RL78/G24

Interleaved CrM PFC and LLC Control Using RL78/G24(CPU Software)

Introduction

This application note describes how to control an interleaved CrM PFC and an LLC converter using the features of the RL78/G24 microcontroller.

Target Device

RL78/G24

Board

RL78/G24 Interleaved PFC + LLC Board 400W Kit (RTK0EL0006D00000BJ)

Note: When applying the sample application to other microcontrollers, modify it according to the specifications of that microcontroller and evaluate it thoroughly.

Related Documents

- Interleaved CrM PFC and LLC Control Using RL78/G24(Hardware & Software Basics) (RA01AN8175)
- Interleaved CrM PFC and LLC Control Using RL78/G24(FAA Software) (RA01AN8176)
- RL78/G24 User’s Manual: Hardware (R01UH0961)
- CS+ Integrated Development Environment User’s Manual: Project Operation (R20UT4691)
- e² studio Integrated Development Environment User’s Manual: Quick Start Guide (R20UT5293)
- RL78 Smart Configurator User's Guide: CS+ (R20AN0580)
- RL78 Smart Configurator User's Guide: IAR (R20AN0581)
- RL78 Smart Configurator User's Guide: e2 studio (R20AN0579)

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1. Specification Overview

In this sample application, the interleaved PFC (Power Factor Correction) converter and the LLC converter are controlled using the Timer KB PWM output function of the RL78/G24 microcontroller. The constant-voltage control of each converter is implemented through a feedback process based on PI (Proportional-Integral) control. As a result, no dedicated external control IC is required, enabling a reduction in overall design cost.

This application note, as the CPU Software Edition, mainly covers the following topics:

- Operating conditions of the sample program
- Software structure and control overview
- Usage with each development environment (CS+, e2 studio, and IAR)
- Specifications of the provided APIs

For detailed information on the target board, hardware configuration, and the software control overview of the sample program, refer to the following document.

Interleaved CrM PFC and LLC Control Using RL78/G24 (Hardware & Basic Software) (R01AN8175)

2. Operating Conditions

The sample program has been tested under the following environment.

Table 2.1 Operating conditions

Item		Description
Microcontroller used		RL78/G24 (R7F101GFGxFP)
Board used		RL78/G24 Interleaved PFC + LLC Board 400W Kit (RTK0EL0006D00000BJ)
Operating frequency		High-speed On-chip Oscillator Clock (fHOCO): 8 MHz PLL Clock (fPLL): 96 MHz CPU / Peripheral Hardware Clock (fCLK): 48 MHz
Operating voltage		AC 100V, 230V
CS+ for CC	Integrated Development Environment (IDE)	Renesas Electronics CS+ for CC V8.14.00
	Compiler	CC-RL V1.15.01
IAR	Integrated Development Environment (IDE)	IAR Systems IAR Embedded Workbench for Renesas RL78 V5.10.3
	Compiler	IAR C/C++ Compiler for Renesas RL78 V5.10.3.2716
e2 studio	Integrated Development Environment (IDE)	Renesas Electronics e2 studio 2025-10
	Compiler	CC-RL V1.15.01
Smart Configurator (SC)		V1.15.0 [Components Used] Board Support Packages V1.91 A/D Converter V1.8.0 D/A Converter V1.5.0 PWM Output V1.10.1 UART Communication V1.10.0 Interval Timer V1.8.0 Comparator V1.5.1 Port V1.8.0 High/Low Pulse Width Measurement V1.7.0 Interrupt Controller V1.7.0 Watchdog Timer V1.7.0 Voltage Detector V1.6.1

3. Hardware Specifications

For detailed information on the target board and hardware, refer to Chapter 2 of the following document:

Interleaved CrM PFC and LLC Control Using RL78/G24 (Hardware & Basic Software) (R01AN8175)

4. Software Specifications

4.1 Environment Setup

This sample program provides projects that operate with two compilers: the CC-RL version and the IAR version. The environment setup procedures for each compiler are described below.

4.1.1 CC-RL Version (CS+ for CC)

This section describes the environment setup procedure for the CC-RL version (CS+ for CC).

4.1.1.1 Downloading and Installing CS+ for CC

To run the sample application, the CS+ for CC integrated development environment is required.

Please download and install it from the Renesas Electronics website.

4.1.1.2 Launching the Sample Application

1. Extract the provided project files and place them in any desired folder.
2. Double-click **TvPower_CPU.mtpj** in the extracted project folder.

4.1.1.3 Building the Sample Application

1. From the CS+ for CC menu bar, click [Build] → [Build Project].
2. The build process will start, and its progress will be shown in “All Messages”. When the message “Build Finished” appears, the build is complete.

4.1.1.4 Debugging the Sample Application

1. Connect the E2 Lite to the E2 Lite connector on the debug board mounted on the target board.
2. Open JP400 on the debug board.
3. Configure the system to supply 3.3V power from the E2 Lite to the debug board.
4. Apply the AC input voltage between CN1 and CN2 on the target board.
5. From the CS+ for CC menu bar, click [Debug] → [Download to Debug Tool].
6. Download the program to the microcontroller.
7. Click [Debug] → [Go] to start debugging the sample application.

Note:
When using breakpoints, for safety reasons, please set “Debug Configuration” → “Debug Tool Settings” → “Stop timer group emulation while stopped” to “Yes”, so that the timer outputs are stopped (Hi-z) while execution is halted at a breakpoint.

In addition, if the program stops at a breakpoint, do not resume execution from that point.
Please reset the CPU and restart the program from the beginning.

4.1.2 CC-RL Version (e2 studio)

This section describes the environment setup procedure for the CC-RL version (e2 studio).

4.1.2.1 Downloading and Installing e2 studio

To run the sample application, the e2 studio integrated development environment is required.
Please download and install it from the Renesas Electronics website.

4.1.2.2 Importing the Sample Application

1. Extract the provided project files and place them in any desired folder.
2. Launch e2 studio.
3. From the e2 studio menu bar, select [File] → [Import].
4. Select Existing Projects into Workspace, then click Next.
5. Select “Browse” under Root Directory Selection, then choose the project root directory placed in step 1.
6. Check TvPower_CPU in the project list, then click Finish.

4.1.2.3 Building the Sample Application

1. In the Project Explorer, right-click the imported sample project and select “Build Project”.
2. The build process will start, and its progress will be shown in the Console view. When the message “Build Finished.” appears, the build is complete.

4.1.2.4 Debugging the Sample Application

1. Connect the E2 Lite to the E2 Lite connector on the debug board mounted on the target board.
2. Open JP400 on the debug board.
3. Configure the system to supply 3.3V power from the E2 Lite to the debug board.
4. Apply the AC input voltage between CN1 and CN2 on the target board.
5. Click the  button in e2 studio.
6. The program will be downloaded to the microcontroller, and debugging will begin.

Note:
For safety, when breakpoints are used, enable “A (Timer)” under “Peripheral Break” in the debugger “Hardware Settings” to ensure that timer outputs enter the Hi-Z state during break.

If the program stops at a breakpoint, do not continue execution from that point. Reset the CPU and execute the program from the beginning.

4.1.3 IAR Version

This section describes the environment setup procedure for the IAR version.

4.1.3.1 Downloading and Installing IAR Embedded Workbench

To run the sample application, the IAR Embedded Workbench for Renesas RL78 integrated development environment is required.
Please download and install it from the IAR Systems website.

4.1.3.2 Launching the Sample Application

1. Launch IAR Embedded Workbench for Renesas RL78.
2. From the “File” menu, select “New Workspace”.
3. From the “File” menu, select “Save Workspace As”, and save the workspace with any desired name and in any desired folder.
4. Extract the provided project files and place them in the workspace folder created in step 3.
5. From the “Project” menu, select “Add Existing Project”, and choose the project file (EWP file) placed in step 3.
6. From the “File” menu, click “Exit”.

4.1.3.3 Building the Sample Application

1. In the workspace, right-click the project and select “Make”.
2. The build process will start, and its progress will be shown in the Console window. When the message “Total number of errors: 0” appears, the build is complete.

4.1.3.4 Debugging the Sample Application

1. Connect the E2 Lite to the E2 Lite connector on the debug board mounted on the target board.
2. Open JP400 on the debug board.
3. Configure the system to supply 3.3V power from the E2 Lite to the debug board.
4. Apply the AC input voltage between CN1 and CN2 on the target board.
5. Click the  button in IAR Embedded Workbench for Renesas RL78.
6. The program will be downloaded to the microcontroller, and debugging will begin.

Note:
When using breakpoints, pay close attention to timer operation, and reset the CPU as necessary.

4.2 Software Control

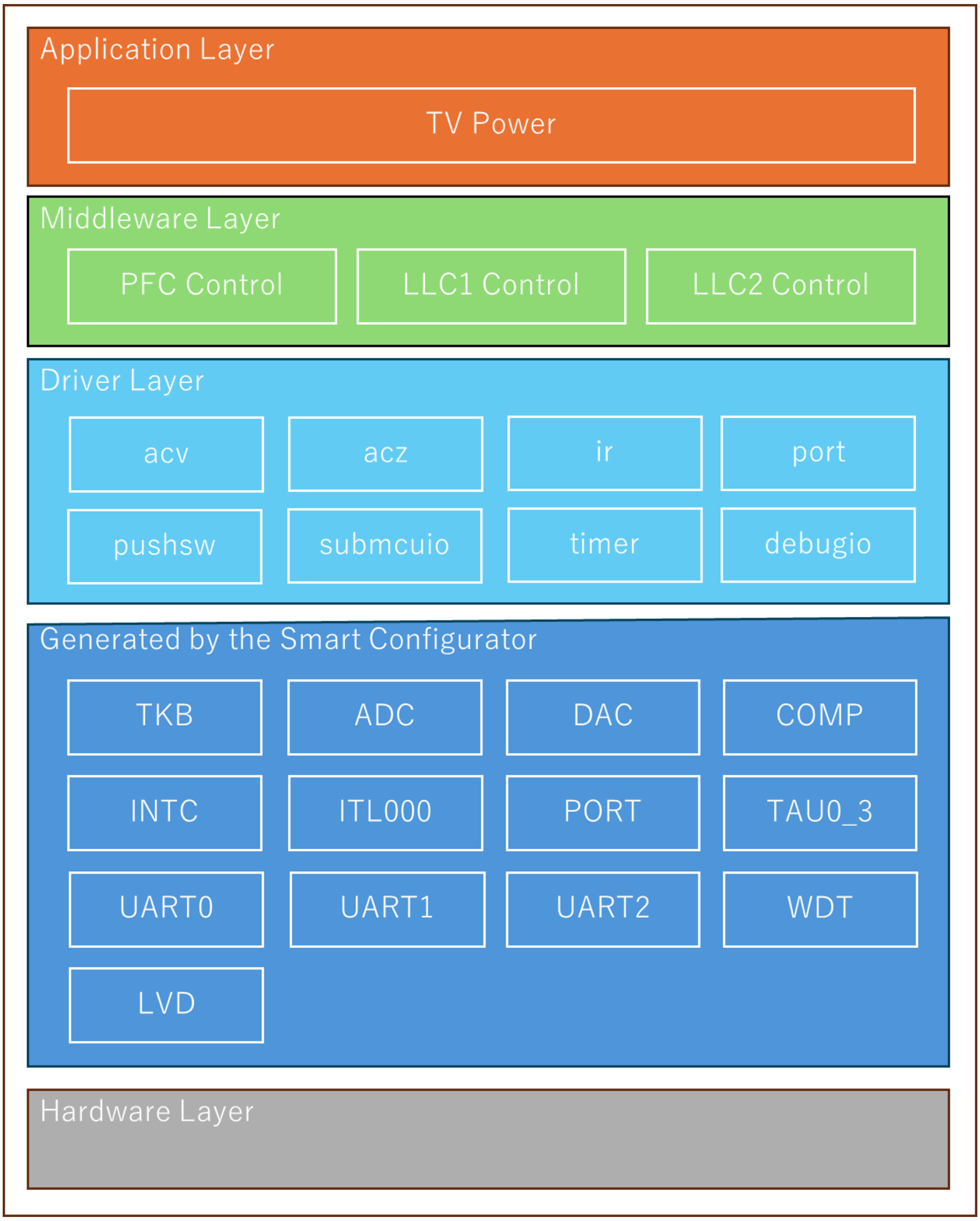
For an overview of the software control implemented in the sample program, refer to Chapter 3 of the following document:

Interleaved CrM PFC and LLC Control with RL78/G24 (Hardware & Software Basics) (R01AN8175)

4.3 Software Configuration

This section describes the software configuration of the sample program.

Figure 4.1 Software Configuration Diagram



4.3.1 Folder Structure

This section describes the folder structure of the sample program.

Table 4.1 Folder Structure

Folder / File Name	Description
TvPower_CPU	Folder containing the sample program
main.c	Main source file
QE Config	Folder for QE for Lighting & Power
r_powerConfig.h	Configuration header file for QE for Lighting & Power
Src	Folder containing source code
r_common.h	Common definitions header file
application	Folder containing application program
r_tvpower.c	Source file for the TV power application
r_tvpower.h	Header file for the TV power application
middleware	Folder containing middleware programs
r_pfc.c	Source file for PFC control middleware
r_pfc.h	Header file for PFC control middleware
r_llc1.c	Source file for LLC1 control middleware
r_llc1.h	Header file for LLC1 control middleware
r_llc2.c	Source file for LLC2 control middleware
r_llc2.h	Header file for LLC2 control middleware
driver	Folder containing driver programs
r_acv.c	Source file for AC voltage detection driver
r_acv.h	Header file for AC voltage detection driver
r_acz.c	Source file for AC zero-cross detection driver
r_acz.h	Header file for AC zero-cross detection driver
r_adc.c	Source file for A/D converter driver
r_adc.h	Header file for A/D converter driver
r_clock.c	Source file for operating clock configuration driver
r_clock.h	Header file for operating clock configuration driver
r_debugio.c	Source file for debug I/O driver
r_debugio.h	Header file for debug I/O driver
r_ir.c	Source file for IR driver
r_ir.h	Header file for IR driver
r_port.c	Source file for port driver
r_port.h	Header file for port driver
r_pushsw.c	Source file for push-switch driver
r_pushsw.h	Header file for push-switch driver
r_submcuio.c	Source file for Sub-MCU I/O driver
r_submcuio.h	Header file for Sub-MCU I/O driver
r_timer.c	Source file for timer driver
r_timer.h	Header file for timer driver
smc_gen	Folder generated by Smart Configurator (remaining items omitted) * Library code used in this sample is generated under this folder.

4.3.2 Option Byte Settings

Table 4.2 shows the option byte settings.

Table 4.2 Option Byte Settings

Address	Setting Value	Description
000C0H/040C0H	1111 0010 (F2H)	Watchdog timer operation permitted ・ Overflow time: 2^8/fIL (7.8125 ms) ・ After reset is released, counting starts ・ Counter operation stopped in the HALT or STOP mode
000C1H/040C1H	0011 1010 (3AH)	LVD reset mode (falling: 2.91 V, rising: 2.97 V)
000C2H/040C2H	1110 1010 (EAH)	Flash operation mode: High-speed main mode High-speed on-chip oscillator frequency: 8 MHz
000C3H/040C3H	1000 0100 (84H)	On-chip debug operation enabled

4.3.3 API Functions

This section describes the API functions used in the application layer and middleware layer of the sample program.

4.3.3.1 r_tvpower.c

This table lists the API functions defined in r_tvpower.c in the application layer.

Table 4.3 Application API Functions

Function Name	Description
R_TVPOWER_Init	Initializes the power-control application operation.
R_TVPOWER_Task	Executes the task processing for the power-control application.

4.3.3.2 r_pfc.c

This table lists the API functions defined in r_pfc.c in the middleware layer.

Table 4.4 PFC Control API Functions

Function Name	Description
R_PFC_Init	Initializes the PFC control function.
R_PFC_StartBoost	Starts the PFC boost-mode control.
R_PFC_StartBurst	Starts the PFC burst-mode control.
R_PFC_StartNormalSingle	Starts normal PFC control (single-output operation).
R_PFC_SwitchToInterleaved	Switches the PFC output to interleaved mode.
R_PFC_SwitchToSingle	Switches the PFC output to single mode.
R_PFC_Stop	Stops the PFC control.
R_PFC_TickMs	Notifies the tick timing for PFC control.
R_PFC_GetStatus	Retrieves the PFC control status.
R_PFC_Tick50us	Executes processing performed every 50 us.
R_PFC_FeedbackCycleProcess	Executes the PFC feedback-cycle processing.
R_PFC_GetMaxFreqLimit	Retrieves the maximum frequency-limit setting for PFC control.
R_PFC_UpdateMaxFreqLimit	Updates the maximum frequency-limit setting for PFC control.
R_PFC_GetLoadPower100V	Estimates and retrieves the load power (AC 100 V).
R_PFC_GetLoadPower200V	Estimates and retrieves the load power (AC 200 V).
R_PFC_DetectOcpCallback	Callback function invoked during an OCP event. This function must be called when OCP occurs.
R_PFC_SetKp	Sets the proportional gain (Kp) for the feedback processing.
R_PFC_SetFz	Sets the zero-point frequency (fz) for the feedback processing.
R_PFC_GetOnWidthCount	Retrieves the on-width setting value for the PFC master side.

4.3.3.3 r_llc1.c

This table lists the API functions defined in r_llc1.c in the middleware layer.

Table 4.5 LLC1 Control API Functions

Function Name	Description
R_LLC1_Init	Initializes the LLC1 control function.
R_LLC1_StartBurst	Starts the LLC1 burst-mode control.
R_LLC1_StartNormal	Starts the LLC1 normal-mode control.
R_LLC1_Stop	Stops the LLC1 control.
R_LLC1_TickMs	Executes processing performed at the tick timing for LLC1 control.
R_LLC1_GetStatus	Retrieves the LLC1 control status.
R_LLC1_Tick50us	Executes processing performed every 50 us for LLC1 control.
R_LLC1_FeedbackCycleProcess	Executes the LLC1 feedback-cycle processing.
R_LLC1_DetectOcpCallback	Callback function invoked during an OCP event. This function must be called when OCP occurs.

4.3.3.4 r_llc2.c

This table lists the API functions defined in r_llc2.c in the middleware layer.

Table 4.6 LLC2 Control API Functions

Function Name	Description
R_LLC2_Init	Initializes the LLC2 control function.
R_LLC2_StartBurst	Starts the LLC2 burst-mode control.
R_LLC2_StartNormal	Starts the LLC2 normal-mode control.
R_LLC2_Stop	Stops the LLC2 control.
R_LLC2_TickMs	Executes processing performed at the tick timing for LLC2 control.
R_LLC2_GetStatus	Retrieves the LLC2 control status.
R_LLC2_Tick50us	Executes processing performed every 50 us for LLC2 control.
R_LLC2_FeedbackCycleProcess	Executes the LLC2 feedback-cycle processing.
R_LLC2_DetectOcpCallback	Callback function invoked during an OCP event. This function must be called when OCP occurs.

5. Operation Using QE for Lighting & Power

QE for Lighting & Power (version 2.0.0 or later) enables an integrated workflow that covers power-control parameter configuration, simulation, evaluation, and code generation.

This chapter describes the sequence of operations for verifying and evaluating the power-control functions of the target board using QE for Lighting & Power.

5.1 Downloading QE for Lighting & Power

Download and install QE for Lighting & Power from the Renesas Electronics website.

5.2 Prepare a Workspace

Configure the workspace, which specifies the target board and the folder where the application program will be stored.

5.2.1 Select a Board

1. Open “2.Prepare a Workspace” and select “Renesas Board.”
2. From Target Project Selection, select:
   [R01AN8175EJ0100] Interleaved CrM PFC and LLC Control with RL78/G24 (Hardware & Software Basics).

5.2.2 Select a Workspace

From “Select a Workspace”, select any folder that will be used to store the application program.

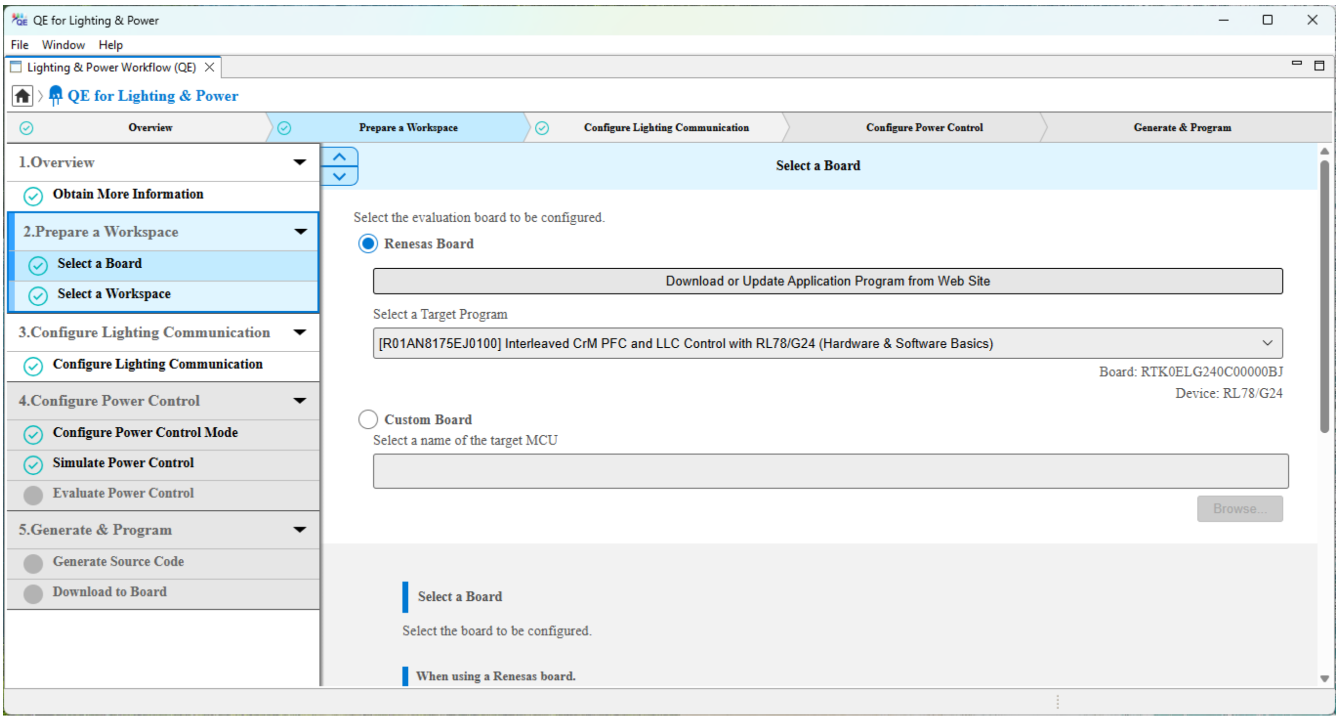


Figure 5.1 Prepare a Workspace

5.3 Configure Lighting Communication

The target project does not support lighting communication; therefore, “3.Configure Lighting Communication” cannot be used.

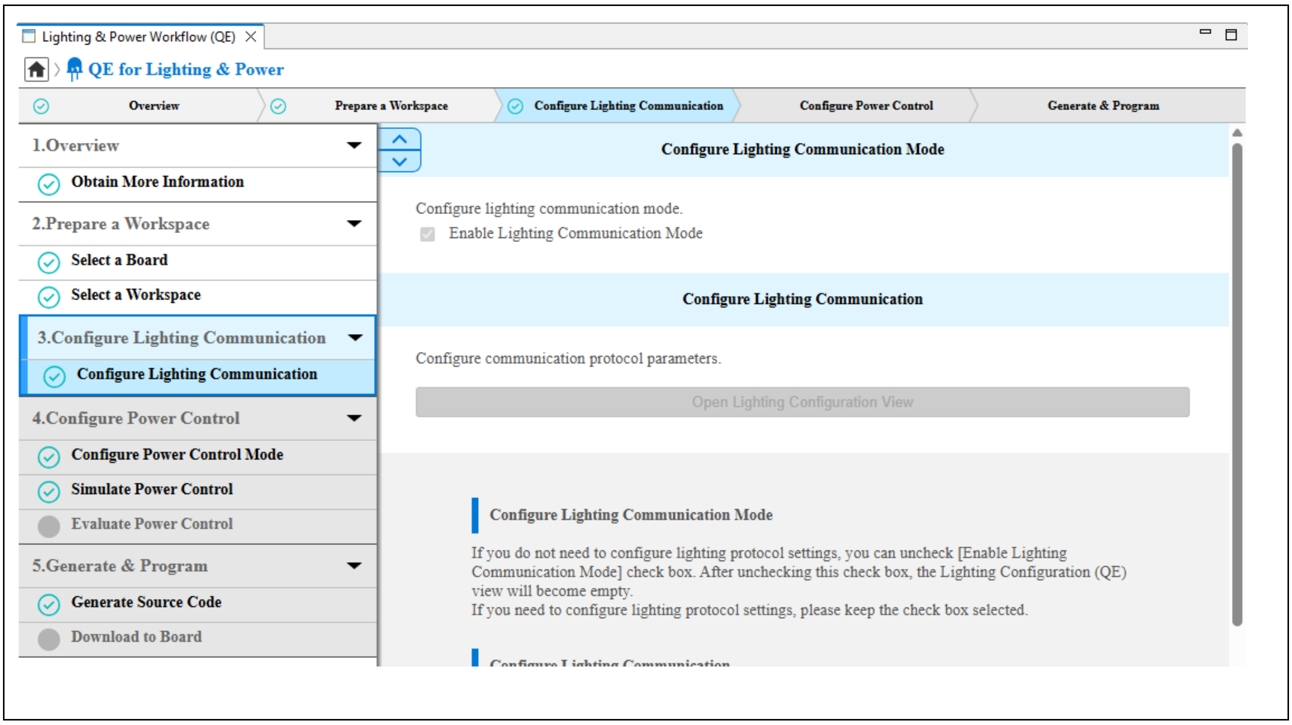


Figure 5.2 Configure Lighting Communication

5.4 Configure Power Control

In “4. Configure Power Control” you can modify circuit characteristics and power-control parameters using the Power Configuration view

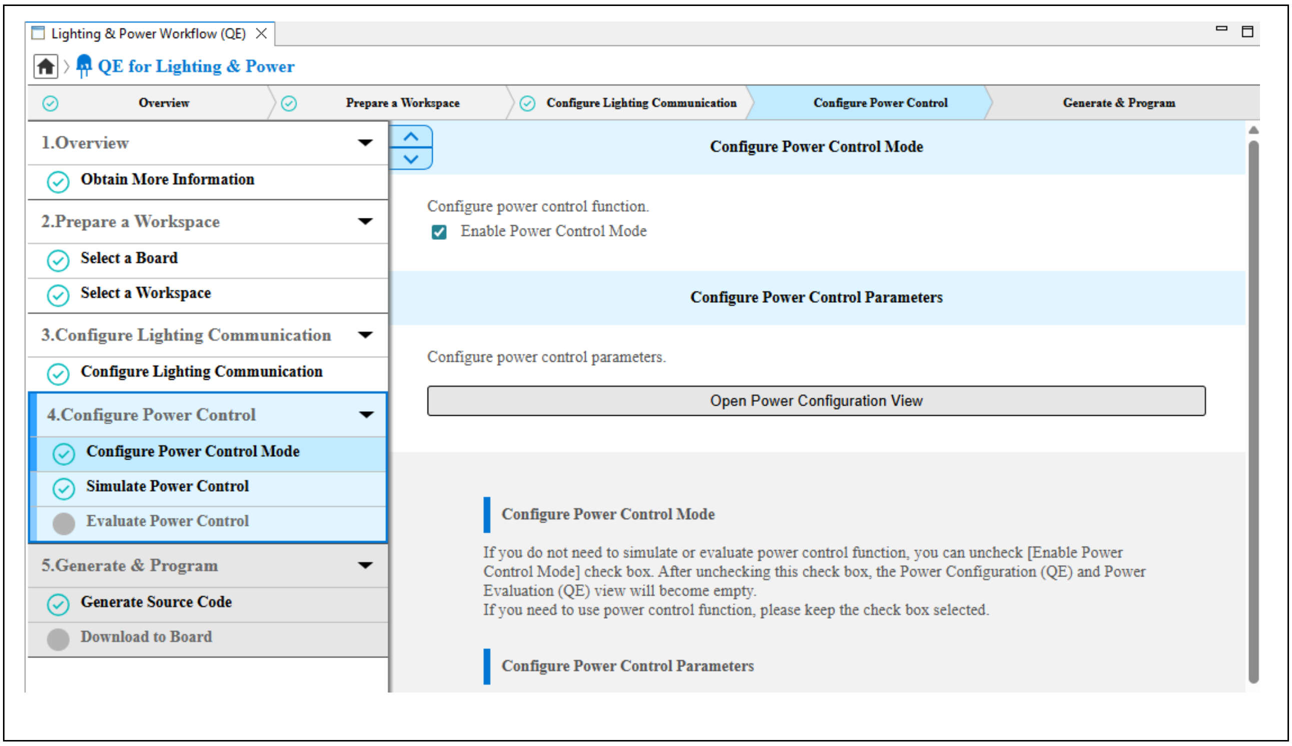


Figure 5.3 Configure Power Control

5.4.1 Configure Power Control Mode

Enabling “Configure Power Control Mode” allows you to use the power-control functions, including parameter configuration, simulation, and code generation.

5.4.1.1 Power Configuration View

By clicking the “Open Power Configuration View” button, you can view the circuit diagram and modify circuit characteristics and power-control parameters. The Power Configuration View consists of the target board’s circuit diagram (upper area) and the configurable parameters (lower area).

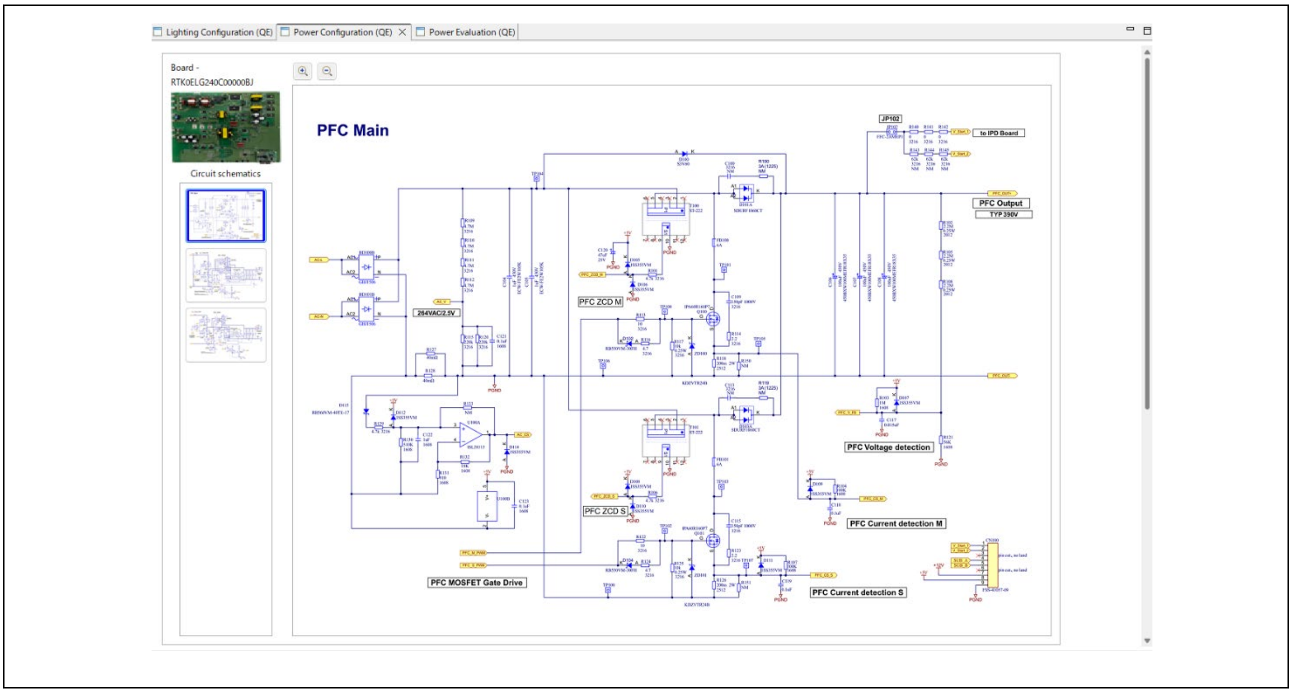


Figure 5.4 Power Configuration (Circuit Diagram of the Target Board)

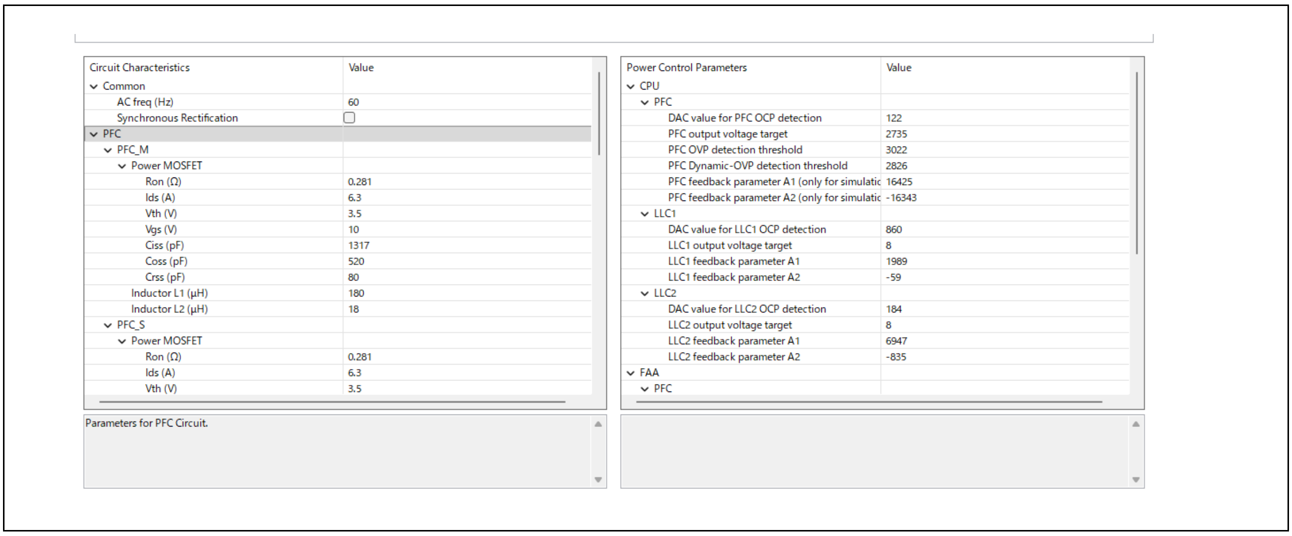


Figure 5.5 Power Configuration (Configurable Parameters)

The configurable parameters consist of “Circuit Characteristics” and “Power Control Parameters.”

The Circuit Characteristics section allows you to configure the circuit-related parameters. The parameters set here are reflected in the power-control simulator described later.

Table 5.1 Circuit Characteristics (1/3)

Item			Default Value	Description
Common	AC freq (Hz)		60	Frequency of the AC input voltage.
	Synchronous Rectification		Unchecked	Switches between synchronous and asynchronous rectification for the LLC stage. When checked, synchronous rectification is enabled.
PFC_M	Power MOSFET	Ron (Ω)	0.281	MOSFET Ron of the PFC master side [Ω]
		Ids (A)	6.3	MOSFET Ids of the PFC master side [A]
		Vth (V)	3.5	MOSFET Vth of the PFC master side [V]
		Vgs (V)	10	MOSFET Vgs of the PFC master side [V]
		Ciss (pF)	1317	MOSFET Ciss of the PFC master side [pF]
		Coss (pF)	520	MOSFET Coss of the PFC master side [pF]
		Crss (pF)	80	MOSFET Crss of the PFC master side [pF]
	Inductor L1 (μH)		180	Primary-side inductance L1 of the PFC master transformer [μH]
	Inductor L2 (μH)		18	Secondary-side inductance L2 of the PFC master transformer [μH]
PFC_S	Power MOSFET	Ron (Ω)	0.5	MOSFET Ron of the PFC slave side [Ω]
		Ids (A)	6.3	MOSFET Ids of the PFC slave side [A]
		Vth (V)	3.5	MOSFET Vth of the PFC slave side [V]
		Vgs (V)	1317	MOSFET Vgs of the PFC slave side [V]
		Ciss (pF)	520	MOSFET Ciss of the PFC slave side [pF]
		Coss (pF)	520	MOSFET Coss of the PFC slave side [pF]
		Crss (pF)	80	MOSFET Crss of the PFC slave side [pF]
	Inductor L1 (μH)		180	Primary-side inductance L1 of the PFC slave transformer [μH]
	Inductor L2 (μH)		18	Secondary-side inductance L2 of the PFC slave transformer [μH]

Table 5.2 Circuit Characteristics (2/3)

Item			Default Value	Description
LLC1	Power MOSFET High Side	Ron (Ω)	0.237	LLC1 high side MOSFET Ron [Ω]
		Ids (A)	3.6	LLC1 high side MOSFET Ids [A]
		Vth (V)	4	LLC1 high side MOSFET Vth [V]
		Vgs (V)	10	LLC1 high side MOSFET Vgs [V]
		Ciss (pF)	807	LLC1 high side MOSFET Ciss [pF]
		Coss (pF)	249	LLC1 high side MOSFET Coss [pF]
		Crss (pF)	80	LLC1 high side MOSFET Crss [pF]
	Power MOSFET Low Side	Ron (Ω)	0.237	LLC1 low side MOSFET Ron [Ω]
		Ids (A)	3.6	LLC1 low side MOSFET Ids [A]
		Vth (V)	4	LLC1 low side MOSFET Vth [V]
		Vgs (V)	10	LLC1 low side MOSFET Vgs [V]
		Ciss (pF)	807	LLC1 low side MOSFET Ciss [pF]
		Coss (pF)	249	LLC1 low side MOSFET Coss [pF]
		Crss (pF)	80	LLC1 low side MOSFET Crss [pF]
	Inductor L1 (μH)		525	Primary-side inductance L1 of the LLC1 transformer [μH]
	Inductor L2 (μH)		2.5	Secondary-side inductance L2 of the LLC1 transformer [μH]
	Inductor L3 (μH)		2.5	LLC1 L3 [μH]
	Inductor LR (μH)		75	Load inductance LR of LLC1 [μH]
	Capacitor CR (μF)		0.044	Resonant capacitor CR of LLC1 [μF]

Table 5.3 Circuit Characteristics (3/3)

Item			Default Value	Description
LLC2	Power MOSFET High Side	Ron (Ω)	0.237	LLC2 high side MOSFET Ron [Ω]
		Ids (A)	3.6	LLC2 high side MOSFET Ids [A]
		Vth (V)	4	LLC2 high side MOSFET Vth [V]
		Vgs (V)	10	LLC2 high side MOSFET Vgs [V]
		Ciss (pF)	807	LLC2 high side MOSFET Ciss [pF]
		Coss (pF)	249	LLC2 high side MOSFET Coss [pF]
		Crss (pF)	80	LLC2 high side MOSFET Crss [pF]
	Power MOSFET Low Side	Ron (Ω)	0.237	LLC2 low side MOSFET Ron [Ω]
		Ids (A)	3.6	LLC2 low side MOSFET Ids [A]
		Vth (V)	4	LLC2 low side MOSFET Vth [V]
		Vgs (V)	10	LLC2 low side MOSFET Vgs [V]
		Ciss (pF)	807	LLC2 low side MOSFET Ciss [pF]
		Coss (pF)	249	LLC2 low side MOSFET Coss [pF]
		Crss (pF)	80	LLC2 low side MOSFET Crss [pF]
	Inductor L1 (μH)		425	Primary-side inductance L1 of the LLC2 transformer [μH]
	Inductor L2 (μH)		28	Secondary-side inductance L2 of the LLC2 transformer [μH]
	Inductor L3 (μH)		28	LLC2 L3 [μH]
	Inductor LR (μH)		75	LLC2 inductor L3 [μH]
	Capacitor CR (μF)		0.044	Resonant capacitor CR of LLC2 [μF]

Power Control Parameters is used to configure parameters related to power control. The parameters configured here are reflected in both the power-control simulator described later and the generated program. This document lists the parameter settings used in the CPU-based evaluation program.

Table 5.4 Power Control Parameter List (1/3)

Item		Default Value	Description
PFC	DAC value for PFC OCP detection	122	DAC value used for PFC OCP detection. Example (VDD = 5 V, peak current = 10 A): DAC output voltage [V] = 10 A × 0.2 Ω × 1.2 (20% margin) = 2.4 V PFC_CS_LIMIT_FOR_DAC = (2.4 V / 5 V) × 256 = 122
	PFC output voltage target	2735	Target A/D value for the PFC_V_FB pin. Based on measured values, the following provisional formula is used: PFC_ADC_TARGET = 6.528 × Voltage + 215.428 Example: Voltage = 386 V PFC_ADC_TARGET = 6.528 × 386 + 215.428 = 2735
	PFC OVP detection threshold	3022	PFC OVP detection threshold (Target pin: PFC_V_FB) Based on measured values, the following provisional formula is used: PFC_ADC_OVP_THRESHOLD = 6.528 × Voltage + 215.428 Example: Voltage = 430 V PFC_ADC_OVP_THRESHOLD = 6.528 × 430 + 215.428 = 3022
	PFC Dynamic-OVP detection threshold	2826	PFC Dynamic-OVP detection threshold (Target pin: PFC_V_FB) Based on measured values, the following provisional formula is used: PFC_ADC_DOVP_THRESHOLD = 6.528 × Voltage + 215.428 Example: Voltage = 400 V PFC_ADC_DOVP_THRESHOLD = 6.528 × 400 + 215.428 = 2826

Table 5.5 Power Control Parameter List (2/3)

Item		Default Value	Description
PFC	PFC feedback parameter A1 (only for simulation)	16425	PI control coefficient A1 $A1 = (\pi \times fz \times T + 1) \times Kp$ To simplify calculation and improve fractional precision, A1 must be multiplied by 65536. Example: fz = 2 Hz, T = 400 µs, Kp = 0.25 PFC_PI_PARAM_A1 = $(\pi \times 2 \times 400 \times 10^{-6} + 1) \times 0.25 \times 65536 = 16425$
	PFC feedback parameter A2 (only for simulation)	-16343	PI control coefficient $A2 = (\pi \times fz \times T - 1) \times Kp$ To simplify calculation and improve fractional precision, A2 must be multiplied by 65536. Example: fz = 2 Hz, T = 400 µs, Kp = 0.25 PFC_PI_PARAM_A2 = $(\pi \times 2 \times 400 \times 10^{-6} - 1) \times 0.25 \times 65536 = -16343$
LLC1	DAC value for LLC1 OCP detection	860	DAC value used for LLC1 OCP detection. Example (VDD = 5 V): DAC output voltage [V] = 3.5 V (peak voltage at rated load) × 1.20 (margin) = 4.2 V LLC1_CS_LIMIT_FOR_DAC = (4.2 V / 5 V) × 1024 = 860
	LLC1 output voltage target	8	During the LLC1 feedback period (200 µs), the A/D value is sampled 16 times, and the sum of the 16 evaluation results becomes LLC1_ADC_TARGET. The valid range of LLC1_ADC_TARGET is 0–16. When the LLC1 output voltage is 13 V, LLC1_ADC_TARGET becomes 8. If the output voltage exceeds 13 V, LLC1_ADC_TARGET increases; if the output voltage decreases, LLC1_ADC_TARGET decreases.
	LLC1 feedback parameter A1	1989	PI control coefficient A1. $A1 = (\pi \times fz \times T + 1) \times Kp$ To simplify calculation and improve fractional precision, A1 must be multiplied by 65536. Example: fz = 1500 Hz, T = 200 µs, Kp = 0.015625 LLC1_PI_PARAM_A1 = $(\pi \times 1500 \times 200 \times 10^{-6} + 1) \times 0.015625 \times 65536 = 1989$

Table 5.6 Power Control Parameter List (3/3)

Macro Name		Default Value	Description
LLC1	LLC1 feedback parameter A2	-59	PI control coefficient A2. A2 = (π × fz × T − 1) × Kp To simplify calculation and improve fractional precision, A2 must be multiplied by 65536. Example: fz = 1500 Hz, T = 200 μs, Kp = 0.015625 LLC1_PI_PARAM_A2 = (π × 1500 × 200 × 10^{-6} - 1) × 0.015625 × 65536 = -59
LLC2	DAC value for LLC2 OCP detection	184	DAC value used for LLC2 OCP detection. Example (VDD = 5 V): DAC output voltage [V] = 3.0 V (peak voltage at rated load) × 1.20 (margin) = 3.6 V LLC2_CS_LIMIT_FOR_DAC = (3.6 V / 5 V) × 256 = 184
	LLC2 output voltage target	8	During the LLC2 feedback period (200 μs), the A/D value is sampled 16 times, and the sum of the 16 evaluation results becomes LLC2_ADC_TARGET. The valid range of LLC2_ADC_TARGET is 0–16. When the LLC2 output voltage is 50 V, LLC2_ADC_TARGET becomes 8. If the output voltage exceeds 50 V, LLC2_ADC_TARGET increases; if the output voltage decreases, LLC2_ADC_TARGET decreases.
	LLC2 feedback parameter A1	6947	PI control coefficient A1. A1 = (π × fz × T + 1) × Kp To simplify calculation and improve fractional precision, A1 must be multiplied by 65536. Example: fz = 1250 Hz, T = 200 μs, Kp = 0.059375 LLC2_PI_PARAM_A1 = (π × 1250 × 200 × 10^{-6} + 1) × 0.059375 × 65536 = 6947
	LLC2 feedback parameter A2	-835	PI control coefficient A2. A2 = (π × fz × T − 1) × Kp To simplify calculation and improve fractional precision, A2 must be multiplied by 65536. Example: fz = 1250 Hz, T = 200 μs, Kp = 0.059375 LLC2_PI_PARAM_A2 = (π × 1250 × 200 × 10^{-6} − 1) × 0.059375 × 65536 = −835

5.4.2 Power Control Simulator

The Power Control Simulator simulates the behavior of the target board in software using the parameters configured in the Power Configuration view.

By using this simulator, you can check the time-domain behavior of voltages, currents, and control responses for the PFC and LLC stages—such as their trends and characteristics—before verifying them on actual hardware.

5.4.2.1 Power Control Simulator Dialog

You can launch the Power Control Simulator by clicking the “Open Power Control Simulation Dialog” button. In the simulator, configure the parameters listed below and then click “Start Simulation” to begin the simulation. During the simulation, the transitions of each parameter value are visualized as graphs.

Table 5.7 List of Configurable Parameters

<table>
<tr><th>Item</th><th>Time [ms]
(Default)</th><th colspan="2">Default Value</th><th>Description</th></tr>
<tr><td>AC Voltage Gain</td><td>0.000</td><td colspan="2">282.000 [V]</td><td>Input voltage.
The configured value is applied after the specified time [ms] has elapsed.</td></tr>
<tr><td>LLC1 Load Resistance</td><td>0.000</td><td colspan="2">100 [Ω]</td><td>LLC1 load resistance.
The configured value is applied after the specified time [ms] has elapsed.</td></tr>
<tr><td>LLC2 Load Resistance</td><td>0.000</td><td colspan="2">100 [Ω]</td><td>LLC2 load resistance.
The configured value is applied after the specified time [ms] has elapsed.</td></tr>
<tr><td rowspan="2">Operating modes</td><td rowspan="2">0.000</td><td>SW1</td><td>SW2</td><td rowspan="2">Operation Mode Switch
Basic Operation:
After the set time [ms] elapses, the configured switch state takes effect.
・ Checked: Switch pressed
・ Unchecked: Switch not pressed
The switch press duration determines short press/long press.
Determination Conditions:
Short press: 1999 ms or less
Long press: 2000 ms or more
Operation:
SW1 Short Press: LLC2 Start/Stop
SW1 Long Press: Maximum Frequency Limit Function ON/OFF
SW2 Short Press: Standby/Normal Mode Switch
SW2 Long Press: Standby/Normal Mode Switch</td></tr>
<tr><td>unchecked</td><td>unchecked</td></tr>
<tr><td>Simulation time [ms]</td><td>-</td><td colspan="2">5</td><td>Simulation duration.</td></tr>
</table>

Table 5.8 Output Waveform List

Item		Description
Common	Input AC Power	AC power [W]
PFC	PFC Output Current	PFC output current [A]
	PFC Output Voltage	PFC output voltage [V]
	PFC M PWM On Duty	PFC master-side PWM duty ratio [%]
	PFC S PWM On Duty	PFC slave-side PWM duty ratio [%]
	PFC PWM Frequency	PFC PWM operating frequency [Hz]
LLC1	LLC1 Output Current	LLC1 output current [A]
	LLC1 Output Voltage	LLC1 output voltage [V]
	LLC1 LC Resonant Current	LLC1 LC resonant current [A]
	LLC1 Secondary Current	LLC1 secondary-side current [A]
	LLC1 PWM Frequency	LLC1 PWM operating frequency [Hz]
LLC2	LLC2 Output Current	LLC2 output current [A]
	LLC2 Output Voltage	LLC2 output voltage [V]
	LLC2 LC Resonant Current	LLC2 LC resonant current [A]
	LLC2 Secondary Current	LLC2 secondary-side current [A]
	LLC2 PWM Frequency	LLC2 PWM operating frequency [Hz]

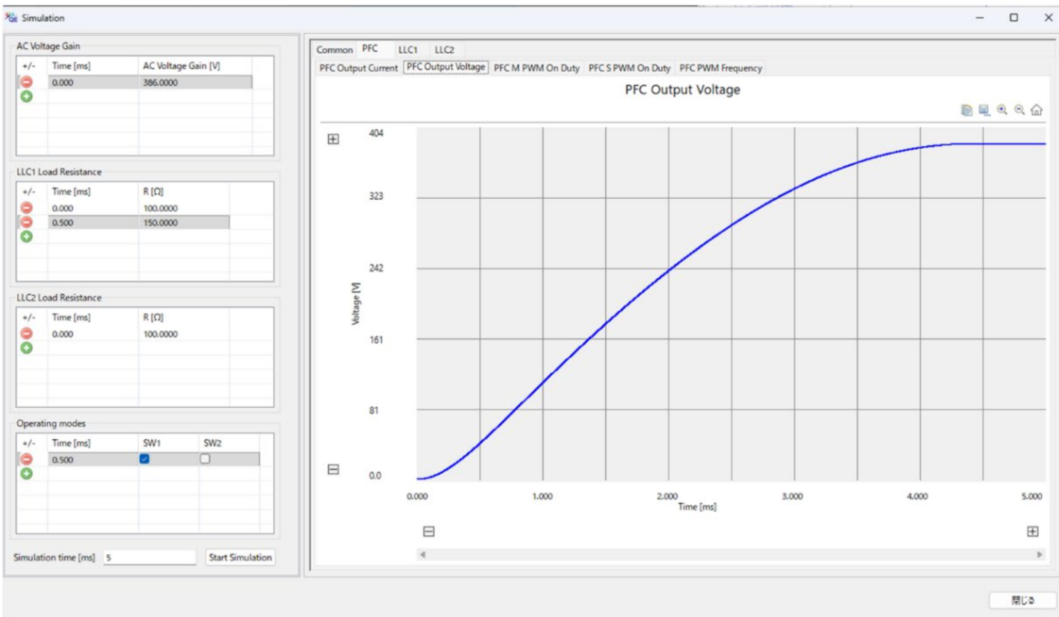


Figure 5.6 Power Control Simulator Dialog

Operation Procedure (Basic Operations)

1. Setting the simulation conditions

   Configure the simulation conditions as needed, such as AC Voltage Gain, load resistance values, and operating-mode switching (SW operation).

   Each parameter can have multiple conditions defined, and the specified value will be dynamically applied during the simulation once the configured time [ms] has elapsed.

2. Setting the simulation time

   Enter the simulation duration in “Simulation time [ms]”.

3. Starting and stopping the simulation

   Click “Start Simulation” to begin the simulation.

   While the simulation is running, the button changes to “Stop Simulation”, which you can click to stop the simulation.

   After stopping, you can click “Start Simulation” again to resume the simulation.

4. Checking Output Waveforms

   During the simulation, you can observe waveform trends of the power-control operation, including time-varying voltages and currents of the PFC and LLC stages, as well as PWM duty ratios.

Operation Procedure (How to Switch to Normal Mode)

To simulate the transition from Standby mode to Normal mode, set “Simulation time [ms]” to 600 ms or longer, configure SW2 in “Operating modes” so that it performs a short-press operation at 600 ms or later, and then start the simulation.

After 600 ms has elapsed from the start of the simulation, the short-press operation of SW2 is applied, and the system switches from Standby mode to Normal mode.

The above procedure is an example based on the default conditions.

Depending on the circuit characteristics and power-control parameters modified in the Power Configuration view, adjust the timing values for “Simulation time [ms]” and “Operating modes” as appropriate.

Estimated Simulation Time

The computation performed on the PC depends on the simulation duration specified in “Simulation time [ms]”.

Although the actual execution time varies depending on the performance of the PC, the following can be used as a general guideline.

Table 5.9 Estimated Simulation Time

Simulation time [ms] (Setting)	Simulation Execution Time	Execution Environment
1000	Approx. 90 minutes	CPU: Intel Core i7-13700 Memory: 32 GB OS: Windows 11

Notes

Setting a large value for “Simulation time” may increase execution time and memory usage, which could lead to errors.

For details, refer to the release notes.

5.4.3 Evaluation of Power Control

You can generate an evaluation program that reflects the parameters configured in the "Power Configuration" view. In addition, by using "Variable Read/Write" and "Variable Monitoring", you can observe various parameter changes on the target board running the evaluation program in real time.

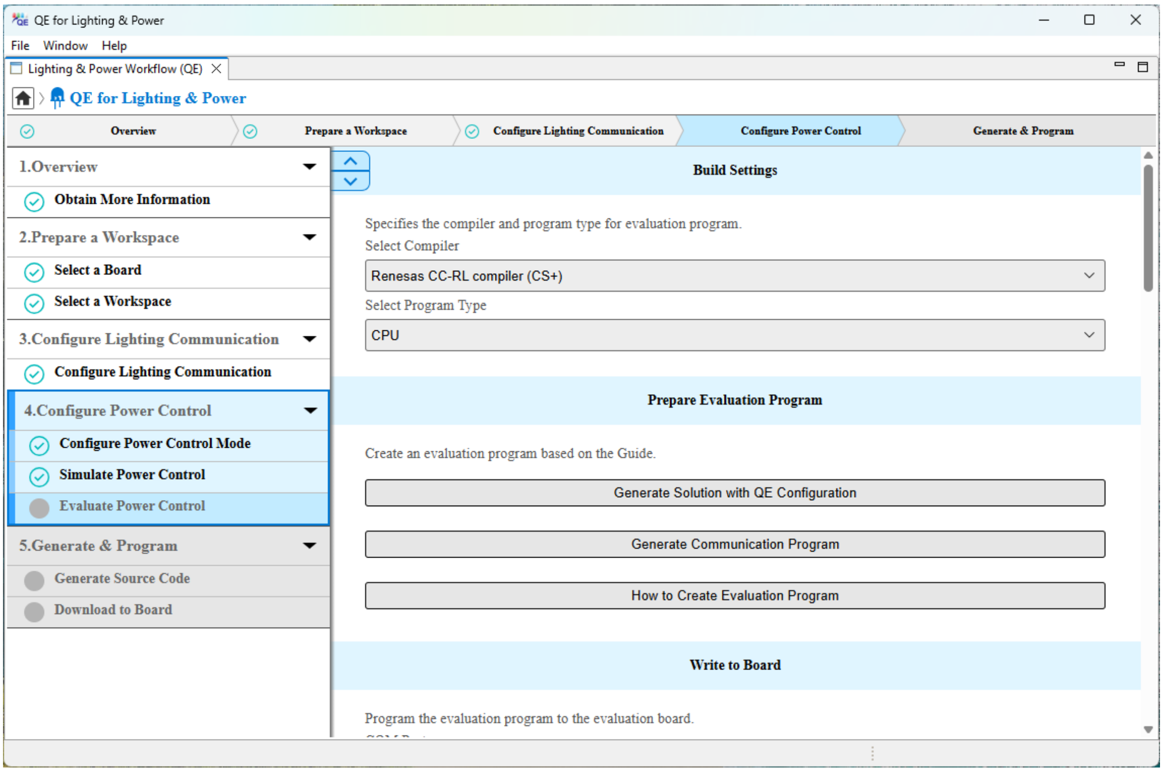


Figure 5.7 Evaluation of Power Control

5.4.3.1 Build Settings

Configure the build settings for the evaluation project so that it reflects the parameters defined in the Power Configuration view.

(1) Selecting the compiler

The generated project supports the following compilers:

- CC-RL Compiler (e² studio)
- CC-RL Compiler (CS+)
- IAR RL78 Compiler

(2) Selecting the program type

You can select the type of core that executes the power-control processing: CPU or FAA.

In this document, the following explanations assume that CPU is selected.

5.4.3.2 Preparing the Evaluation Program

Generate the evaluation program according to the selected compiler and program type.

(1) Generating a project based on the settings

Click “Generate project based on settings” to create the evaluation project.

The project is generated in the following folder:

<workspace>¥qeLighting_gen¥<u>tuning program</u>

(2) Adding the communication program to the project

Click “Add communication program to project” to add the communication modules used for Variable Read/Write and Variable Monitoring.

*After adding the communication program, integrate the generated application program according to the instructions in the help documentation (select “Modify settings and create evaluation program (see Help)”).

5.4.3.3 Downloading to the Board

Write the generated project to the target board.

Connect the E2 Lite to the E2 Lite connector on the debug board mounted on the target board, then click “Write evaluation program to evaluation board”.

5.4.3.4 Board Connection

Use a USB cable to connect the target board to the host PC.

This connection is used for communication during power-control evaluation with Variable Read/Write and Variable Monitoring.

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

1. Set “Bitrate” to 500000.
2. Select the COM port connected to the PC in “COM Port”.
3. Click the “Connect” button.

5.4.3.5 Power Control Evaluation

Evaluate the power-control parameters on the target board in real time.

Two evaluation functions are available.

(1) Variable Read/Write

Variable Read/Write allows you to read and monitor internal variables and register values of the application program in real time.

All internal variables that can be monitored in this application note are read-only, and their values cannot be written or modified.

Click “Open [Variable Read/Write] tab” to open the [Variable Read/Write] tab in the [Power Evaluation (QE)] view.

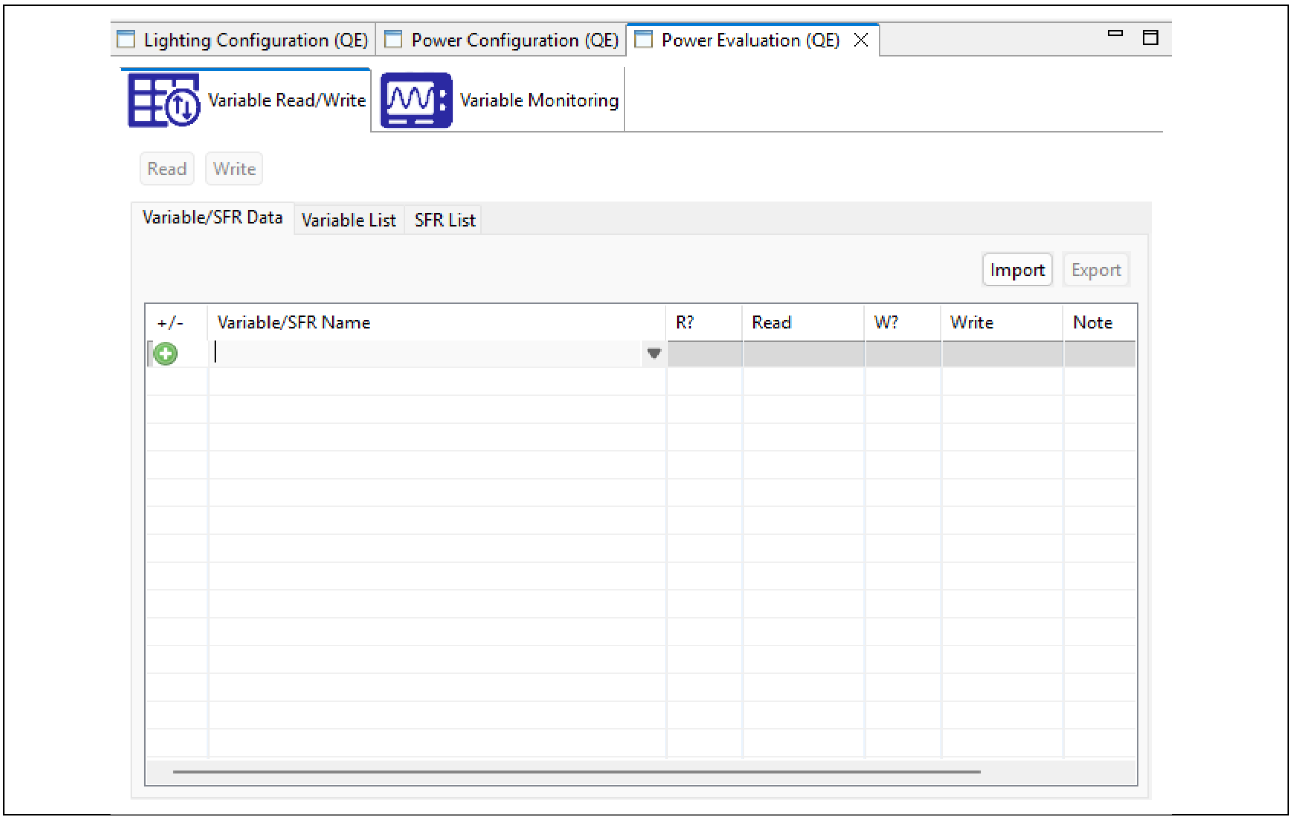


Figure 5.8 Variable Read/Write

Operation Procedure

1. Selecting variables for evaluation

Select the power-control variables to be evaluated from the variable list in the tab.

2. Reading variable values

Click the “Read” button to display the current values of the selected variables.

(2) Variable Monitoring

Variable Monitoring continuously acquires internal variables and registers values of the evaluation program at a fixed interval and displays their time-varying behavior as graphs.

Click “Open [Variable Monitoring] tab” to open the [Variable Monitoring] tab in the [Power Evaluation (QE)] view.

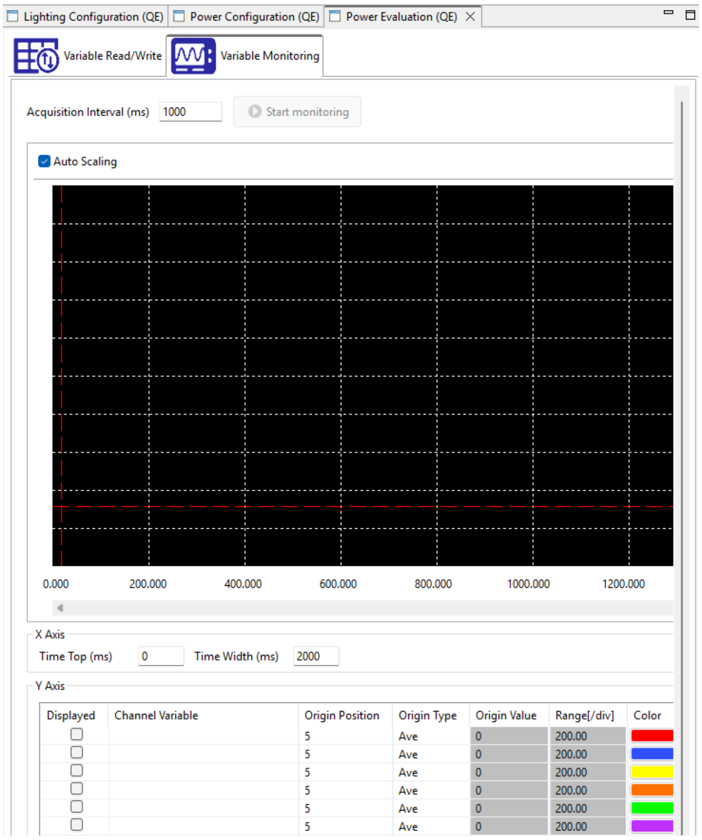


Figure 5.9 Variable Monitoring

Operation Procedure

1. Selecting variables to monitor

Select the variables you want to display as waveforms from the channel drop-down list in the tab.

Multiple variables can be selected simultaneously.

2. Setting acquisition conditions

Configure the monitoring time and the display range of the output waveforms.

3. Starting monitoring

Click “Start Monitoring” to begin acquiring variable values and displaying the waveforms.

5.5 Code Generation and Programming

You can generate a project that reflects the parameters configured during power-control evaluation and write it to the target board.

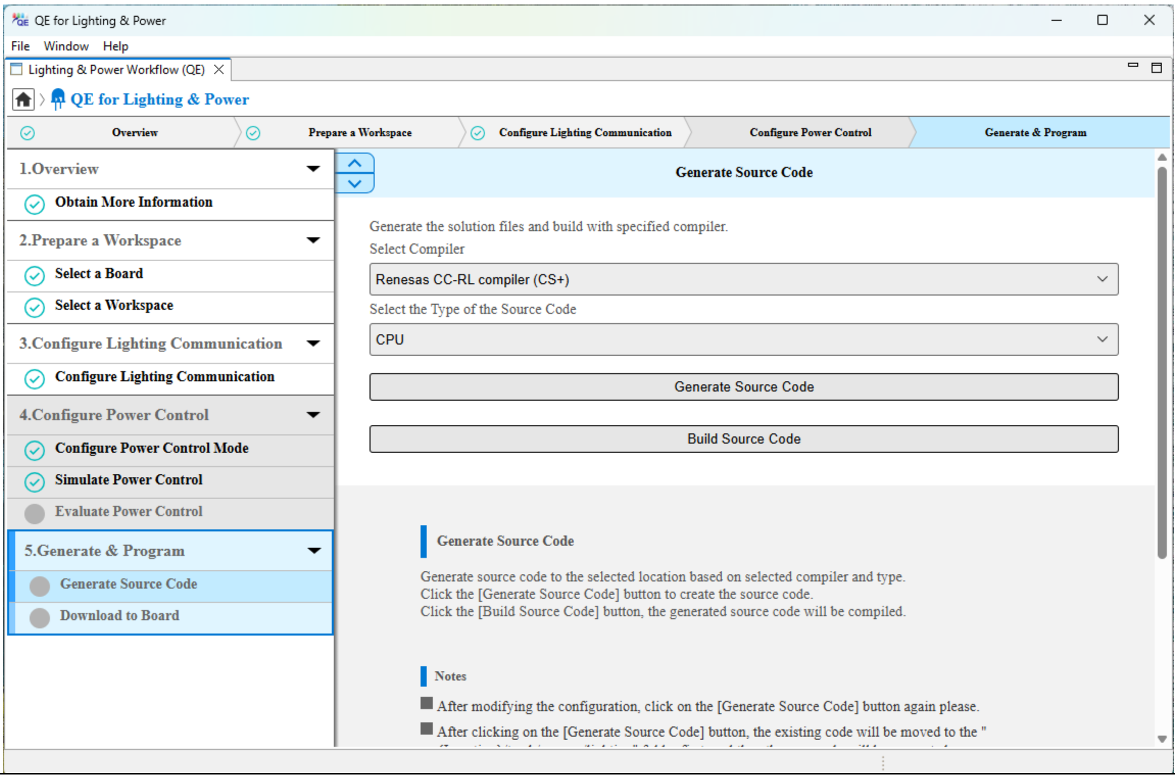


Figure 5.10 Code Generation and Programming

5.5.1 Generating Source Code

Click “Generate Source Code” to create the project.

The project is generated in the following folder:

“<workspace>¥qeLighting_gen¥solution”

5.5.2 Downloading to the Board

Click “Download to Board” to write the project to the target board via the E2 Lite.

5.6 Notes on PFC Control Parameters A1 and A2

The coefficients A1 and A2 used in PFC PI control are internally calculated within the evaluation program based on parameters such as the zero-point frequency (fZ) and proportional gain (Kp). Therefore, the A1 and A2 values computed or configured in the Power Configuration view or the simulator are not applied to the generated application program.

To modify these parameters, you must directly change the values of the zero-point frequency (fZ) and proportional gain (Kp) defined in the application program.

5.6.1 Calculation Method for Kp and fZ

You can calculate the zero-point frequency (fZ) and proportional gain (Kp) from the A1 and A2 values computed or configured in the Power Configuration view or the simulator, using the formulas shown below.

Note that the A1 and A2 values are multiplied by 65536 in the application program. Therefore, when performing the calculation, divide the A1 and A2 values by 65536 before substituting them into the formulas.

In addition, the PFC feedback period T used in the target program is fixed at 400 μs.

$$Kp = \frac{A1 - A2}{2}$$

$$fz = \frac{A1 + A2}{\pi T(A1 - A2)}$$

5.6.2 Applying Kp and fZ

The zero-point frequency (fZ) and proportional gain (Kp) obtained from the calculation formulas can be modified by directly editing the macro values in the application program. Specify each value as an integer.

Table 5.10 Program Locations for Updating fZ and Kp

Target File	Macro Name	Default Value	Notes
r_pfc.c	PFC_DEFAULT_FZ	2	Unit: Hz
	PFC_DEFAULT_KP_EXT12	1024	Set the value multiplied by 4096, as required by the application program. **Example:** If Kp = 0.25 0.25 * 4096 = 1024

6. Notes

The sample program operations provided in this document are just examples. The application layer must be modified and evaluated according to the intended use.

7. Reference Documents

RL78/G24 User's Manual: Hardware (R01UH0961)

RL78 Family User's Manual: Software (R01US0015)

(Obtain the latest version of the manual from the website of Renesas Electronics.)

Technical Update/Technical News

(Obtain the latest information from the website of Renesas Electronics.)

Revision History

Rev.	Date	Description	
		Page	Summary
1.00	2026.03.19	—	First edition

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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(Rev.5.0-1 October 2020)

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