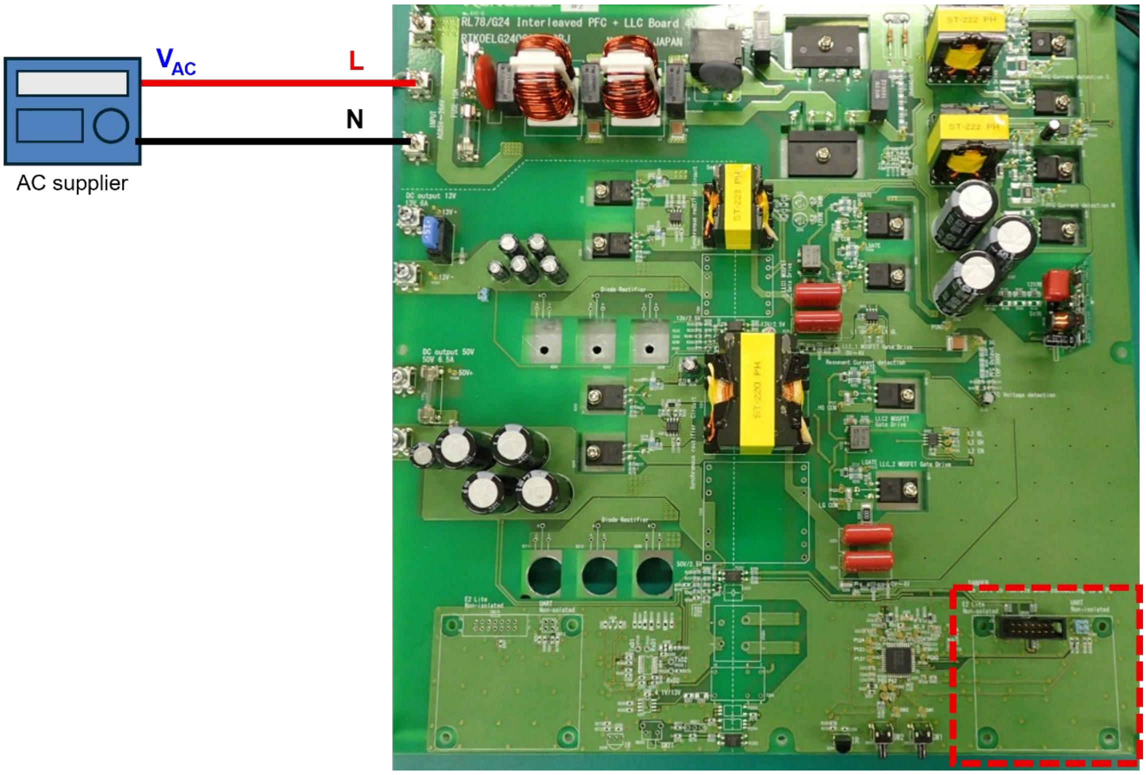


Figure 3.17 AC power connection

8. After executing RUN, press the switch on the main board to continue the startup sequence (this applies only to the current firmware).

SW2: Standby / Normal mode switching

SW1 (short press): Start/stop LLC2

SW1 (long press): Maximum frequency limit function ON/OFF

※Short press: less than 2 seconds / Long press: 3 seconds or more

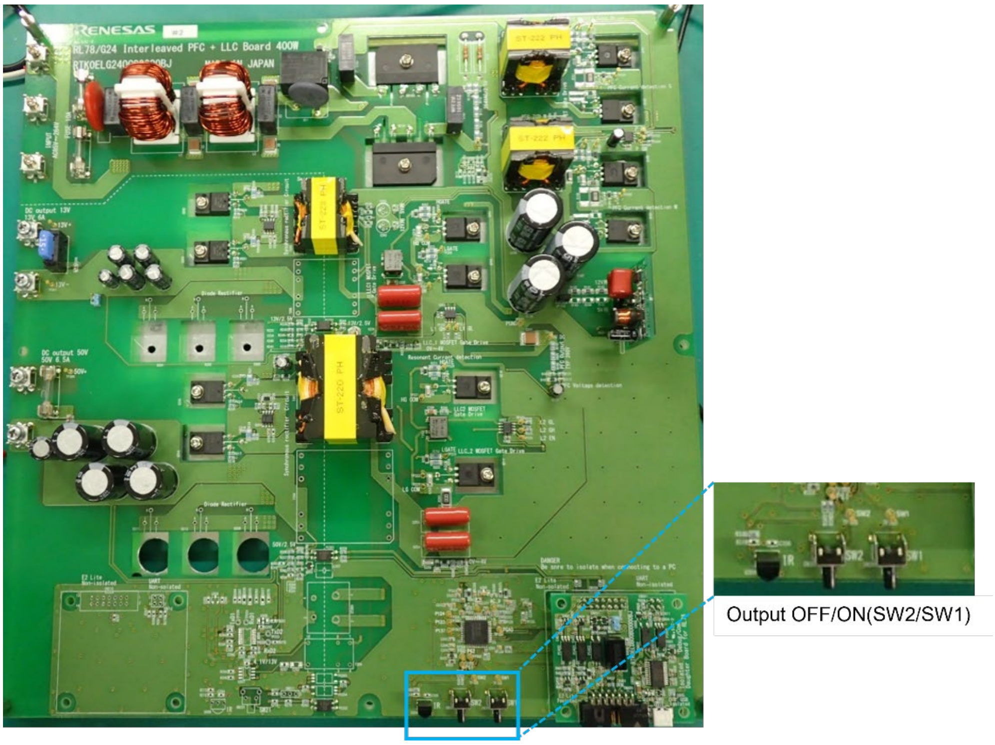


Figure 3.18 Position of the switches on the main board

3.5.2 Power Supply Route

The power supply route is as shown in Figure 3.19 Power Supply Route below.

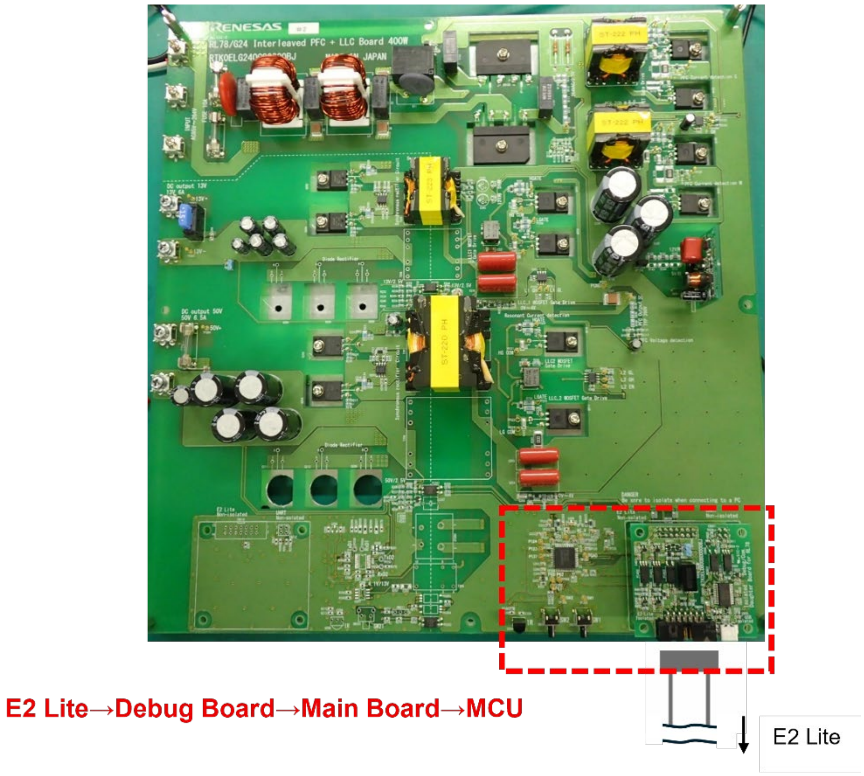


Figure 3.19 Power Supply Route

4. Evaluation

4.1 Evaluation Using an Electronic Load

Make the connections as shown in Figure 4.1 Connection method during evaluation below.

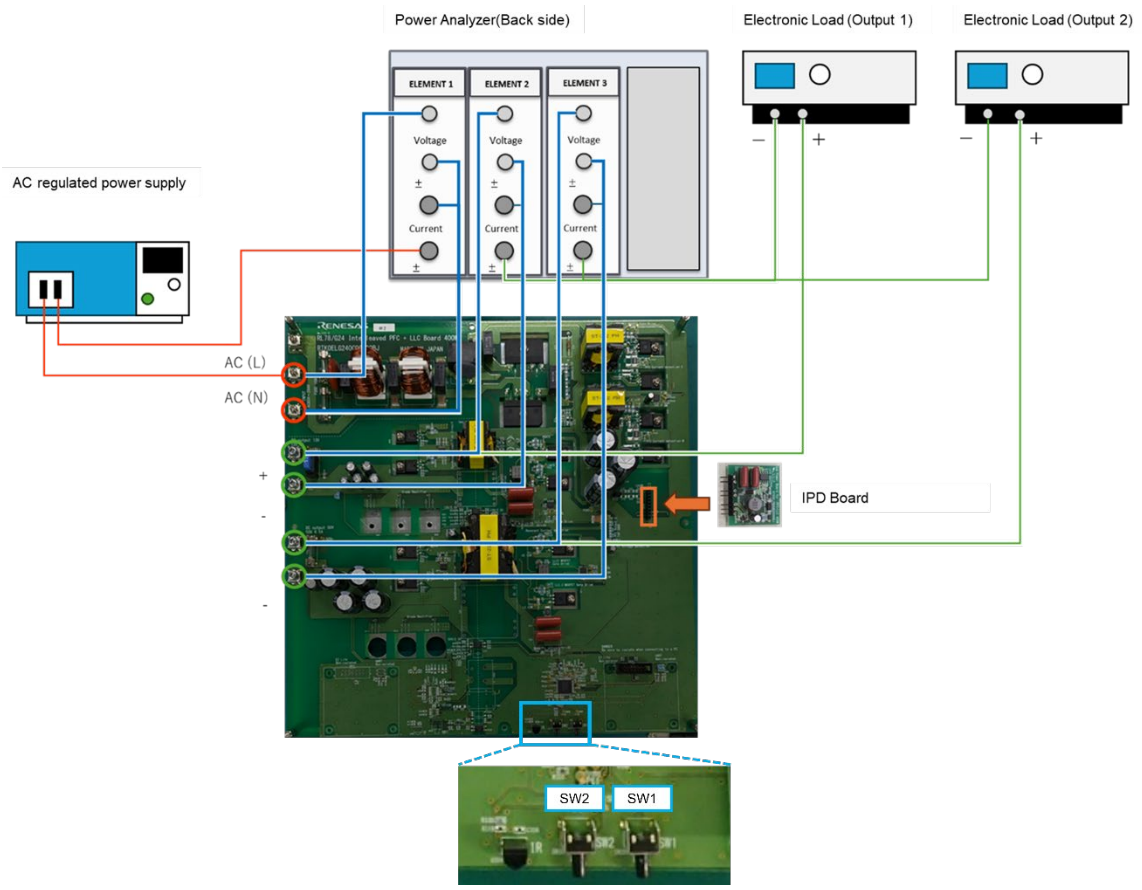


Figure 4.1 Connection method during evaluation

SW2: Standby / Normal mode switching

SW1 (short press): Start/stop LLC2

SW1 (long press): Maximum frequency limit function ON/OFF

※Short press: less than 2 seconds / Long press: 3 seconds or more

Note: When operating the system in standalone mode to measure standby power consumption, please remove the debug board to avoid the influence of the debug board's current consumption.

Debugging Precautions

1. When debugging with E2 Lite, make sure to configure the following settings:

   ･In **Property Settings (Debug Tool Settings)**, set **"Stop timer emulation when halted"** to **"Yes"**.
   ･In **Memory Access During Execution**, set **"Temporarily halt execution for access"** to **"No"**.
2. Do **not** resume execution directly at a breakpoint. If you need to resume, always click the **Reset** button in the IDE first, then continue execution**.**
3. Due to possible overload causing system crashes, before switching from **Normal Operation Mode** to **Standby Mode**, ensure that the load on **LLC1** is less than **1.125W**, or turn it off.
4. If performing single-step debugging from the beginning, pay close attention to the operations being debugged. Actions such as **Timer ON/OFF** or changes to **Comparator Settings** may damage the circuit.
5. For safe program execution verification, consider using a simulator as an alternative method.
6. **Ensure that the power is turned off before attaching or detaching the debug board.**

4.2 Evaluation Using QE for Lighting & Power

4.2.1 Operating Procedure

1. Confirm that JP400 on the debug board is open.

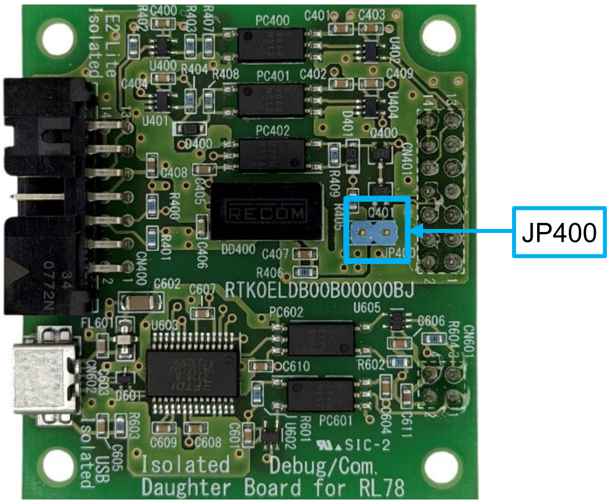


Figure 4.2 Location of the Jumper Pin

2. Connect CN400 on the debug board to the E2 Lite using the user interface cable.
3. Connect the E2 Lite to the PC using a USB Mini-B cable.
4. Connect CN602 on the debug board to the PC using a USB Mini-B cable.
5. Connect an AC regulated power supply to CN2 (L) and CN3 (N) on the main board, and supply power to the board.

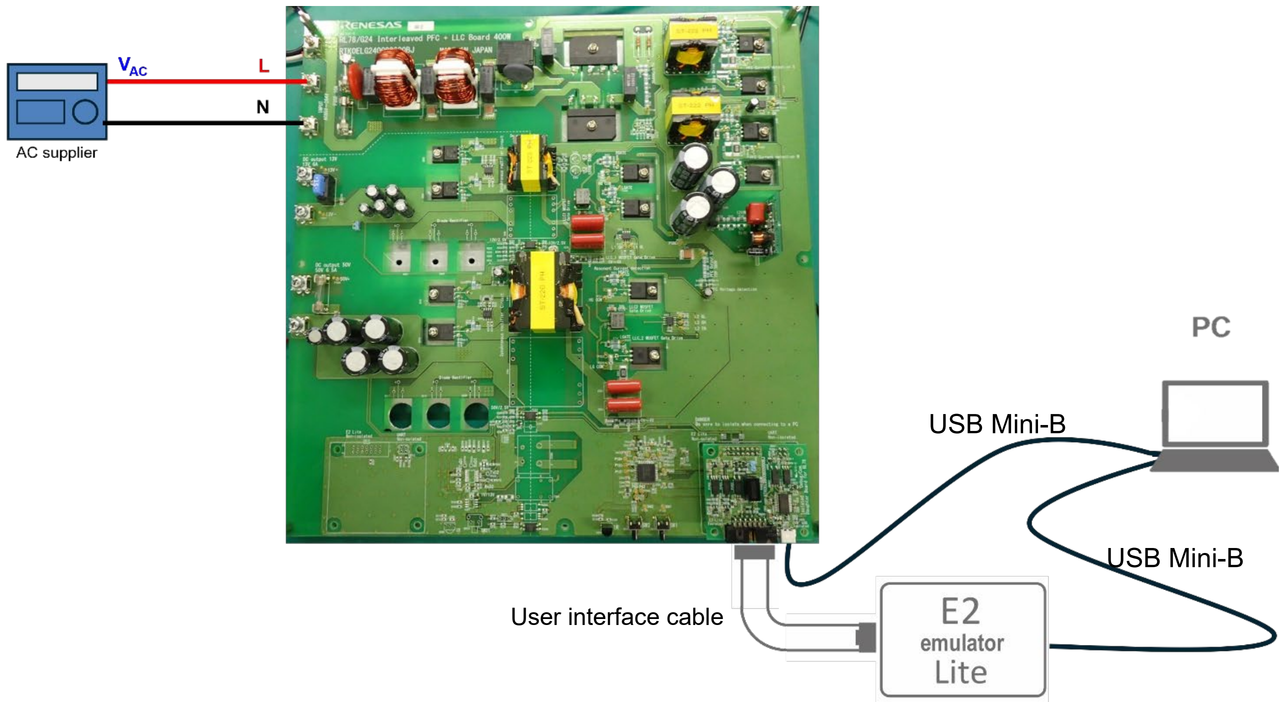


Figure 4.1 Connection diagram for evaluation using QE for Lighting & Power

6. Launch QE for Lighting & Power on the PC.

7. From the menu on the left, click “4. Configure Power Control” and then select “Configure Power Control Mode.”

   The “3. Configure Lighting Communication” menu is not used with this board.

8. If the checkbox for “Enable Power Control Mode” is not selected, click it to enable the function.

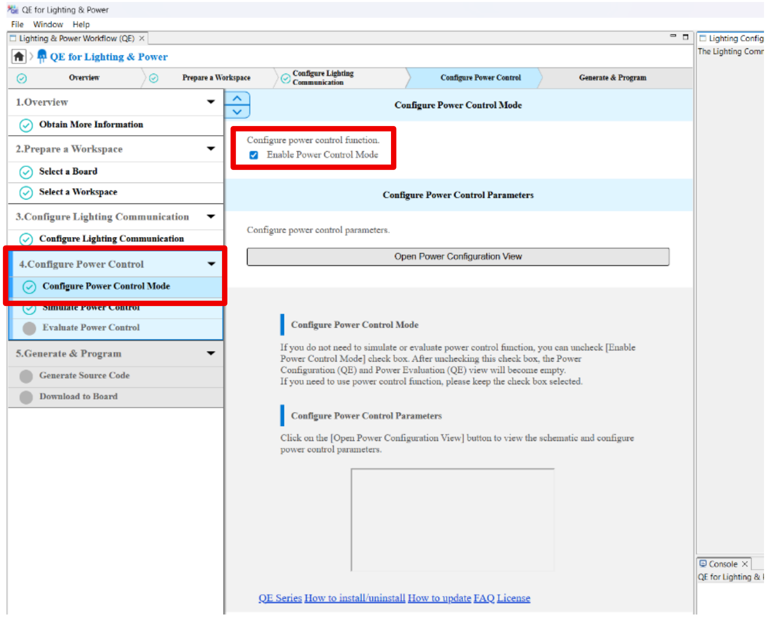


Figure 4.2 Configure Power Control Mode

9. Click “Open Power Configuration View.” The circuit diagram, Circuit Characteristics, and Power Control Parameters will be displayed in the window on the right. The parameters can be modified. Set them to appropriate values. For details on each item, refer to the application note “Interleaved CrM PFC and LLC Control Using RL78/G24 (CPU Software)(R01AN8177)”.

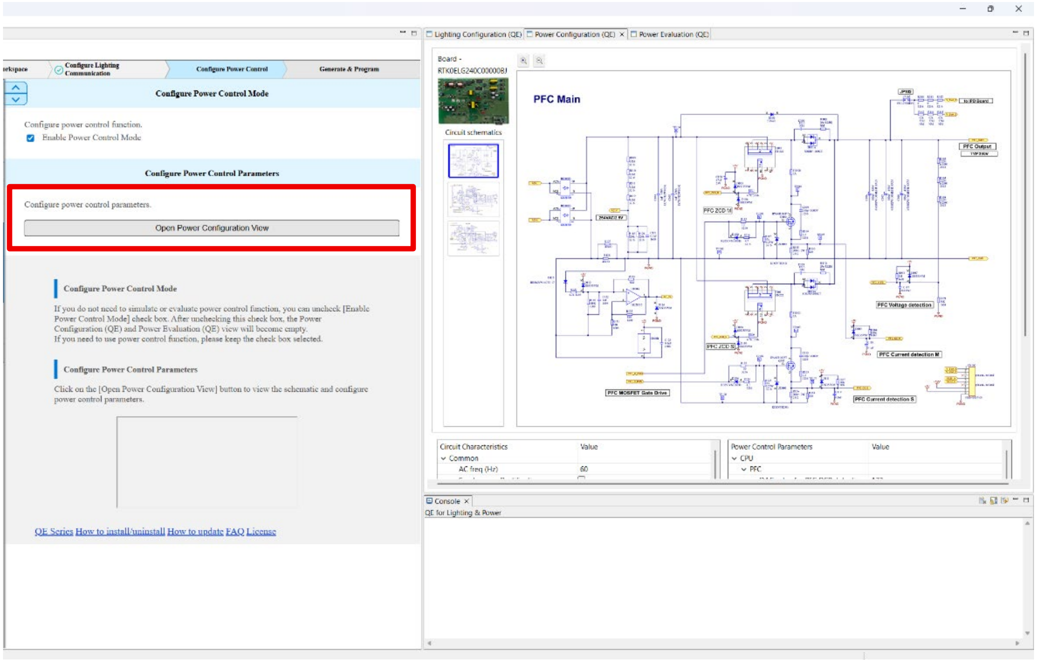


Figure 4.3 Power Configuration View

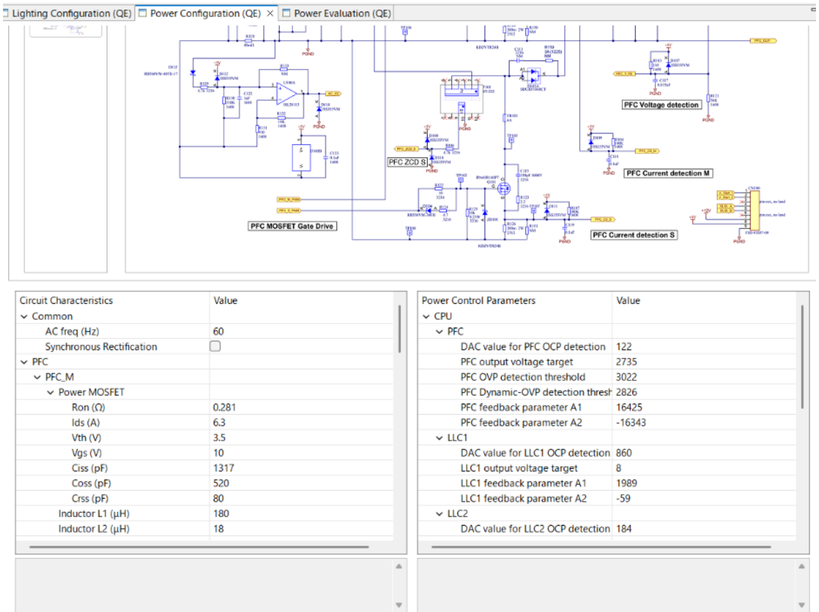


Figure 4.4 Circuit Characteristics and Power Control Parameters

10. From the menu on the left, click "Simulate Power Control."
11. Click "Open Power Simulation Dialog." The Power Control Simulator will launch.

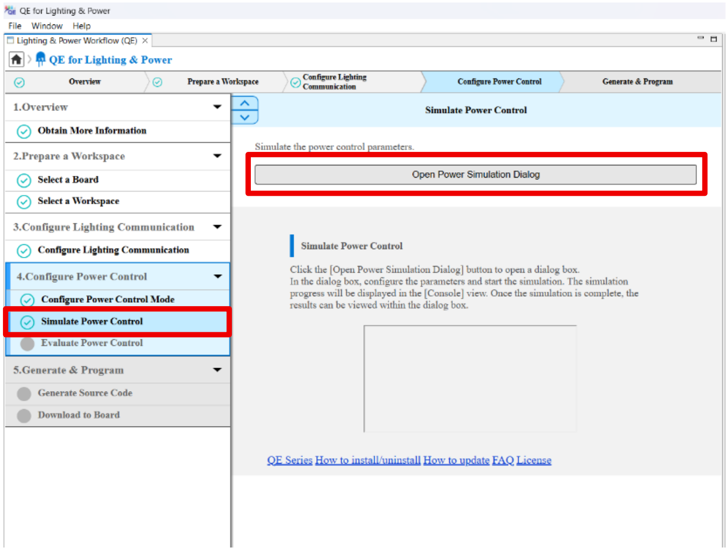


Figure 4.5 Power Control Simulator

In the Power Control Simulator, configure each parameter and click "Start Simulation." The simulation will begin, and the transitions of various values will be displayed as graphs.

For details on the configurable parameters and the types of output waveforms, refer to the application note "Interleaved CrM PFC and LLC Control Using RL78/G24 (CPU Software)(R01AN8177)".

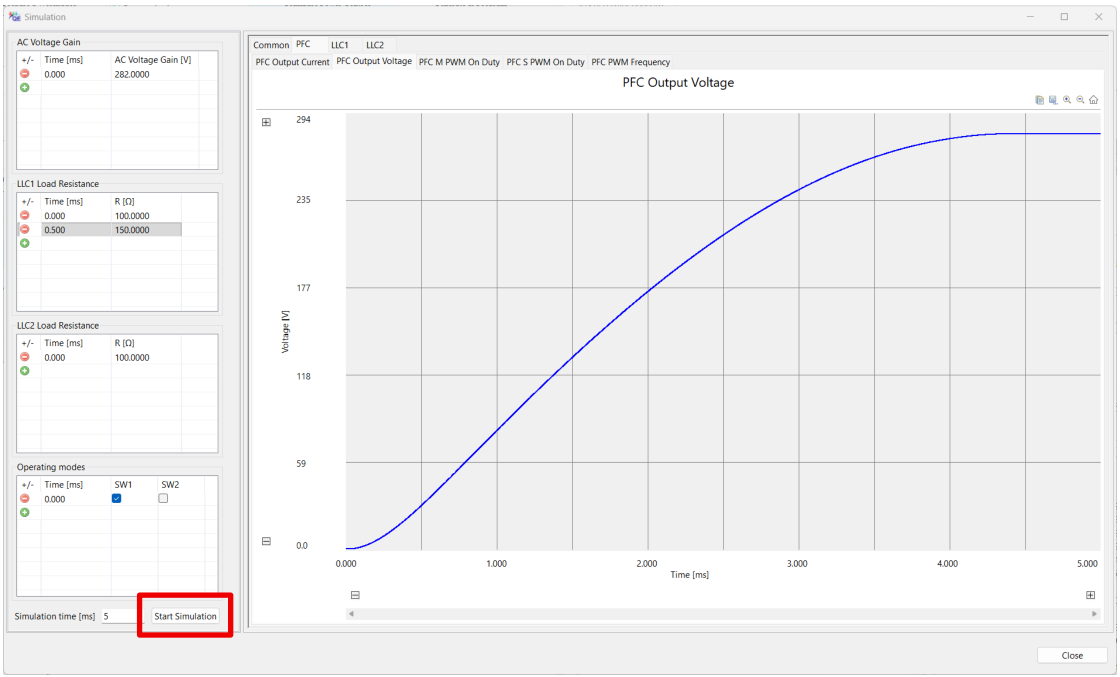


Figure 4.6 Power Control Simulation Dialog

12. From the menu on the left, click “Evaluate Power Control.”

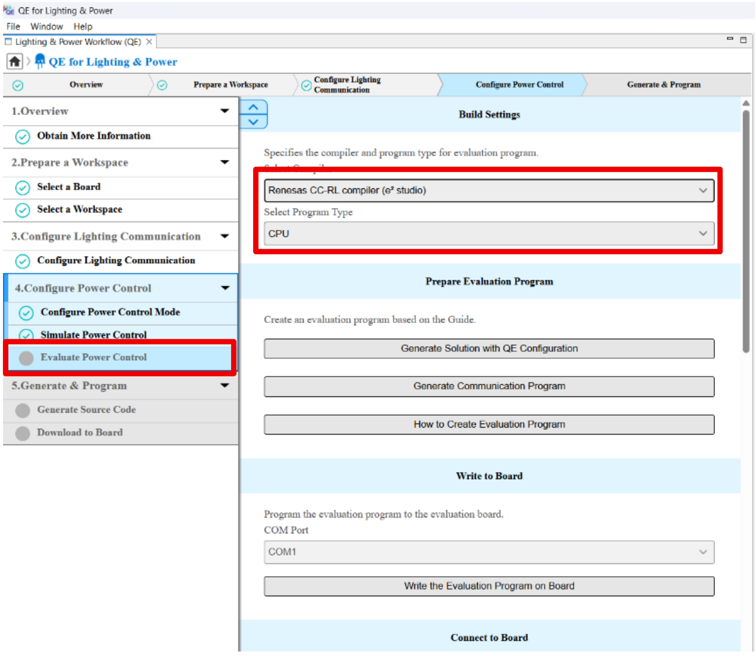


Figure 4.7 Evaluate Power Control

13. Follow the on-screen instructions and use the pull-down buttons to select the compiler used to build the program and the program type. Select the program type according to the core that executes the power-control processing.

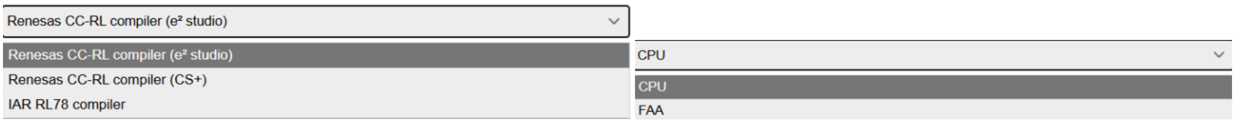


Figure 4.8 Compiler and Program Type Options

14. Click "Generate Solution with QE Configuration." The code will be generated using the parameter values configured above. After generation is complete, the results will be output to the console window.

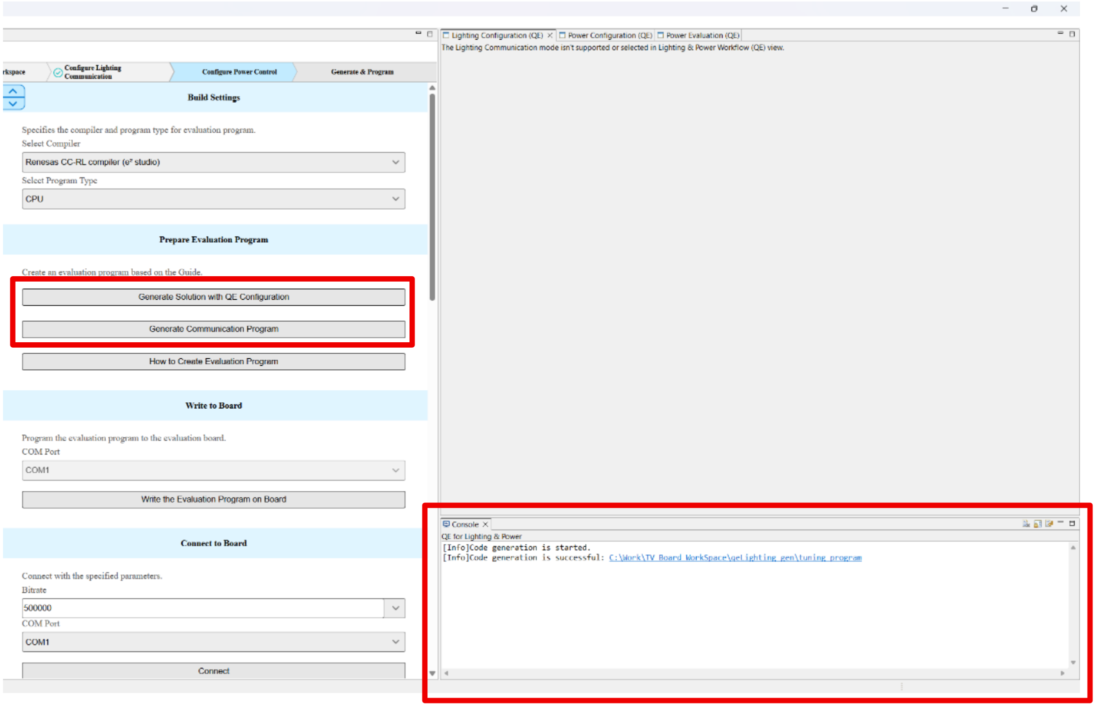


Figure 4.9 Console Window

15. Similarly, click "Generate Communication Program." The results will be output to the console window.

16. Click "How to Create Evaluation Program." The help window will open in a separate window. Follow the procedures described in the help to integrate the sample application and the communication program, and consolidate them into an evaluation program.

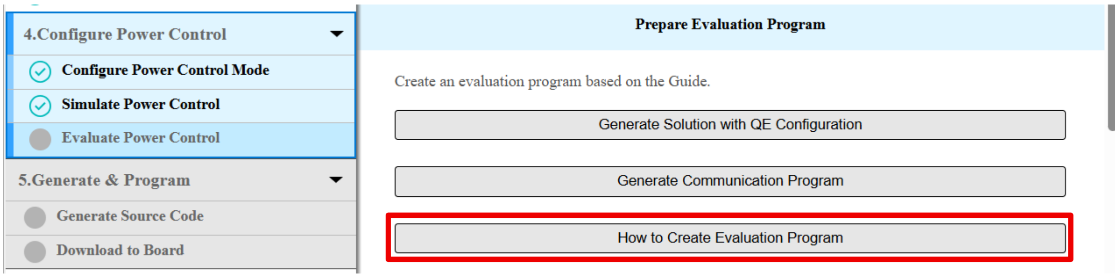


Figure 4.10 How to Create Evaluation Program

17. From the pull-down menu under “Write to Board,” select “E2Lite,” and click “Write the Evaluation Program on Board.” QE for Lighting & Power will build the program in the background and download it to the board via the E2Lite. During the build process, a progress bar will appear at the lower right of the window. After completion, the results will be output to the console window.

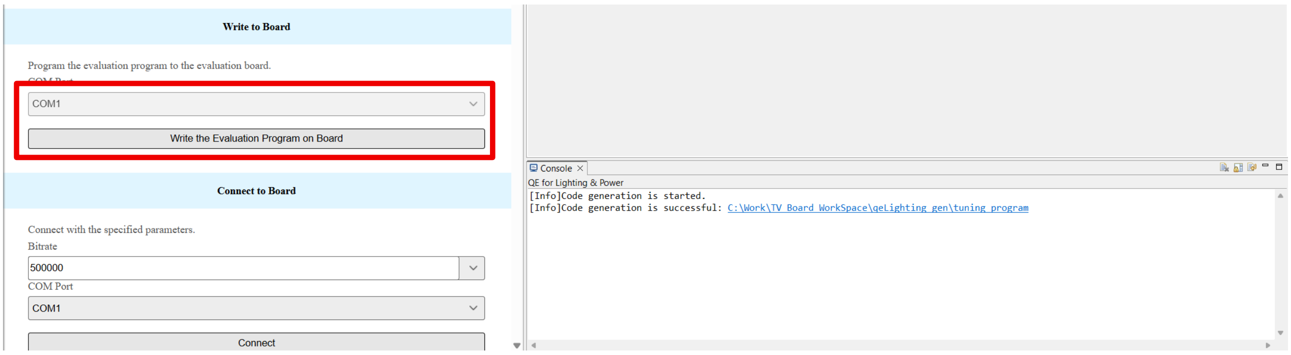


Figure 4.11 Write to Board

18. Scroll down the page and, under the “Write to Board” section, locate the “Connect to Board” settings, set the “Bitrate” value to 500000, select the COM port that connects the PC to the evaluation board from the pull-down menu, and click “Connect.” After completion, the results will be output to the console window.

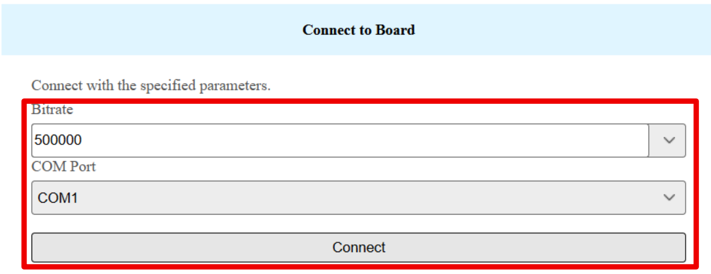


Figure 4.12 Connect to Board

19. Once the connection to the board has been established, you can evaluate the power-control operation in real time using the following two items under the “Evaluate Power Control” section.

    Note: Before communicating, manually press SW2 to set the target board to Normal mode.

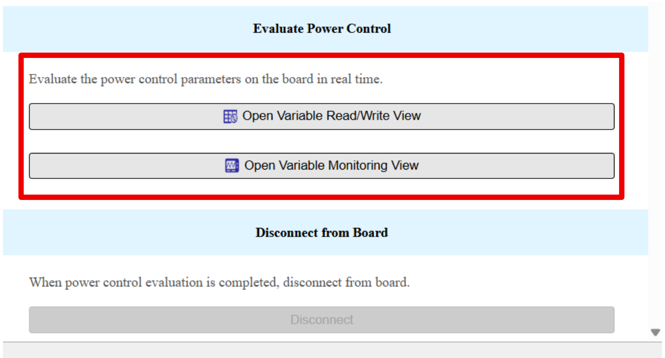


Figure 4.13 Evaluate Power Control

(1) Variable Read/Write

In Variable Read/Write, you can read and monitor internal variables and register values of the application program in real time.
Click “Open Variable Read/Write View” to open the [Variable Read/Write] tab in the window on the right.

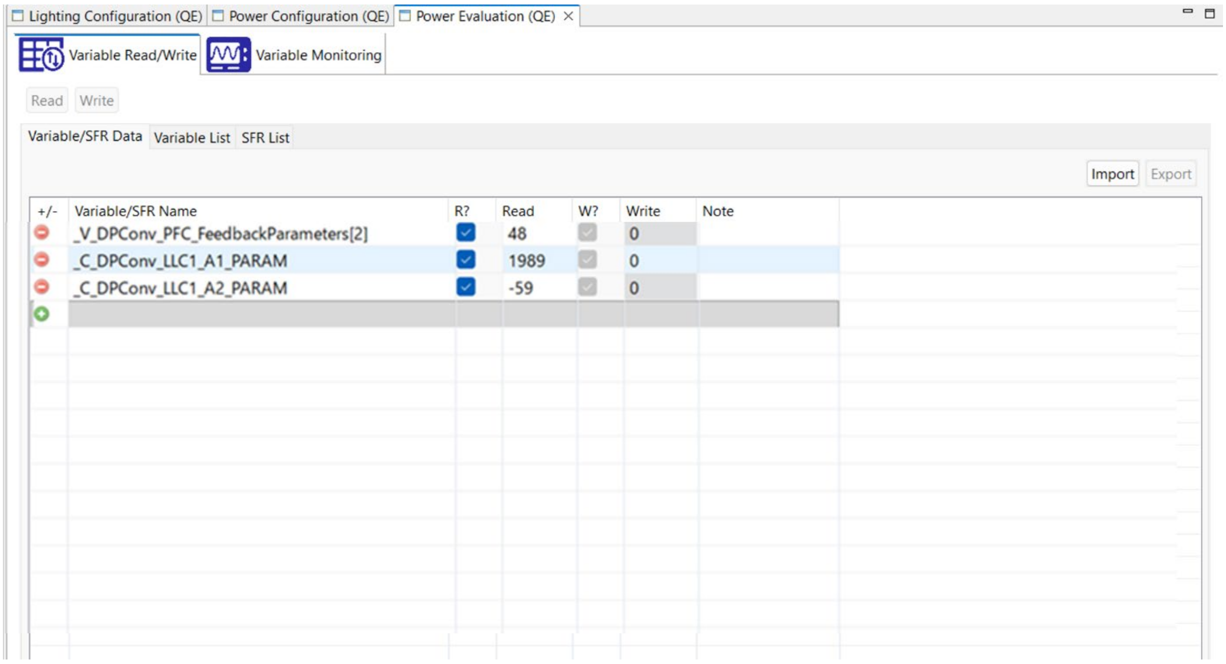


Figure 4.14 [Variable Read/Write] Tab

Operating Procedure
1. Selecting Variables for Evaluation
From the variable selection list in the tab, select the power-control variables to be evaluated.
2. Reading Variable Values
Click “Read” to display the current values of the variables.

Note: Changes made to variable values in this tab are not applied to the running application program. If you need the changes to take effect in the application, edit the program source code directly.

(2) Variable Monitoring

In Variable Monitoring, you can continuously acquire internal variables and register values of the evaluation program at fixed intervals and display their time-based changes as a graph.
Click "Open Variable Monitoring View" to open the [Variable Monitoring] tab in the window on the right.

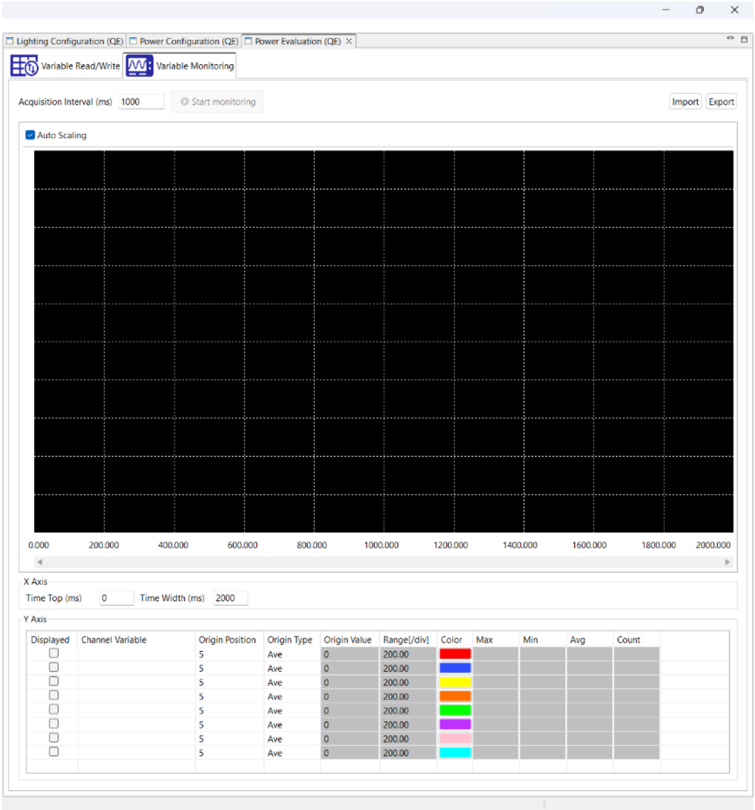


Figure 4.15 [Variable Monitoring] Tab

Operating Procedure
1. Selecting Variables for Monitoring
From "Channel Variable" drop-down list in the tab, select the variables whose waveforms you want to display.
Multiple variables can be selected simultaneously.
2. Setting Acquisition Conditions
You can configure the monitoring interval and the output waveform range.
3. Starting Monitoring
Click "Start monitoring" to begin acquiring variable values and displaying the waveforms.

20. When the evaluation is complete, click "Disconnect" in the section below.
21. After all of the above steps have been successfully completed, disconnect the USB cable and turn off the regulated power supply.

4.3 Writing Using QE for Lighting & Power

4.3.1 Operating Procedure

1. Confirm that JP400 on the debug board is open.

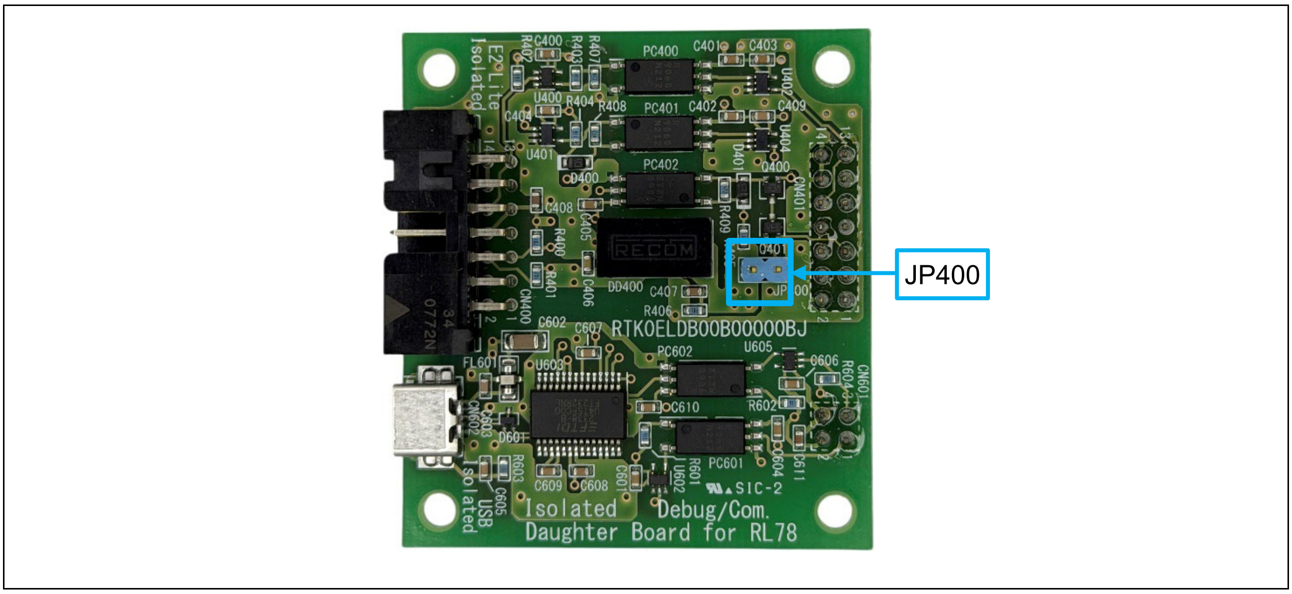


Figure 4.16 Location of the Jumper Pin

2. Connect CN400 on the debug board to the E2 Lite using the user interface cable.
3. Connect the E2 Lite to the PC using a USB Mini-B cable.
4. Connect an AC regulated power supply to CN2 (L) and CN3 (N) on the main board, and supply power to the board.

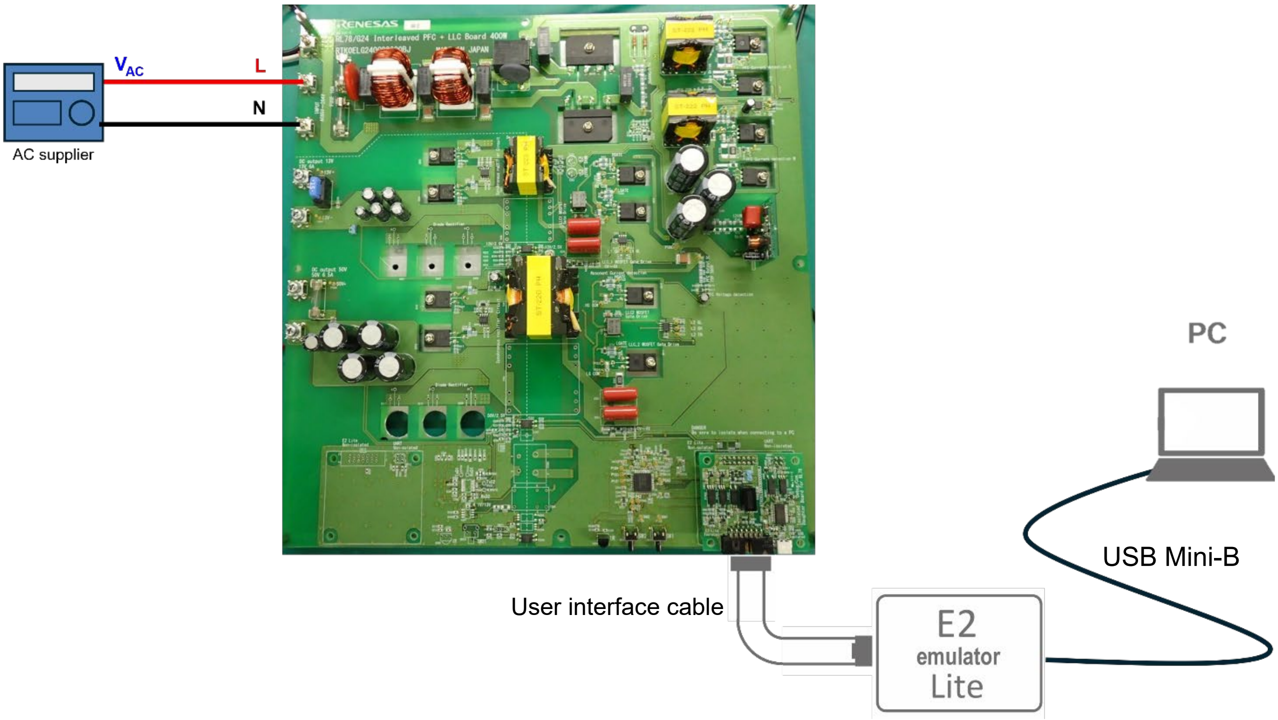


Figure 4.17 Connection Diagram for Writing with QE for Lighting & Power

5. Launch QE for Lighting & Power on the PC.
6. From the menu on the left, click “Generate Source Code” under “5. Generate & Program.”

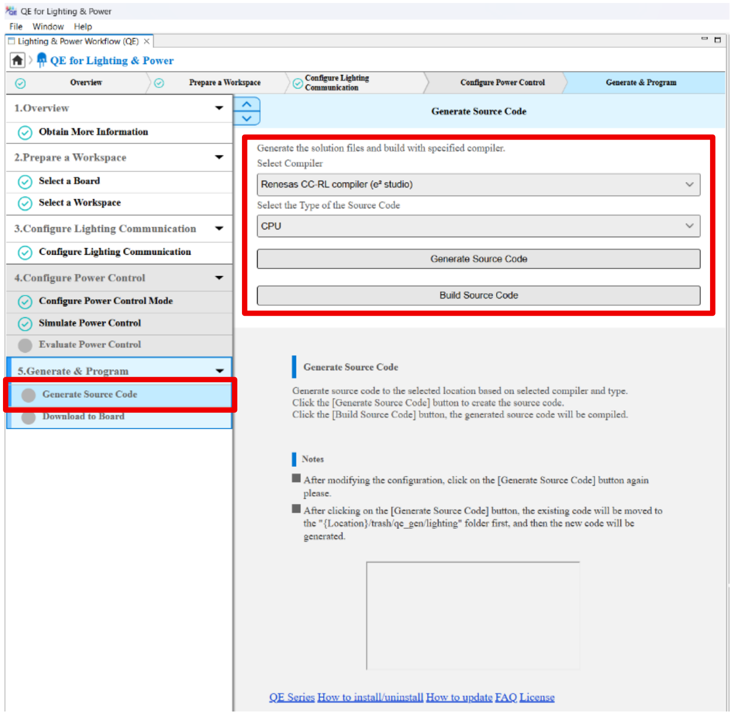


Figure 4.18 Generate Source Code

7. Click the pull-down button and select the compiler and program type to be used for building the program.

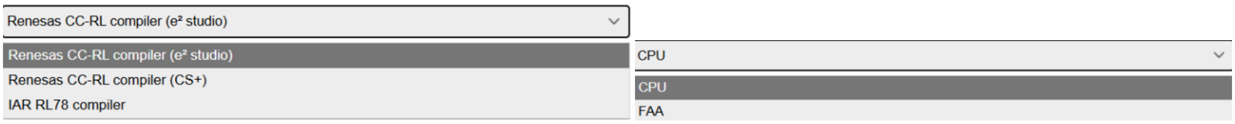


Figure 4.19 Compiler and Program Type Options

8. Click “Generate Source Code.” The source code will be generated in the folder specified in the workspace.

9. Click “Build Source Code” to start the build process. When the build is complete, the results will be displayed in the console window at the bottom right.

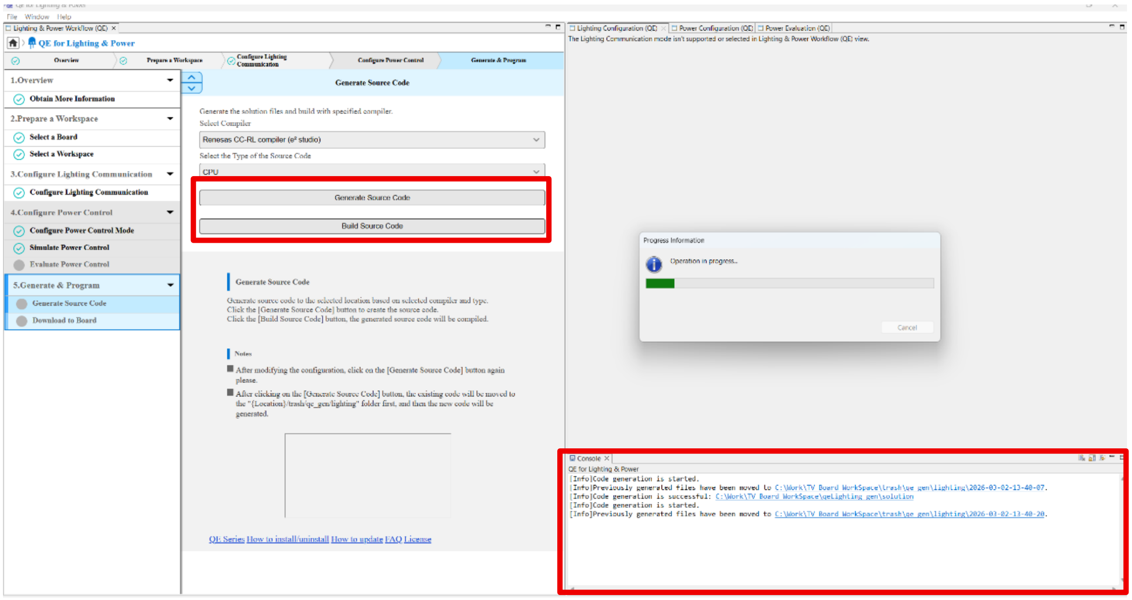


Figure 4.20 Generate Source Code

10. From the menu on the left, click “Download to Board.”
11. Select “E2 Lite” from the pull-down menu.
12. Click “Download to Board.” The program will be downloaded to the evaluation board via the E2 Lite. When the download is complete, the results will be displayed in the console window at the bottom right.

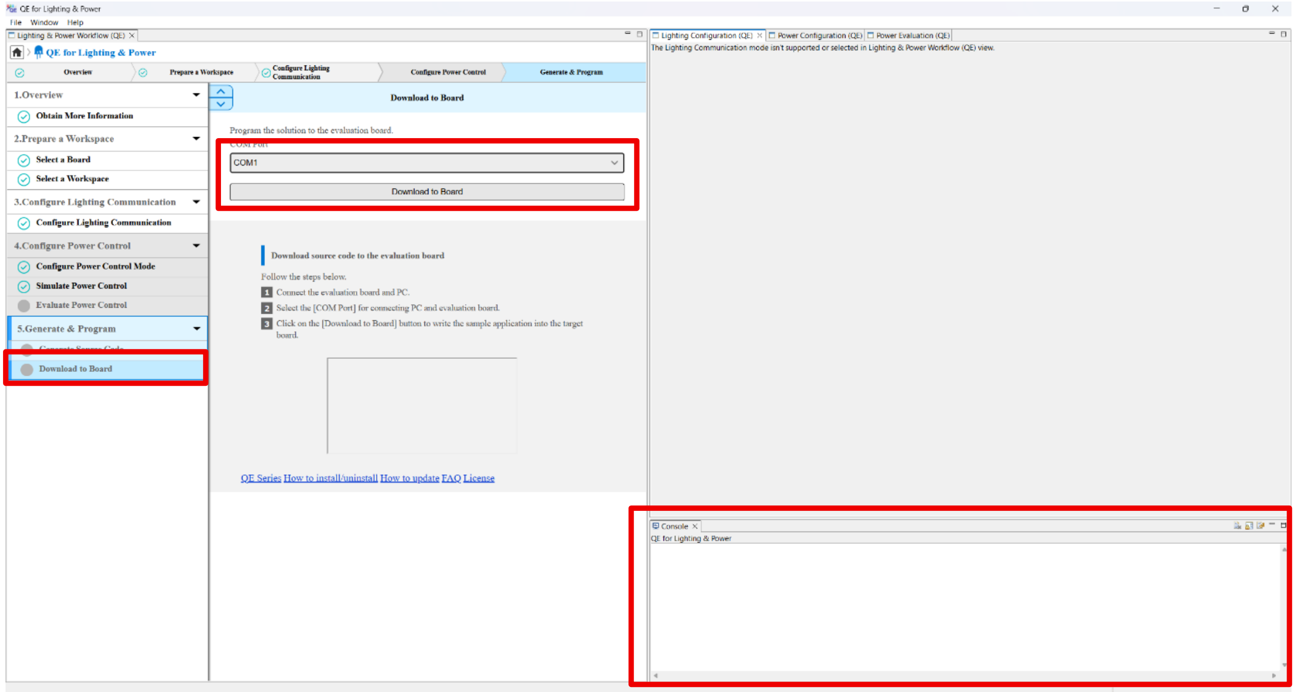


Figure 4.21 Download to Board

13. After the download is complete, turn off the regulated power supply and power down the evaluation board.
14. Once all of the above steps have been successfully completed, disconnect the USB cable.

5. Hardware Design Overview

The hardware consists of multiple components, as shown in Figure 5.1. Each component is described in the following sections. Refer to the circuit diagram as needed.
For detailed information on the control method and software operation, please refer to “Interleaved CrM PFC and LLC Control with RL78/G24 (Hardware & Software Basics) (R01AN8177)”.

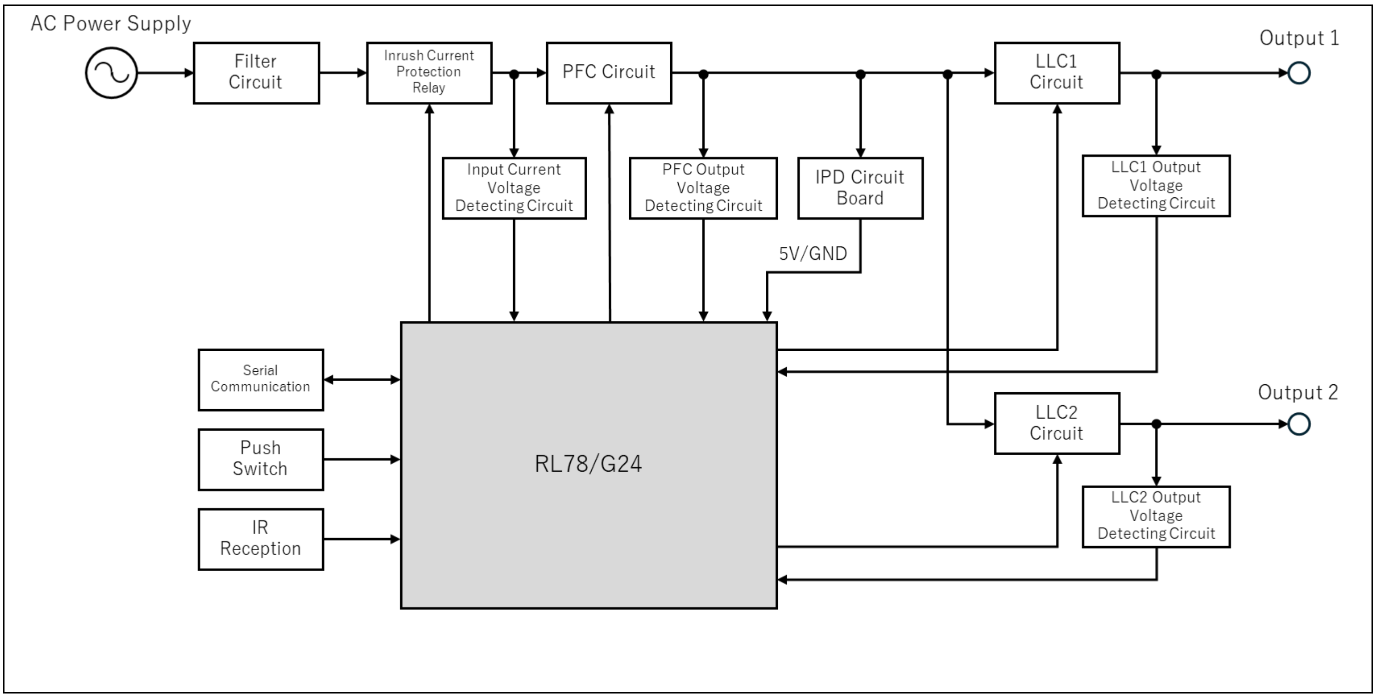


Figure 5.1 Functional Block Diagram

5.1 Inrush Current Protection Relay

A switching power supply generates a large current at power-on as current flows into the smoothing capacitor. This is known as inrush current. On the target board, an NTC thermistor (RT1) is used to limit the inrush current in a simple yet effective manner. Because the internal resistance of an NTC thermistor continuously causes power loss, it reduces efficiency. To improve efficiency, the MCU switches the relay ON and OFF depending on the operating mode, thereby controlling the path through which the input current I_{in} flows.

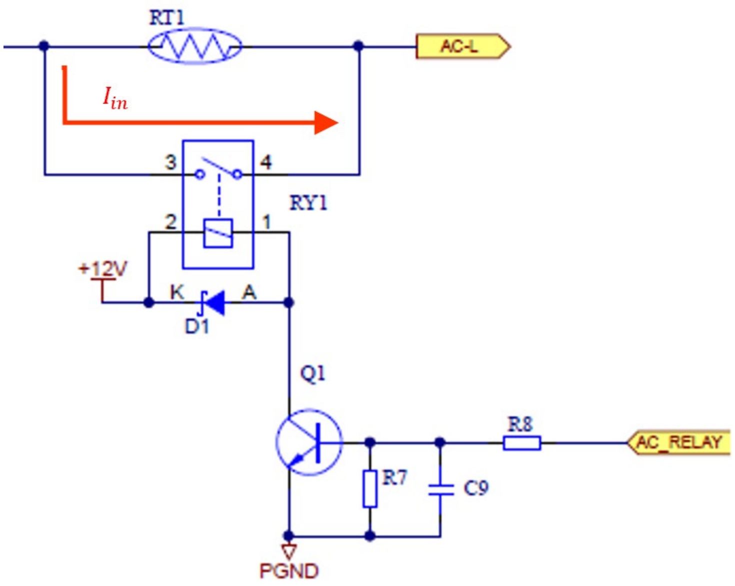


Figure 5.2 Inrush Current Protection Relay Circuit

5.2 AC Input Voltage Detection Circuit (AC_V)

This circuit detects the rectified AC input voltage as an analog input. To enable detection by the RL78/G24's analog input, the voltage divided by the resistor network is referred to as AC_V.

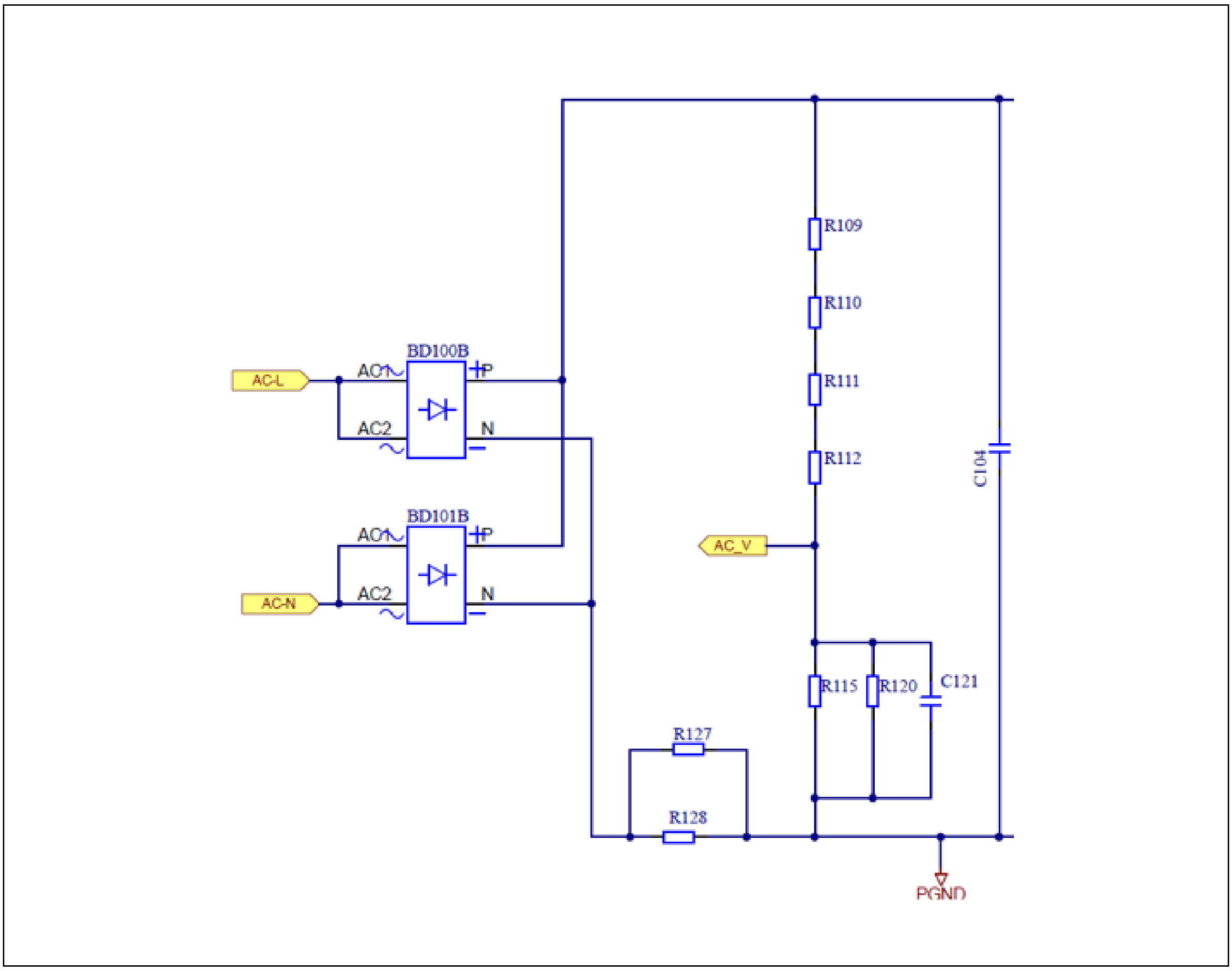


Figure 5.3 AC Input Voltage Detection Circuit

The voltage AC_V is obtained using the following formula, where the peak value of the AC input current is defined as $V_{AC\_IN\_PEAK}$:

$$AC\_V = V_{AC\_IN\_PEAK} \times \frac{(R115+R120)}{(R109+R110+R111+R112)+(R115+R120)}$$

5.3 AC Consumption Current Detection Circuit (AC_CS)

Figure 5.4 shows a circuit that allows simple detection of the AC consumption current. By multiplying the current flowing through the current-sense resistors R127 and R128 (denoted as I_{FB_PEAK}), the magnitude of the current can be detected. To minimize power loss and increase the detection voltage, low-inductance resistors and an amplifier are employed.

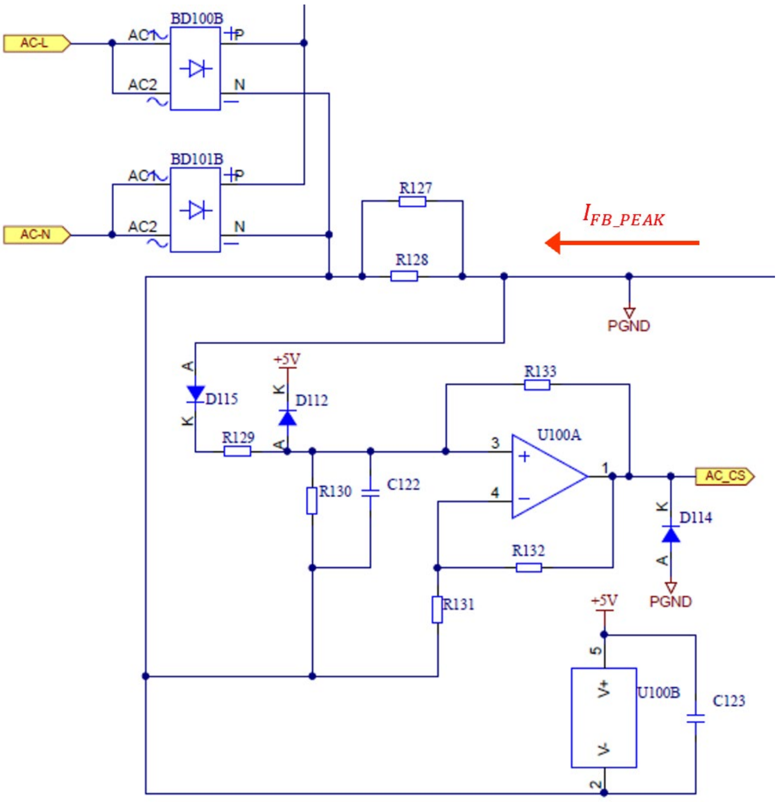


Figure 5.4 AC Consumption Current Detection Circuit

The voltage AC_CS is obtained using the following formula:

$$\text{AC\_CS} = I_{\text{FB PEAK}} \times \left(\frac{\text{R127} \times \text{R128}}{\text{R127} + \text{R128}}\right) \times \text{Gain}$$

$$\text{where: Gain} = 1 + \frac{\text{R132}}{\text{R131}}$$

5.4 PFC Circuit

5.4.1 Overview of Circuit Control

The PFC circuit consists of two boost converters operating in critical-conduction mode. Figure 5.5 shows the relationship between the PFC circuit and the microcontroller I/O.

The RL78/G24 periodically monitors the load and switches appropriately between single-phase output and interleaved output depending on the load level, thereby achieving high efficiency across a wide load range. With the interleaved PFC function of the RL78/G24's Timer KB, the phase is automatically shifted by 180° during interleaved operation, which suppresses ripple.

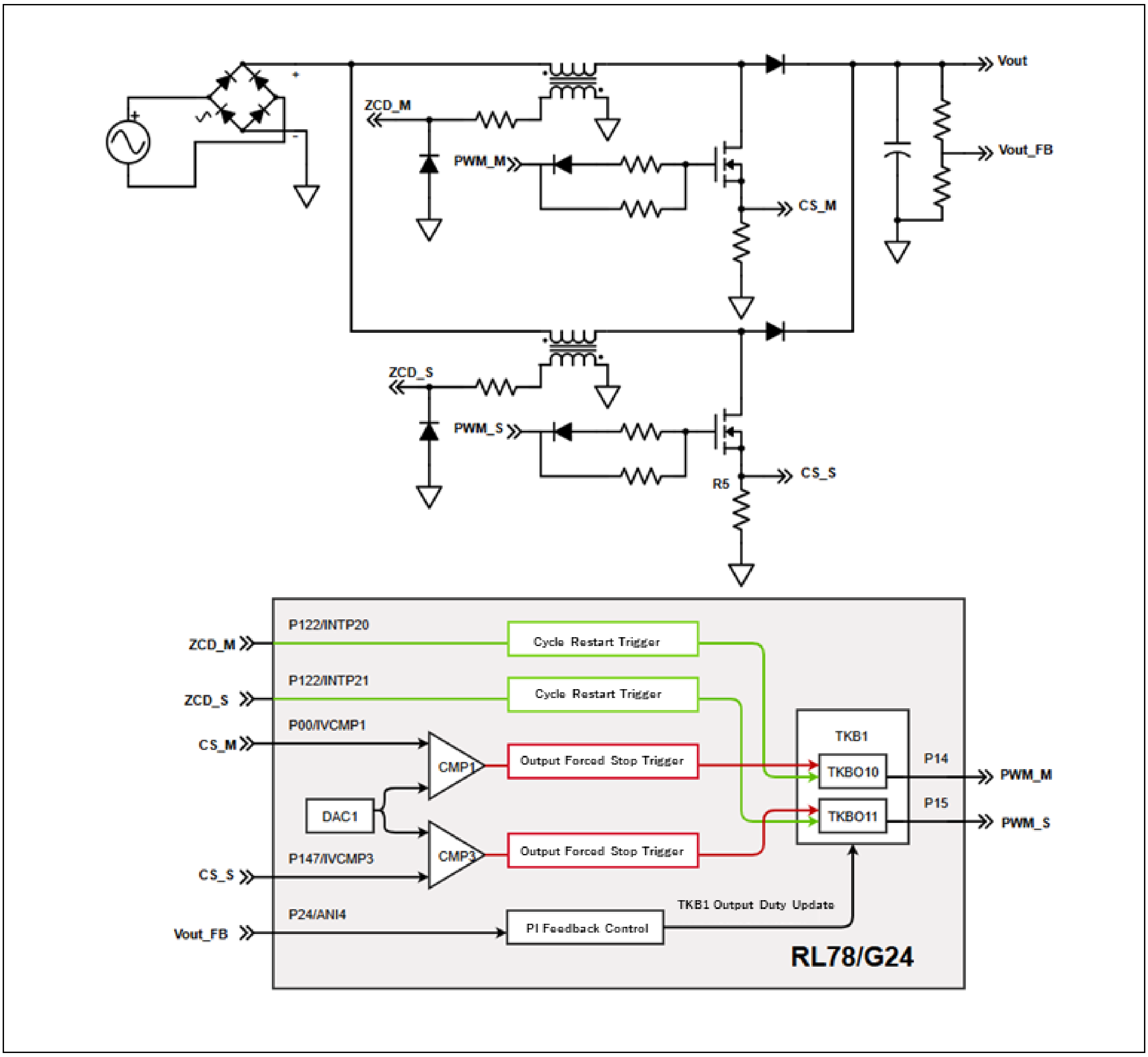


Figure 5.5 PFC Circuit

5.4.2 Output Overcurrent Detection Circuit (PFC_CS_M / PFC_CS_S)

To prevent device failure caused by abnormal inrush current or overload conditions, a shunt resistor is connected in series with the MOSFET source to enable current sensing. This signal is fed into the RL78/G24's comparator, and when it exceeds the value set by the internal DAC (configured by software), the forced-output-stop function of Timer KBn is activated, thereby detecting overcurrent and stopping the PWM output.

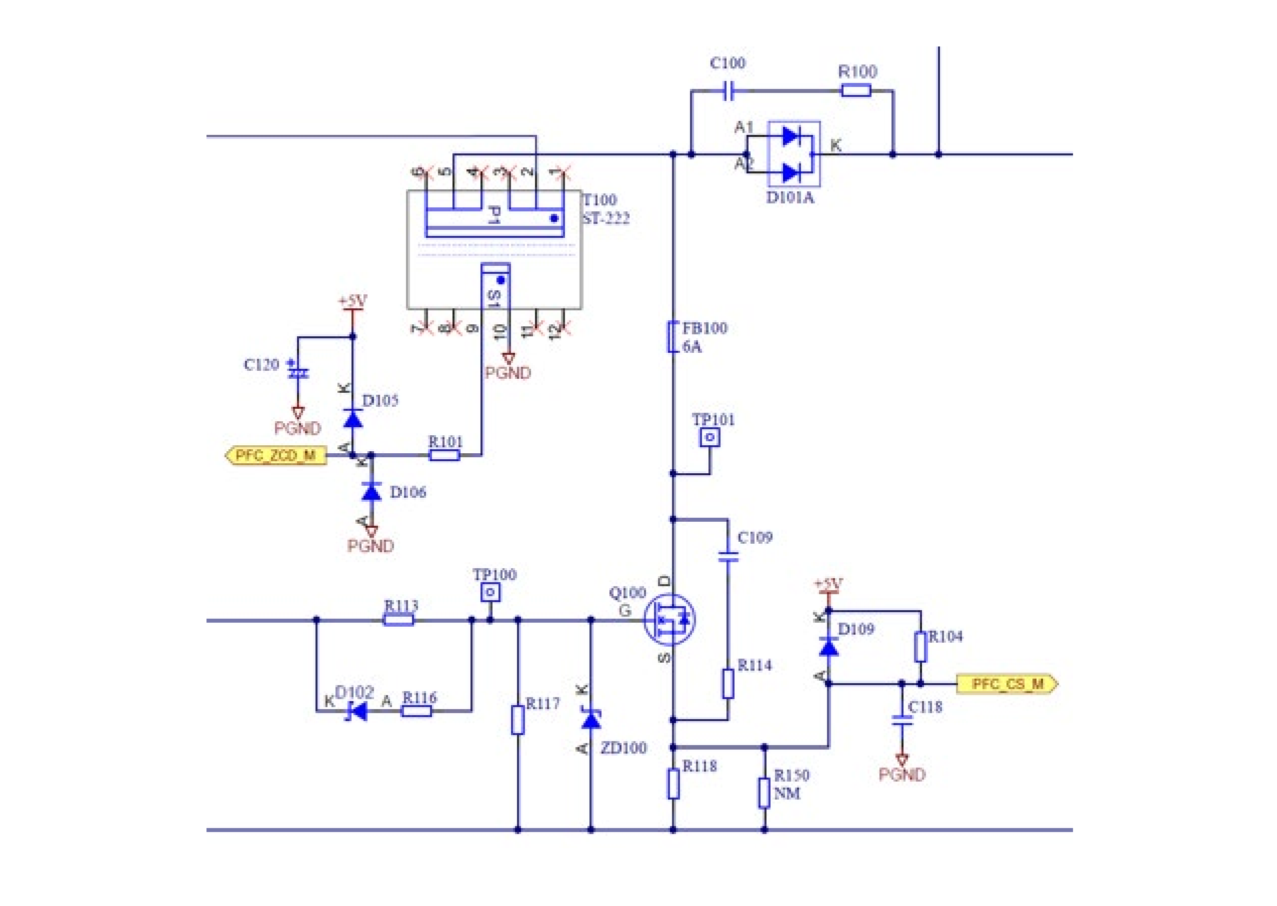


Figure 5.6 PFC Output Overcurrent Detection Circuit

The current-sense signal PFC_CS is obtained using the following formula:

$$\mathrm{PFC\_CS} = \mathrm{I_{PEAK}} \times \mathrm{R118}$$

5.4.3 Output Voltage Detection Circuit (PFC_V_FB)

The PFC output voltage is monitored by dividing the output voltage and feeding it into the RL78/G24's analog input pin. Because signal accuracy and noise immunity are required to ensure stable output-voltage control, this signal is routed with short wiring and connected directly to ground.

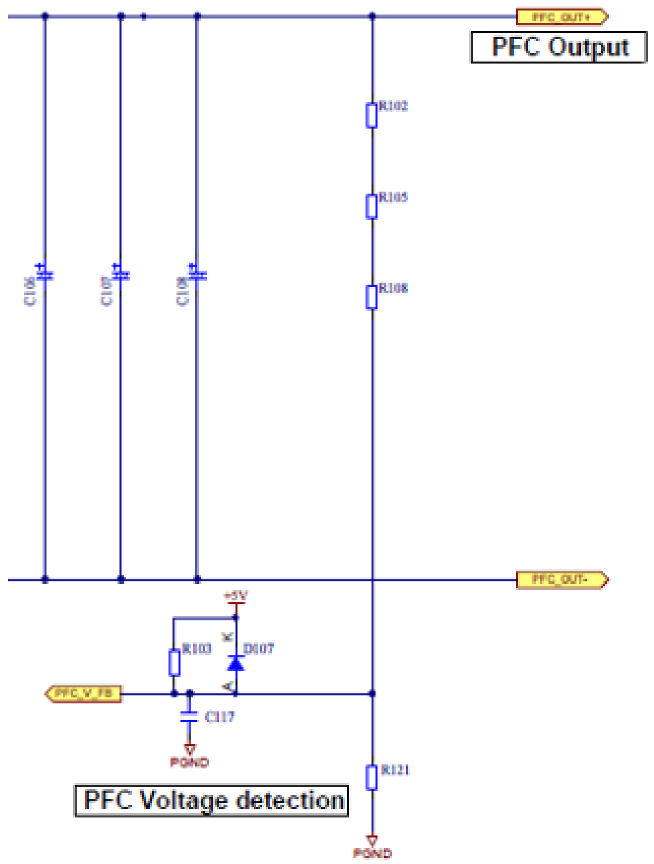


Figure 5.7 PFC Output Voltage Detection Circuit (PFC_V_FB)

The PFC output voltage is obtained using the following formula:

$$\mathrm{PFC\_OUT} = \frac{\mathrm{PFC\_V\_FB} \times (\mathrm{R102+R105+R108+R121})}{\mathrm{R121}}$$

5.5 LLC Circuit

5.5.1 Overview of the Circuit

The LLC circuit is a high-efficiency, low-noise switching power supply that utilizes current-resonant operation. A simplified basic model is shown in Figure 5.8. Descriptions of each circuit block are provided below.

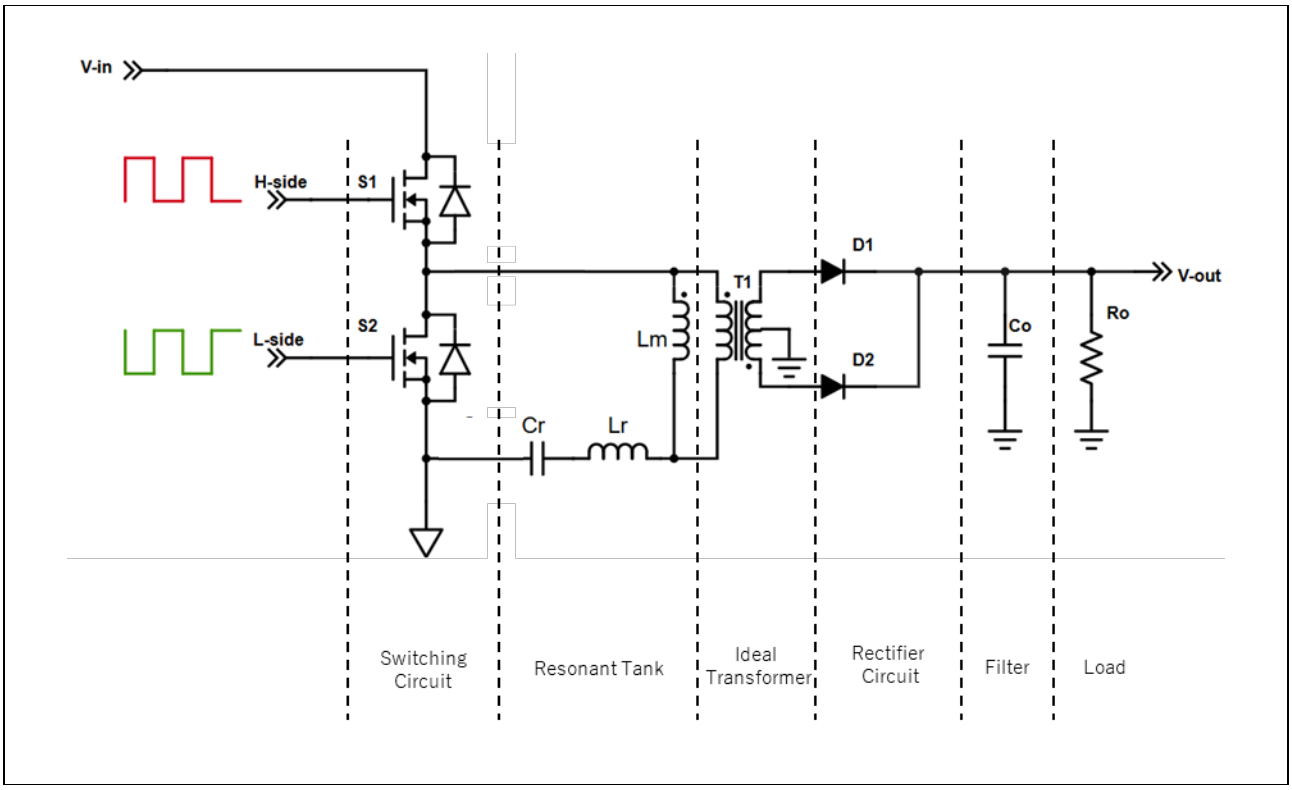


Figure 5.8 LLC Circuit

- Switching Circuit

The switching circuit is implemented as a half-bridge consisting of a high-side MOSFET and a low-side MOSFET.

- Resonant Tank

The circuit is composed of the resonant capacitor Cr, the resonant inductance Lr, and the magnetizing inductance Lm, and generates two resonant frequencies inside the circuit.

- Ideal Transformer

For simplicity, the transformer is treated as an ideal model.

- Rectifier Circuit

Because the detailed behavior of the rectifier is not essential for describing the LLC operation, the current-waveform calculations assume full-wave rectification.

- Filter

The output filter is represented by the capacitor Co.

- Load

The load is represented by the resistor Ro.

5.5.2 Operation

The two MOSFETs operate in a complementary manner with a fixed dead time and a 50% duty cycle, resulting in a square-wave output from the switching circuit.

Under normal-mode operation, the switching frequency is designed to match the resonant frequency of the tank, and the tank components are selected to satisfy this condition. When a waveform that matches the tank characteristics is applied, only the sinusoidal component is transferred to the output. Varying the switching frequency applied to the MOSFETs enables regulation of the output voltage.

After filtering by the capacitor Co, a constant current is supplied to the load Ro.

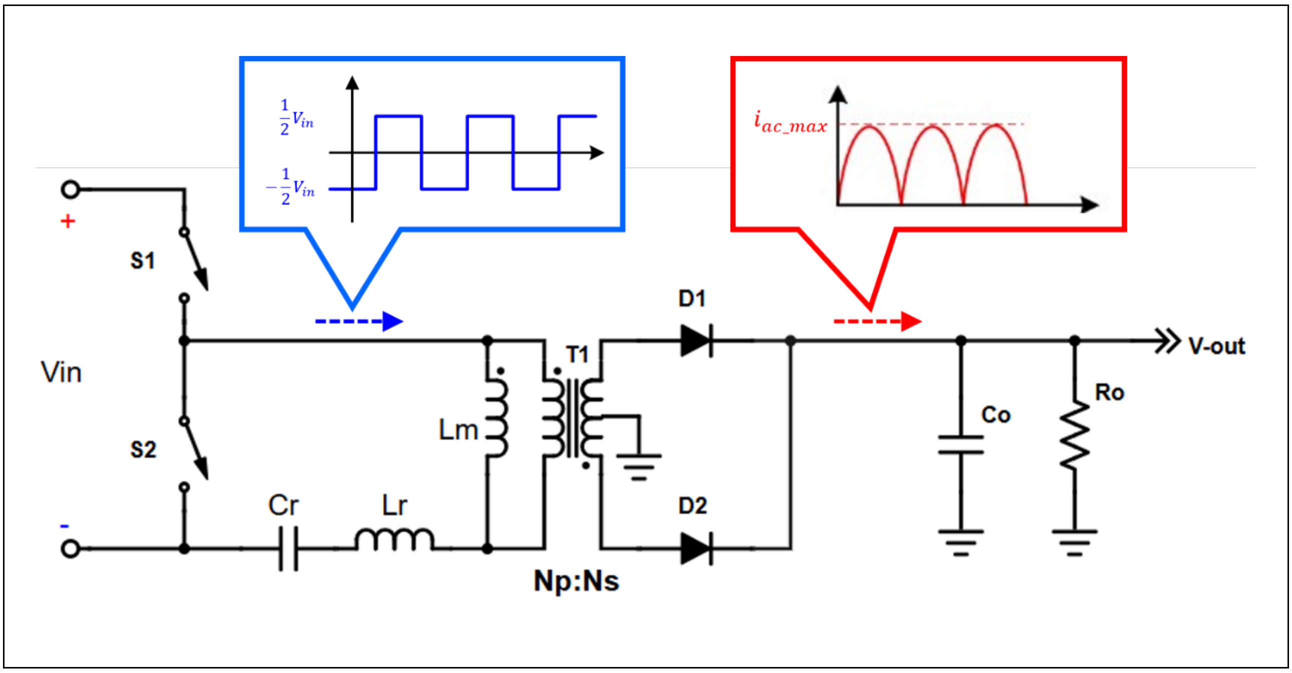


Figure 5.9 Input Voltage and Load Current of the LLC Circuit

5.5.3 Output Voltage Detection Circuit (LLC_x_V_FB)

The secondary-side output voltage is configured using an optocoupler, a TL431, and resistors, as shown in Figure 5.10. The output voltage is determined by the resistor values R1 and R2. The microcontroller receives the feedback signal from the primary side of the optocoupler and performs MOSFET switching control according to the load conditions.

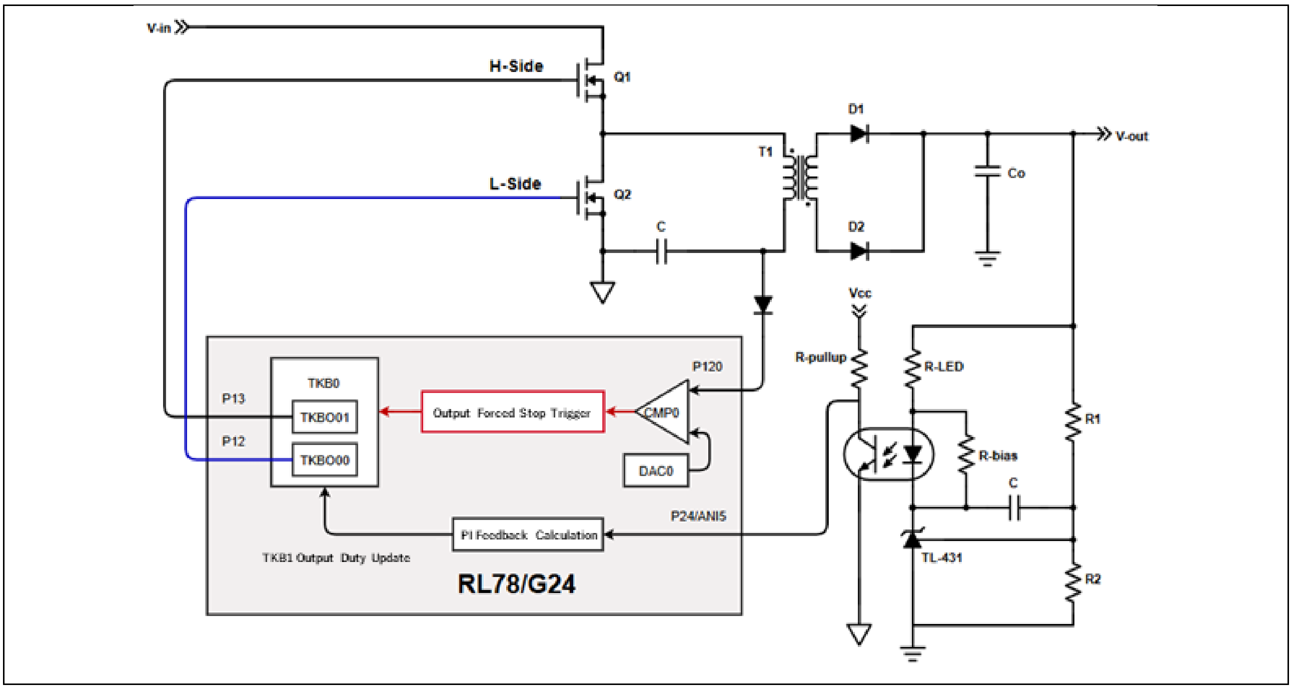


Figure 5.10 LLC1 Output Voltage Detection Circuit

The output voltage is obtained using the following formula:

$$V_{out} = \left(1 + \frac{R1}{R2}\right) \times V_{REF}$$

Because the TL431 requires a reference input current I_{ref} of approximately 2 µA to 4 µA (depending on the device), the value of R1 must be selected appropriately. In addition, the cathode pin must be supplied with a current greater than 1 mA (device-dependent). Assuming a forward-voltage drop of 1 V across the optocoupler, the minimum cathode current I_{min} flows. As a result, once the reference voltage V_{REF} is established, stable control operation can be achieved.

When considering the CTR derating of the optocoupler, it is necessary to account for environmental temperature, long-term degradation (approximately 50%), and design margin (approximately 50%). Based on these considerations, the resistor value $R_{LED\text{-}max}$ calculated using the formula below can be set to approximately four times the computed value.

$$R_{bias} \times I_{min} \leq V_F$$

$$\therefore R_{bias} \leq \frac{1V}{1mA}$$

$$R_{LED\text{-}max} \leq \frac{V_{RLED}}{I_{KA}} = \frac{V_{out} - V_F - V_{KA\text{-}min}}{I_F + I_{bias}}$$

5.5.4 Overcurrent Protection (LLC_CS)

When an overload occurs and the components continue operating beyond their rated specifications, hazards such as overheating or ignition may arise. To quickly shut down the circuit in the event of an overload, an overcurrent protection circuit is implemented. Figure 5.11 shows the LLC overcurrent protection circuit. This circuit detects overcurrent by rectifying the AC component flowing through the transformer and converting it into a DC signal.

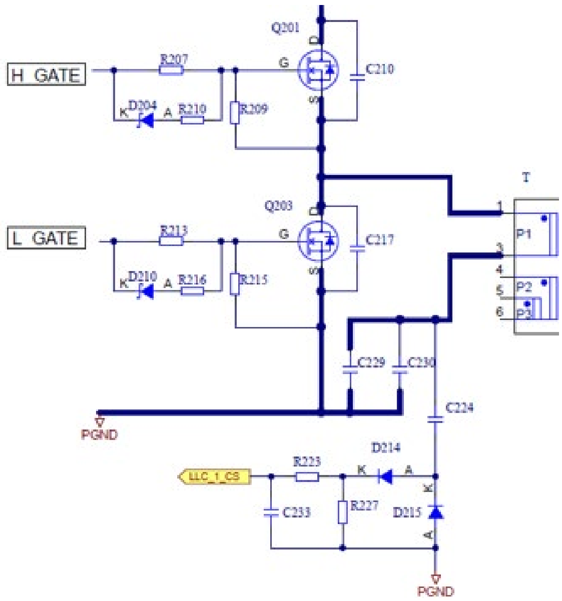


Figure 5.11 LLC Overcurrent Protection Circuit

The LLC_1_CS terminal is applied with a voltage waveform such as the one shown in Figure 5.12. When this waveform exceeds the threshold voltage set in software, the microcontroller stops the LLC output as an overcurrent event, without going through software processing. (The same applies to LLC_2_CS.)

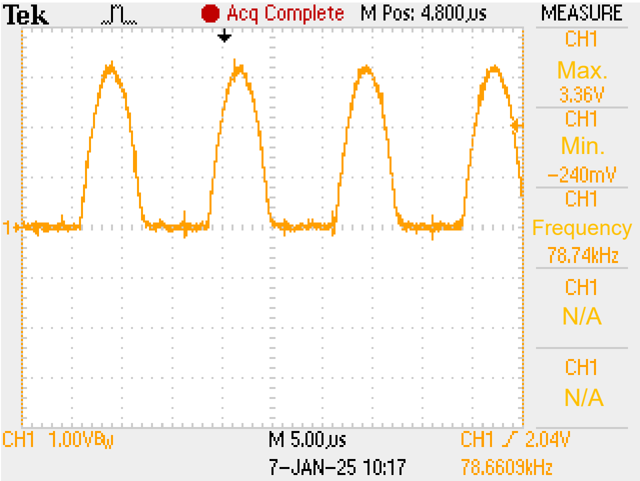


Figure 5.12 LLC_CS Voltage Waveform

The peak voltage of LLC_CS can be obtained using the following formula:

$$\mathrm{LLC\_CS} = \mathrm{R227} \times I_{ac} \times \left(\frac{\mathrm{C224}}{\mathrm{C224} + \mathrm{C229} + \mathrm{C230}} \right)$$

Here, I_{ac} is the current flowing through the primary side of the ideal transformer in the equivalent circuit shown in Section 5.5.1.

5.6 Other I/O

5.6.1 Serial Communication

Serial communication with a PC or another microcontroller can be performed through the CN301 connector.

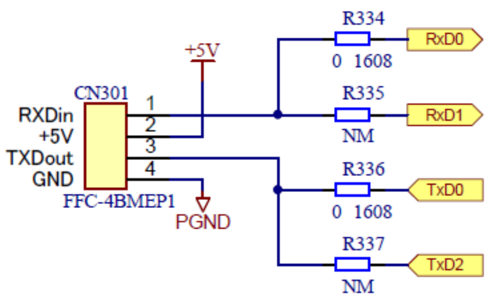


Figure 5.13 Serial Communication

5.6.2 Push Switches

Two push switches are implemented, which can be used for switching the operating mode.

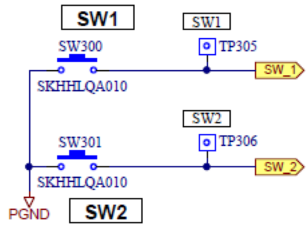


Figure 5.14 Push Switches

5.6.3 IR Reception

This circuit is used for receiving infrared signals. By embedding an infrared-reception program as part of the user code, signals from a remote controller can be received.

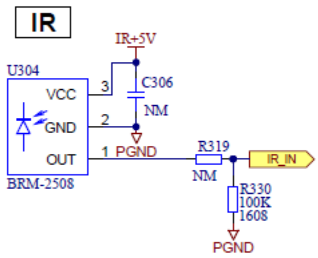


Figure 5.15 IR Reception

6. Safety Precautions

- If this product is used in a manner not specified in this document or in the safety manual, the safety protection provided by the product may be impaired. Always use this product in accordance with the instructions described in this document and the safety manual.
- High voltage is applied to this product during operation. Touching the product while it is operating may result in electric shock. Do not touch the product during operation under any circumstances.
- Do not perform wiring work while the power is on. Doing so may cause electric shock or damage to the circuit. Always perform wiring with the power turned off.
- Before use, be sure to read this manual carefully. Incorrect jumper settings may result in damage to the circuit.

7. Information on Regulations

This product complies with the following directive.

- EMC Directive : EN61326-1:2021

EMI : Class A
EMS : Industrial Electromagnetic Environment
Note: This product is optimized for use in evaluation and development phases. Therefore, conformity assessment and certification in accordance with the EU Low Voltage Directive (LVD: 2014/35/EU) have not been performed.

7.1 Standards for Material Selection, Consumption, Recycling, and Disposal

- EU RoHS
- China SJ/T 113642014, 10-year environmental protection use period.
- WEEE Directive (2012/19/EU) & The Waste Electrical and Electronic Equipment Regulations 2013

The WEEE (Waste Electrical and Electronic Equipment) regulations put responsibilities on producers for the collection and recycling or disposal of electrical and electronic waste. Return of WEEE under these regulations is applicable in the UK and European Union.

This equipment (including all accessories) is not intended for household use. After use the equipment cannot be disposed of as household waste, and the WEEE must be treated, recycled and disposed of in an environmentally sound manner.

Renesas Electronics Europe GmbH can take back end of life equipment. Register for this service at;
https://www.renesas.com/eu/en/support/regional-customer-support/weee

8. Website and Support

You can obtain information on the design and manufacture of this product from renesas.com.
In order to learn about the kit, download tools and documents, or obtain technical support, visit the websites listed below..

• Renesas Support renesas.com/support

9. Reference Documents

RL78/G24 Constant Voltage Control Using PFC+LLC Converter (R01AN8175)
Interleaved CrM PFC and LLC Control Using RL78/G24(CPU Software) (R01AN8177)

Revision History

Rev.	Date	Description	
		Page	Summary
1.00	Mar.19.2026	—	First Edition

RL78/G24
Interleaved PFC + LLC Board 400W
Kit Manual

Renesas Electronics Corporation

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