RL78/G24

LED control with RL78/G24

Introduction

This application note describes how to control an LED lighting system using the features of the RL78/G24 microcontroller.

Target Reader

This document is intended for system engineers who design and develop LED lighting and power systems.

Target Device

- 64-pin: R7F101GLG

When applying the sample program covered in this application note to another microcomputer, modify the program according to the specifications for the target microcomputer and conduct an extensive evaluation of the modified program.

Contents

1. Introduction

This application note describes a sample program to control high-brightness LEDs using the RL78/G24 microcontroller. The sample program performs independent control of 3-channel LEDs by constant current control and individual dimming control using DALI communication. The feedback process of the constant-current control is based on PI (proportional-integral) control.

This Application Note can be evaluated using the RL78/G24 DC/DC LED control evaluation board (RTK7RLG240P00000BJ).

Please refer to the documents below for information on the board.

RL78/G24 DC/DC LED Control Evaluation Board User's Manual (R20UT5371)

RTK7RLG240P00000BJ Schematics (R12TU0260)

2. Overview of LED control with RL78/G24

2.1 RL78/G24 Features for LED System Control

The RL78/G24 microcontroller incorporates various features to efficiently control LED lighting systems, including

- The RL78/G24 microcontroller can provide up to six channels of LED constant-current control and PWM dimming control using the timer output features of 16-bit timers KB0, KB1, and KB2 and timer RD2. This eliminates the need for an external IC dedicated to LED constant-current control and reduces design cost. 16-bit timer KBn has powerful features, including a dithering feature used in the sample program. Using this feature, the average PWM resolution can be increased to 0.65 ns.
- In addition, the RL78/IG24 allows power factor correction (PFC) control in critical conduction mode (CRM) using a comparator linked to the 16-bit timer KBn and a timer restart feature via external interrupt. Since a dedicated IC for PFC control is no longer required, design costs are further reduced.
- The RL78/G24 also has a built-in protection function that can stop the PWM output without CPU intervention if an overcurrent or overvoltage is detected in the LED or PFC control circuit. This feature is achieved by using a comparator in conjunction with the 16-bit timer KBn and a forced output stop feature triggered by an external interrupt. Furthermore, the resumption of operation after an emergency stop can be controlled by software, providing a flexible protection feature according to system requirements.
- The RL78/G24 microcontroller supports the DALI communication feature and can transmit and receive in compliance with the DALI communication standard (IEC 62386-101 Edition 1.0/2.0/2.1). This reduces the CPU load during data transmission and reception.
- The RL78/G24 also supports DMX512 communication using the UART0 serial interface. Here, the input signal pulse width measurement feature on channel 7 of the Timer Array Unit can be used to detect the falling edge of the break time on the RxD0 pin and measure its width (low level over 88 μs). The 16-bit timer array unit's interval timer feature can also be used to calculate the width of the Mark After Break signal (8μs to 1 s high level) and accept the signal. Mark Time Between Slots can also be measured.
- The pulse interval measurement feature of the 16-bit timer array unit can be used to receive infrared (IR) remote control signals. This reduces the CPU load during data reception.

Note PWM dimming using the Timer RD2 gate control feature is not used in the sample programs described in this application note. Only DC dimming by adjusting the PWM values of timer KB0 and KB1 channels is used.

2.2 System Block Diagram

Figure 2-1 shows the system block diagram of the RL78/G24 DC/DC LED control evaluation board (RTK7RLG240P00000BJ board). This LED lighting system performs 3-channel LED control using 16-bit timers KB0 and KB1, and performs dimming control by using the following

- Volume control with on-board variable resistors (using 12-bit A/D converter).
- DALI communication (using DALI interface). Only this dimming is described in this application note.
- DMX512 communication (using UART0 interface).
- IR communication (using Timer Array Unit channel in pulse interval measurement mode).

No additional external ICs are required because full control is achieved with the RL78/G24 microcontroller alone.

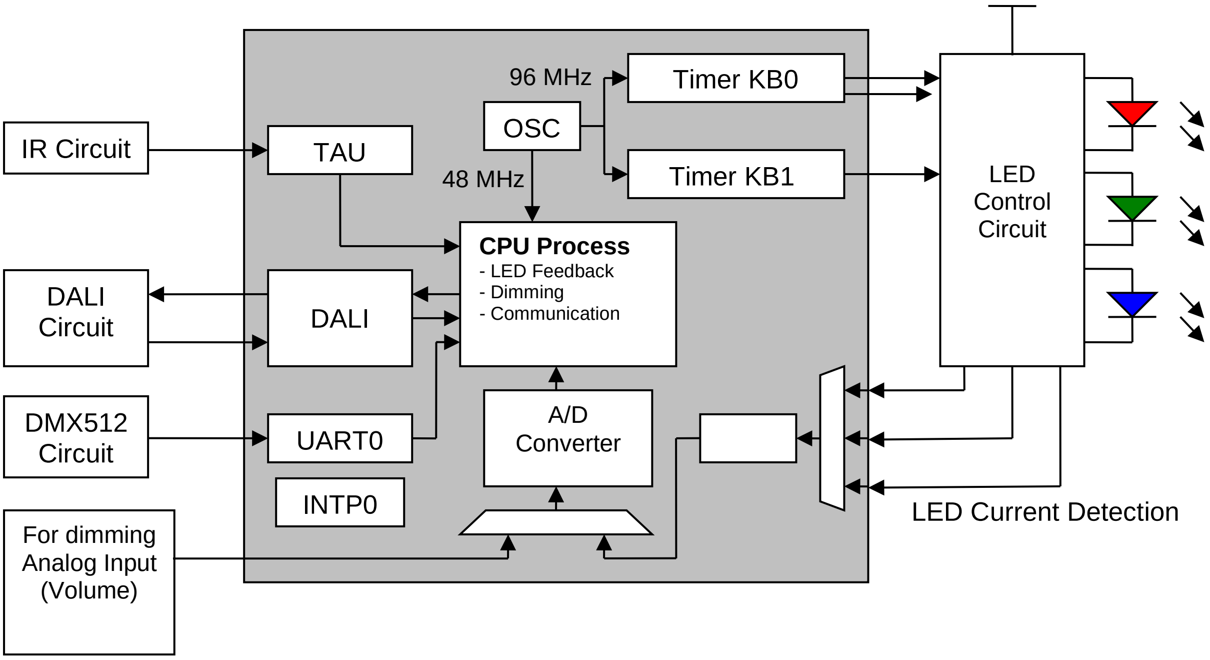


Figure 2-1 RL78/G24 DC/DC LED Control Evaluation Board Block Diagram

2.3 RL78/G24 Pin Features

The following table briefly describes the pins used and their respective features in the LED control system.

Feature	Feature Name	Pin Name	I/O	Description
LED Control	TKBO00	P12	O	PWM output of LED1
	TKBO01	P13	O	PWM output of LED2
	TKBO10	P14	O	PWM output of LED3
	ANI19	P120	I	Feedback current input of LED1
	ANI29	P00	I	Feedback current input of LED2
	ANI30	P01	I	Feedback current input of LED3
	ANI2	P22	I	LED2 dimming volume input
	ANI18	P147	I	LED3 dimming volume input
	ANI28	P146	I	LED1 dimming volume input
Communication	DALITxD0	P02	O	DALI transmit output
	DALIRxD0	P03	I	DALI receive input
	TxD2	P77	O	DMX512 transmit output
	RxD2	P76	I	DMX512 receive input
	TI02	P17	I	IR receive input

Table 2-1 Pin Features

3. LED Control Software

This section describes the file structure of the file to be downloaded from the Renesas Electronics website, the built-in peripheral features of the RL78/G24 to be used, and their initial settings. It also outlines the overall operation of this sample program (constant current and dimming control) and provides a comprehensive description and flow chart for the PI control implemented for feedback control.

In this application note, we will explain using the sample project provided in the application note below.

RL78/G24 DALI-2 Control Gear Basic (102) LED (207) Colour Control (209) Sample Application (R01AN7043)

3.1 File Structure

Program of the Sample Application is divided into several files as follows

Project Folder Structure

./	
│ DALI102_207_209_sample.mtpj :	Project file[Note1]
│ DALI102_207_209_sample.scfg :	Smart configurator file[Note1]
├─App :	Application folder
├─DefaultBuild :	Build artifact folder
│ DALI102_207_209_sample.mot :	Hexa file[Note1]
├─Driver :	Driver folder
├─Library :	Library folder
├─src :	Smart configurator generation folde[Note2]
└─Utility :	Utilityfolder

Note1 Sample project examples for the 102+207+209 standards. The file name differs depending on the corresponding standard.

Note2 Please do not regenerate the file as some parts of the code have been overwritten.

App folder structure
Implement code with little hardware dependence.

App	
r_cg.c :	Control Gear Implementation
r_cg.h :	Control Gear Implementation
r_common.h :	Common header file
r_debug.c :	Debugging feature using UART
r_debug.h :	Debugging feature using UART
r_lamp.c or r_lamp_tc.c :	Lamp dimming/dimming feature according to DALI standard[Note1]
r_lamp.h or r_lamp_tc.h :	Lamp dimming/dimming feature according to DALI standard[Note1]
r_main.c :	Main function
r_memory_bank.c :	Memory Bank control
r_memory_bank.h :	Memory Bank control
r_memory_banks.c :	Multiple Memory Bank control
r_memory_banks.h :	Multiple Memory Bank control
r_nvm.c :	NVM processing using RFD
r_nvm.h :	NVM processing using RFD
r_random.c :	Pseudo-random number generation using Xorshift
r_random.h :	Pseudo-random number generation using Xorshift
r_unit0_memory_bank.c :	Memory Bank definition for Logical Unit 0
r_unit0_memory_bank.h :	Memory Bank definition for Logical Unit 0
r_unit1_memory_bank.c :	Memory Bank definition for Logical Unit 1
r_unit1_memory_bank.h :	Memory Bank definition for Logical Unit 1
r_unit2_memory_bank.c :	Memory Bank definition for Logical Unit 2
r_unit2_memory_bank.h :	Memory Bank definition for Logical Unit 2

Note1 Only sample projects that support the 209 standard (dimming) are applicable to r_lamp_tc, and those that do not support the 209 standard (r_lamp) are applicable.

Driver folder structure

Implement hardware-dependent code.

Driver	
r_dali101.c :	DALI Driver Interface
r_dali101.h :	DALI Driver Interface
r_dali101_bft.c :	DALI Driver/Backward Frame Transmitter Implementation
r_dali101_bft.h :	DALI Driver/Backward Frame Transmitter Implementation
r_dali101_common.h :	DALI Driver/Common header file
r_dali101_rx.c :	DALI Driver/Receiver Implementation
r_dali101_rx.h :	DALI Driver/Receiver Implementation
r_led.c :	LED Driver Interface, Feedback Processing
r_led.h :	LED Driver Interface, Feedback Processing
r_led1.c :	LED Driver/LED1 Implementation
r_led1.h :	LED Driver/LED1 Implementation
r_led2.c :	LED Driver/LED2 Implementation
r_led2.h :	LED Driver/LED2 Implementation
r_led3.c :	LED Driver/LED3 Implementation
r_led3.h :	LED Driver/LED3 Implementation
r_port.c :	GPIO Read/Write
r_port.h :	GPIO Read/Write
r_trng.c :	True Random Number Generator
r_trng.h :	True Random Number Generator

Library folder structure

Place existing libraries and code.

Library	
├──DALI102 :	Folder to place DALI102 library[Note1]
├──DALI207 :	Folder to place DALI207 library[Note1]
├──DALI209 :	Folder to place DALI209 library[Note2]
└──RFD :	Folder to place RFD[Note2]

Note1 The user must place each library.

Note2 Abbreviation for Renesas Flash Driver RL78 Type01. User must place include, source, and userown folders. (sample folder is not necessary)

src folder structure

Place the code generated by the smart configurator.

```
src
 └─smc_gen
     ├─Config_ADC
     ├─Config_COMP0
     ├─Config_COMP1
     ├─Config_COMP2
     ├─Config_DAC0
     ├─Config_DALI
     ├─Config_PGA
     ├─Config_PORT
     ├─Config_TAU0_0
     ├─Config_TAU0_1
     ├─Config_TAU0_2
     ├─Config_TAU0_3
     ├─Config_TKB0
     ├─Config_TKB1
     ├─Config_UART0
     ├─Config_WDT
     ├─general
     ├─r_bsp
     └─r_config
```

Utility folder structure

Implement auxiliary code that can be used throughout the project.

```
Utility
    r_timer16.c :          16-bit software timer
    r_timer16.h :          16-bit software timer
    r_user_typedefs.h :    User-defined typedefs
```

3.2 Initialization of Built-in Peripheral Features

The sample program uses the following RL78/G24 microcontroller built-in peripheral features.

- Clock setting: High-speed main mode 4.0V to 5.5V, 4.0V <EVDD0 <5.5V, high-speed on-chip oscillator 8MHz, PLL oscillator circuit 96MHz
- LVD0: Reset mode (V_{LVD0}=2.91V)
- TAU channel 0: Clock frequency 48MHz, Interval time 1ms, Interrupt disabled
- TAU channel 1: Clock frequency 48 MHz, Interval time 100 us, Interrupt enabled (level 0)
- TAU channel 2: Clock frequency 48 MHz, Interval time 100 us, Interrupt enabled (level 1)
- TAU channel 3: Clock frequency 24 MHz, Interval time 1458 us, Interrupt enabled (level 1)
- TKB0: Clock frequency 96MHz, PWM cycle 2.5us (400KHz)
  TKBO00: Output permitted, Default Low, Active High, Dithering enabled
  Enable forced output stop feature 1, Output level low, Type 4, Trigger Comparator 0
  TKBO01: Output permitted, Default Low, Active High, Dithering enabled
  Enable forced output stop feature 1, Output level low, Type 4, Trigger Comparator 1
- TKB1: Clock frequency 96MHz, PWM cycle 2.5us (400KHz)
  TKBO10: Output permitted, Default Low, Active High, Dithering enabled
  Enable forced output stop feature 1, Output level low, Type 4, Trigger Comparator 2
  TKBO11: Not used
- WDT: Used in HALT/STOP/SNOOZE mode, Overflow time 2^7/fIL (3.90625ms), Window open period 100%, Interrupt disabled
- DAC0: 10 bits, Conversion value 133 (500mA detection voltage)
- COMP0: DAC0 output as reference, Rising edge, Interrupt disabled
- COMP1: DAC0 output as reference, Rising edge, Interrupt disabled
- COMP2: DAC0 output as reference, Rising edge, Interrupt disabled
- ADC: 12-bit, AVREFP is referenced to +, AVREFM is referenced to -, One-shot conversion mode, Standard 1, 55/fCLK (1.14583us)
  ADS0: Software trigger, Input source = PGA output, Conversion priority = high, Interrupt disabled
  ADS1: Not used
  ADS2: Not used
  ADS3: Not used
- PGA: PGAGND, Input channel = PGAI0, Amplification ratio 8x
- DALI: Clock frequency 48MHz, Non-extended mode, Transmit data length 8bit, Transfer rate 1200bps, Edge preservation mode standard for gray area, Bit timing violation enabled, Edges in gray area between half bit and 2 half bit are not detected as bit timing violation. BTV1=0 (0us), BTV2=96 (624us), BTV3=90 (585us), BTV4=92 (598us), BTV5=169 (1098.5), BTV6=292 (1898us), Stop bit detection interrupt enabled (level 3), Falling edge detection interrupt enabled (level 3), Bus power-down detection interrupt enabled (level 3)
- UART：
  Transmit: Clock frequency 1500 KHz, Continuous transfer mode, 8 bits, LSB, No parity, 1 stop bit, Non-inverted, 9600 bps, Interrupt enabled (level 3)
  Receive: Clock frequency 1500 KHz, Continuous transfer mode, 8 bits, LSB, No parity, 1 stop bit, Non-inverted, 9600 bps, Interrupt disabled

After initialization, 400 kHz PWM signals are output from 16-bit timers KB0 and KB1 to drive the LEDs. The A/D converter detects sense voltages from the feedback input pins, compares them to the ADC target level, and adjusts the duty cycle of the PWM output to maintain a constant current.

3.3 Constant current and Dimming control

TAU channel 0, TAU channel 1, Timer KB0, Timer KB1, and A/D converter are started after initialization.

Once started, the main loop program retrieves the dimming rate of the LEDs set via DALI communication and calculates the target dimming level ('VRn' Note1) for each LED channel. When operation starts, the main loop program obtains the LED dimming rate Note1 set via DALI communication and calculates the target dimming level ('VRn' Note1) for each LED channel. In this sample program, LED1 and LED2 are controlled and LED3 is not. To control LED3, set the dimming level using the R_LED_SetLevel function provided in the "r_led.h" file. LED3 can be controlled by specifying ch = 2 as the first argument and setting the target value as the second argument.

Note1 Refer to the following on how to set the dimming rate of the LEDs.

(Tentative) DALI102,207,209 Sample APN

The feedback process performs constant current control of LEDn Note2 by adjusting the duty cycle of the PWM output within the interrupt processing routine of TAU0_1 (INTTM01), which occurs every 100µs.

The A/D conversion result 'LEDn_FB_AD' Note2 is compared to the last result 'LEDn_FB_AD_OLD' Note2 and the target level VRn' Note1. Refer to section 3.4 for more details on the PI-controlled feedback process.

Using this feedback process, the sense voltage can be brought closer to the target level voltage. If the target level changes, the feedback process is executed two or more times before the sense voltage reaches the target.

In the LEDnNote2 target value calculation, the dimming rate of the LED set by DALI communication is acquired, and the dimming level (target level: 'VRn' Note2) representing the LED brightness is calculated. This sample program converts to obtain 'VRn' Note1 range (initially between values corresponding to 0 and 5 V) equivalent to the 'LEDn_FB_AD' Note2 range (0 to 0.45 V). .

Note2 n=1, 2, 3 (on board RTK7RLG24, LED1 is red, LED2 is green, LED3 is blue)

When TM01 interrupts occur every 100µs, the analog input channel is changed to one of the feedback channels. In addition, the "gs_feedback" variable is updated to shift the input channel to the next feedback channel on the next iteration of the interrupt handling routine.

The circuit used for constant current control of LED1 is shown in the figure below. The RL78/G24 PWM output controls the back-converter MOSFET ON/OFF via the Pre-Driver, then the ADC input measures the LED feedback current, and the RL78/G24 CPU implements PI control to maintain constant current in the LED. The target value VRn is determined according to the dimming rate of the LEDs set via DALI communication.

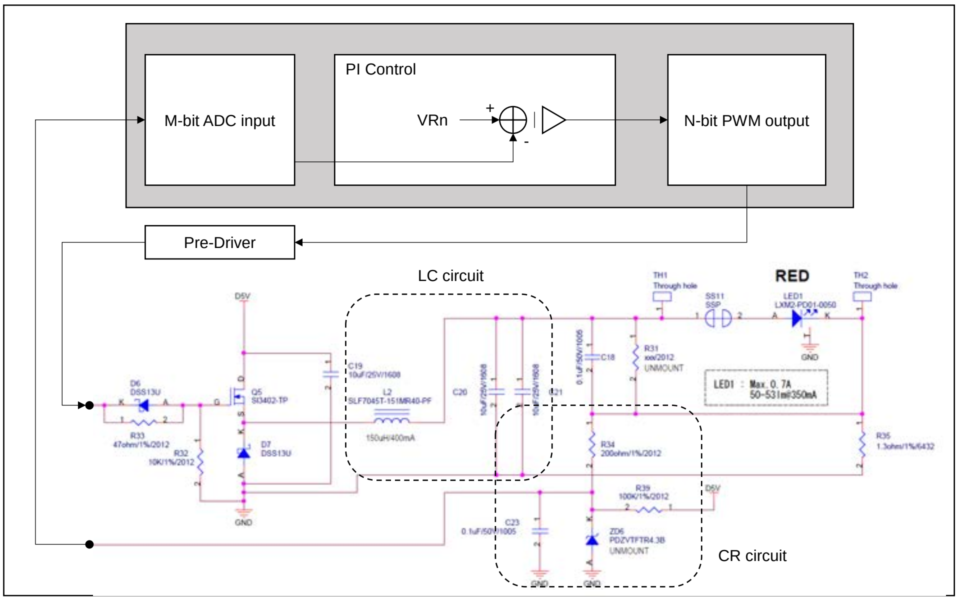


Figure 3-1 LED1 Back converter circuit for constant current control

The following figure shows the shift flow for the analog input channels.

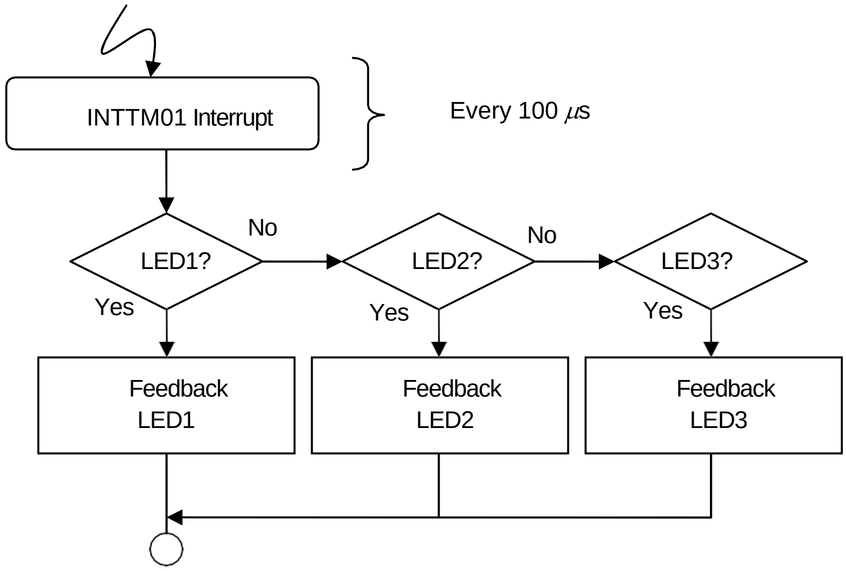


Figure 3-2 Shift flow of analog input channel

3.4 Feedback Method by PI Control

Both constant current control and dimming control (including on/off) of LEDs can be achieved by using feedback processing with PI control.

The general equation for PI feedback is shown below.

Refer to 3.5 Calculation of the coefficients of the PI control equation for the calculation of coefficients A1 and A2.

$$D(n) = D(n-1) + A_1 \cdot E(n) + A_2 \cdot E(n-1)$$

D(n): Latest PWM output duty

D(n-1): Previous PWM output duty

E(n): Latest error value = (A/D conversion target value) - (latest measured A/D conversion value)

E(n-1): Previous error value = (A/D conversion target value) - (previous A/D conversion measured value)

A1, A2: Coefficients

1) Constant current control of LED

The target value of LED CURRENT ILED is determined based on the A/D conversion target value. The setting method when the A/D conversion target value is X_{TARGET}**Note** is shown below.

$$X_{TARGET} = \frac{(I_{LED} \times 8) \times R_S}{V_{REF}} \times (2^M - 1)$$

Note In the sample program in this section, the A/D conversion target value X_{TARGET} is defined as 'VRn'.

For example, when performing constant current control with LED current I_{LED}= 350 mA, set the A/D conversion target value X_{TARGET} = 2981, assuming sense resistor R_S= 1.3 Ω, A/D converter reference voltage VREF = 5 V and A/D conversion resolution M = 12-bit. The LED current feedback measurements are amplified using a programmable gain amplifier with a gain of 8, so the A/D conversion target value X_{TARGET} must be multiplied by 8.

2) LED dimming control

Current dimming control can be performed by changing the target value of the LED constant current. This means that the A/D conversion target value X_{TARGET} can be changed for dimming. As a result, the target value of the PI control is changed and the RL78/G24 microcontroller performs feedback control toward the ideal value of X_{TARGET}. For example, to change the LED current from 350 mA to 100 mA, change the X_{TARGET} value from 2981 to 852.

3) PGA input offset voltage correction

When using a PGA (programmable gain amplifier), an input offset voltage of ±5 mV to ±10 mV is amplified. As a result, the PGA cannot provide accurate voltage to the feedback loop. Therefore, the sample program takes the positive offset voltage into account and compensates for it.

At the first time of LED feedback processing for each channel, that is, when the LEDs are still off, the LED feedback voltage values are calculated and these values are stored as 'LEDn_OFFSET'. These values represent the offset voltage induced by the PGA when current is not flowing through the LEDs. The LED feedback process subtracts these values from the next LED feedback voltage value to erase the offset voltage when the LED is turned on.

In addition, the RL78/G24 DC/DC LED Control Evaluation Board is designed to reduce the effects from positive offset voltages with pull-up resistors (R39, R48, R57) on each channel feedback circuit.

An overview of the operation is shown below.

<1> Starts PGA amplification.
<2> Starts A/D conversion of the LED feedback voltage measured using the sense resistor.
<3> Reads the A/D conversion target value.
<4> Calculates "A2×E(n-1)" of PI control taking into account the offset voltage.
<5> If the A/D conversion results in an overcurrent at the LED, the LED output process is stopped.
(In this case, the PI control process from <6> to <8> below is not executed.)
<6> If no overcurrent occurs at the LED as a result of A/D conversion, the PI control "A1 x E(n) + A2 x E(n-1)" is calculated taking the offset voltage into account.
<7> Compare the last PWM output duty D(n-1) with the result of "A1×E(n) + A2×E(n-1)" in <6>.
If the calculation result of "D(n-1) + A1×E(n) + A2×E(n-1)" is within the range from the minimum PWM duty value to the maximum PWM duty value, set duty D(n) according to the error calculation result; otherwise, set duty D(n) is set to the maximum or minimum value.
<8> Updates the duty setting value of the PWM output.
<9> Saves the A/D conversion value of the LED feedback voltage as the last value.

The part of the sample program corresponding to the above flow of operations (<1> to <9>) for the LED1 channel is shown on the next page.

```
PGAINS = FEEDBACK_LED1;
pga_start();                                                    /* <1> */
gs_get_value = adc_ads0_execute();                              /* <2> */

LED1_FB_AD = gs_get_value;                                      /* <3> */
temp11 = LED1_VR- (LED1_FB_AD_OLD - LED1_OFFSET);               /* <4> */
LED1_ERR = MACSW(0,A2,temp11);

If (LED1_FB_AD >= (CURRENT_MAX + LED1_OFFSET))                  /* <5> */
{
        force_stop();
}
else
{
        temp12 = LED1_VR - (LED1_FB_AD - LED1_OFFSET);          /* <6> */
        LED1_ERR = MACSW(LED1_ERR,A1,temp12) ;
        if (LED1_ERR > 0)                                       /* <7> */
        {
            if (DUTY_MAX - LED1_DUTY >= LED1_ERR)
            {
                LED1_DUTY += LED1_ERR;
            }
            else
            {
                LED1_DUTY = DUTY_MAX;
            }
        }
        else if (LED1_ERR < 0)
        {
            if (LED1_DUTY > - LED1_ERR)
            {
                LED1_DUTY += LED1_ERR;
            }
            else
            {
                LED1_DUTY = 0;
            }
        else if ((LED1_ERR == 0) && (LED1_VR == 0))
        {
            LED1_DUTY = 0;
        }
        else
        {
        }
        LED1_TKBCRLD =
        (uint16_t)(LED1_DUTY >> 8) << TKBCRLD_BIT_SHIFT_SIZE; /* <8> */
}
LED1_FB_AD_OLD = LED1_FB_AD;                                    /* <9> */
tkb0_set_batch_overwrite_request_on();
NOP();
```

3.5 Calculation of the coefficients of the PI control equation

This section describes how to calculate the coefficients using the PI control equation shown in Section 3.4.

$$A1 = (\pi \times f_Z \times T + 1) \times K_P$$
$$A2 = (\pi \times f_Z \times T - 1) \times K_P$$

π: Pi
f_Z: Zero point frequency
T: Feedback period
K_P: Proportional constant

That is, the coefficients A1 and A2 can be calculated by determining the three parameters fZ, T, and KP. These parameters are obtained from the gain of the LED control circuit.

1) Calculation of the zero point frequency (fZ) from the extreme frequency of the control circuit

As shown in **Figure 3-1**, this control circuit has two extreme points (the extreme point of the LC circuit and the extreme point of the CR circuit).

These extreme point frequencies can be regarded as equal to their respective cutoff frequencies. Let the former be f_{C1} and the latter f_{C2} L1 = 150 μH, C1 = 20 μF, C2 = 0.1 μF, and R2 = 200 Ω, the following values are obtained

$$f_{C1} = \frac{1}{2\pi\sqrt{L_1 \cdot C_1}} = 2.9KHz$$

$$f_{C2} = \frac{1}{2\pi \cdot C_2 \cdot R_2} = 7.9KHz$$

Then select a zero point frequency lower than these two frequencies, as shown below.

$$f_Z = 1.5KHz$$

2) Calculation of feedback period (T) from zero point frequency (f_Z)

By the sampling theorem, the sampling frequency equal to the inverse of the feedback period T must be at least twice the zero point frequency f_z.

That is, the relationship between the feedback period T and the zero point frequency fZ should be the following equation

$$T < \frac{1}{2f_Z}$$

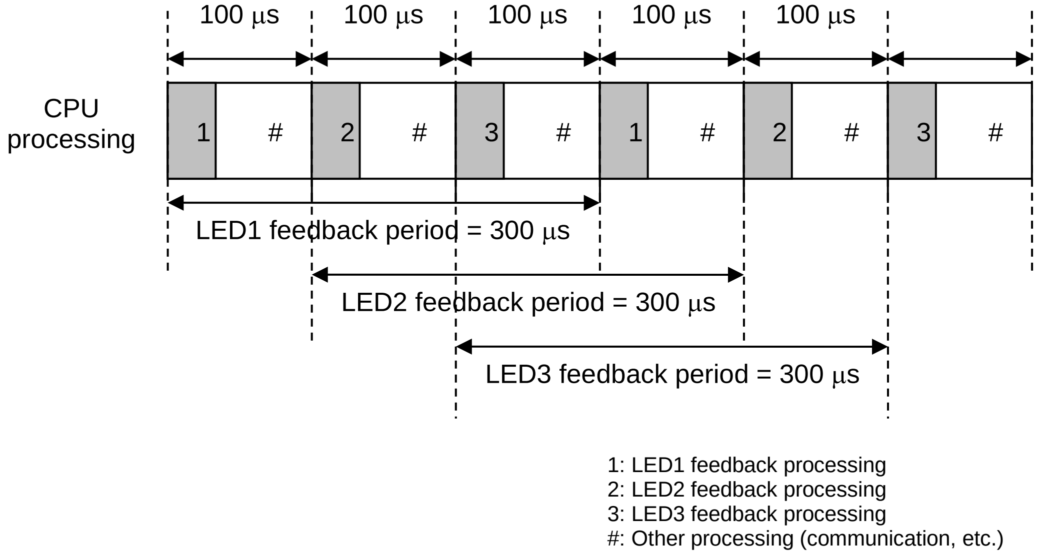
Therefore, if f_Z = 1.5 kHz, the feedback period T must be less than 333 us.

In addition, CPU load dedicated to feedback processing must be considered. A total of three LED channels require constant current feedback control. Therefore, in this sample program, the CPU load is distributed in 100 µs cycles to perform feedback control for each LED channel as shown in Figure 3-3 below.

This sets the feedback period T as follows

$$T = 300\mu s$$

Figure 3-3 CPU load balancing for feedback processing



3) Calculation of proportionality constant Kp from microcontroller gain (ADC input / PWM output)

The gain of the microcontroller (A/D converter input/PWM output) can be obtained by noting the change in LED current for a given A/D conversion resolution and PWM resolution.

First, it is necessary to determine the change in LED current relative to the inherent A/D conversion resolution: if the LED current is I_{LED}, the A/D conversion result of the feedback voltage with sense resistor R_S is X, the A/D conversion resolution is Mbit, and the ADC reference voltage is V_{REF}, the following equation holds.

$$I_{LED} \cdot R_S = \frac{V_{REF} \cdot X}{2^M}$$

Here, if the change in LED current for an A/D conversion value equal to 1 (X = 1) is denoted as i_{AD}, the following result is obtained

$$i_{AD} = \frac{V_{REF}}{R_S \cdot 2^M}$$

Next, it is necessary to determine the LED current variation with respect to the inherent PWM resolution: if the LED current is I_{LED}, the total LED forward voltage is VFT, the input voltage is VI, the (PWM output duty register value + 1) is Y, and the PWM output resolution is N bits, then the following equation holds.

$$I_{LED} \cdot R_S + V_{FT} = \frac{V_I \cdot Y}{2^N}$$

Here, if the change in LED current for PWM duty value equal to 1 (Y = 1) is i_{PWM}, furthermore, since the LED forward voltage remains constant, the following results are obtained.

$$i_{PWM} = \frac{V_I}{R_S \cdot 2^N}$$

Therefore, the gain i_{PWM}／i_{AD} is estimated from the above equation to be

$$\frac{i_{PWM}}{i_{AD}} = \frac{V_I}{V_{REF}} \cdot 2^{(M-N)}$$

Considering that the A/D conversion resolution M is 15 bits (12 bits of ADC + 3 bits of PGA with 2^3 = 8 amplification gains), the PWM output resolution N is 12 bits (8 bits of PWM + 4 bits for dithering function), the input voltage V_I is 5 V and the A/D converter reference voltage V_{REF} is 5 V, the following gain results (A/D converter input / PWM output) are obtained.

$$\frac{i_{PWM}}{i_{AD}} = 2^3$$

The proportionality constant K_P should be set to a value less than the inverse of this gain.

$$K_P < \frac{1}{\left(\frac{i_{PWM}}{i_{AD}}\right)}$$

Here, KP is selected as follows

$$K_P = 0.1$$

From the above results, the PI control coefficients A1 and A2 can be calculated.

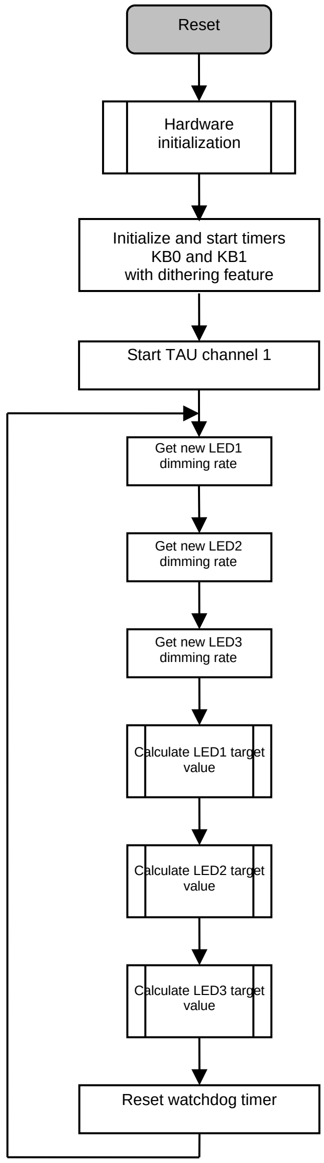
$$A_1 = 0.241$$
$$A_2 = 0.041$$

In the sample program, both coefficients, as well as the PWM duty and error values, take integer variables and are multiplied by 2^8 (= 256) to facilitate calculation.

$$A_1 = 61$$
$$A_2 = 11$$

3.6 Software Flow Chart

Figure 3-4 Main Program Loop Flow Chart



Get dimming rate of new LEDn:
Get the dimming rate of LEDs set by DALI communication

Calculate LEDn target value:
Calculate the dimming level VRn, which represents the LED luminance, from the obtained LED dimming rate.
***n = 1, 2 or 3**

Figure 3-5 Flow chart of LEDn target value (VRn) calculation process (n=1, 2, 3)

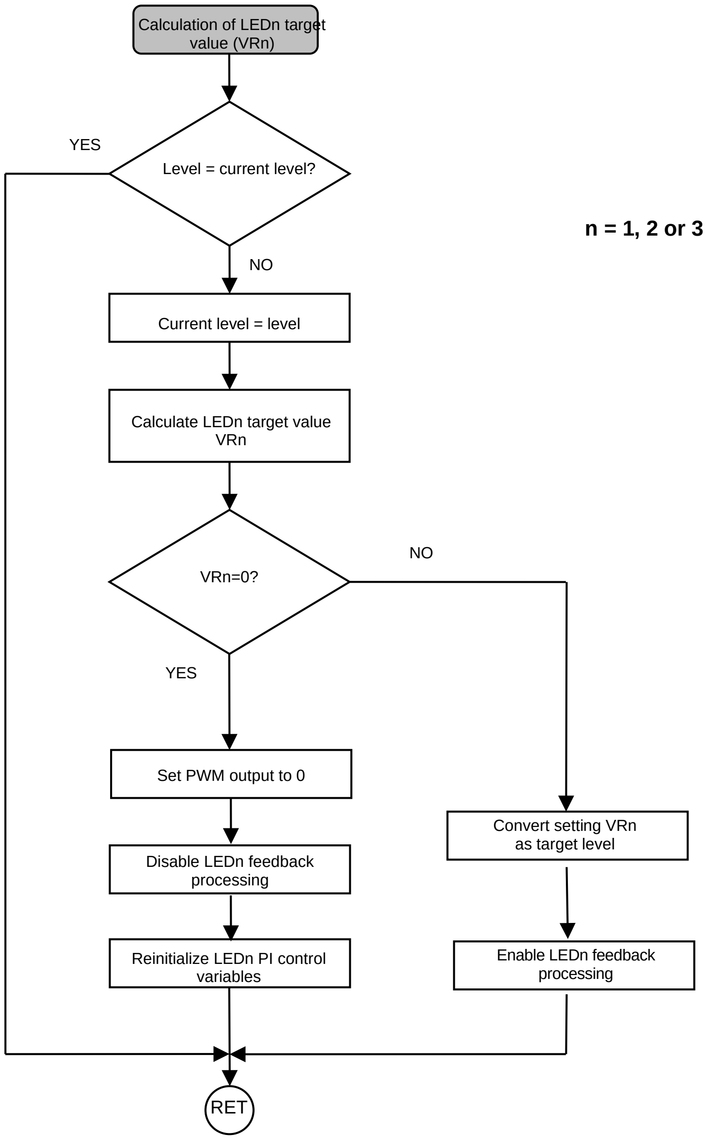
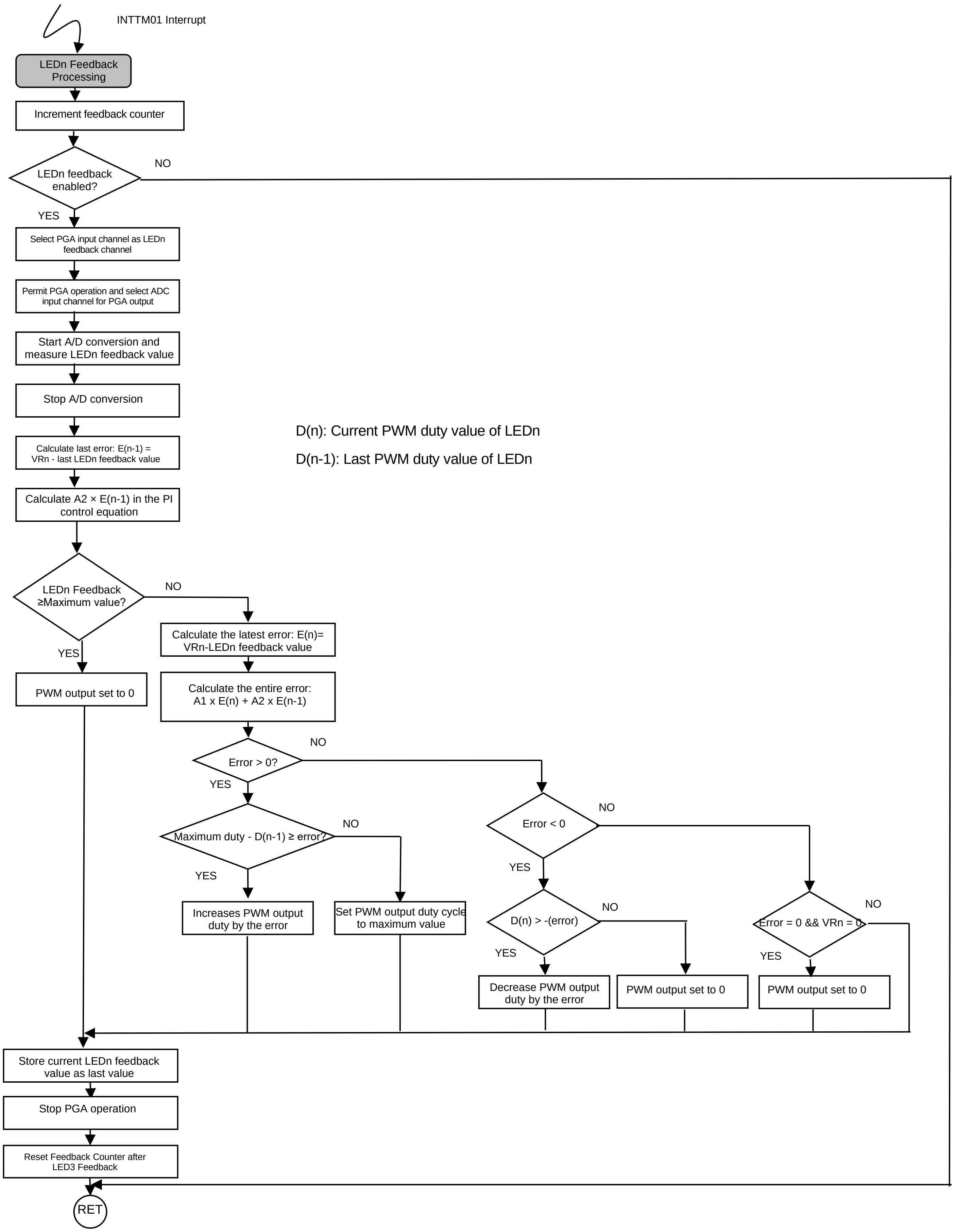


Figure 3-6 Flow chart of LEDn feedback process (n=1, 2, 3)



4. How to start up the RL78/G24 DC/DC LED Control Evaluation Board

Before starting the evaluation of the RL78/G24 DC/DC LED Control Evaluation Board using the given sample programs, please follow the steps below.

The following steps show the process of downloading the sample programs to the RL78/G24 flash memory using the RFP (Renesas Flash Programmer) software tool.

1. Select flash programming mode by setting SW1 bits 1-3-5 to the ON position (all other bits to the OFF position) to enable flash programming via the COM port.
2. Connect 5V power to the CN1 DC jack connector.
3. Connect the RL78/G24 DC/DC LED Control Evaluation Board to the PC USB port using a Type A Mini-B USB cable.

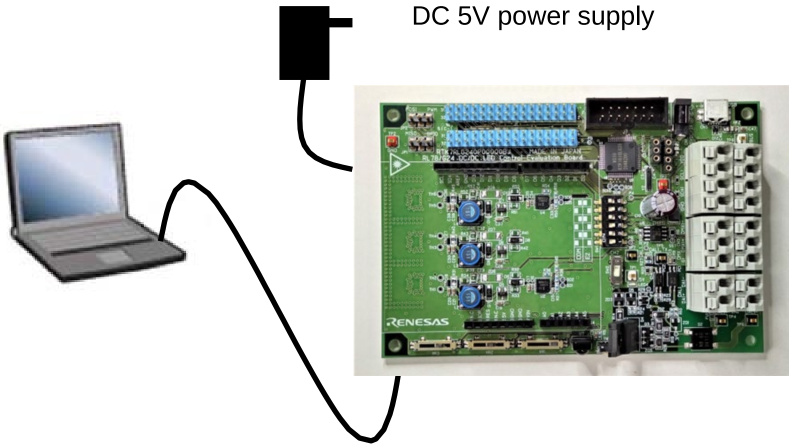


Figure 4-1 System Environment

4. Open the "RFP" flash programmer tool.

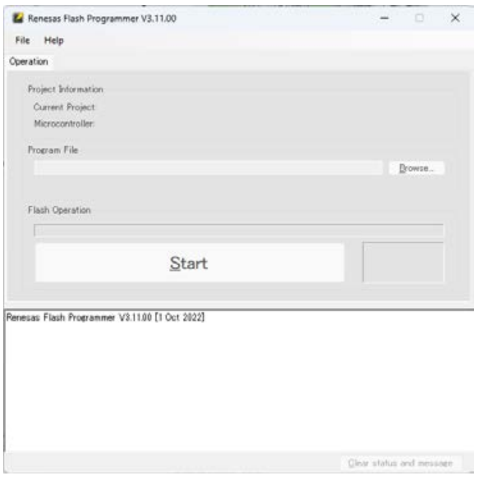


Figure 4-2 RFP Startup Screen

5. Click on "File" => "New Project" to open the "Create New Project" window. Select "RL78/G2x" for the Microcontroller.

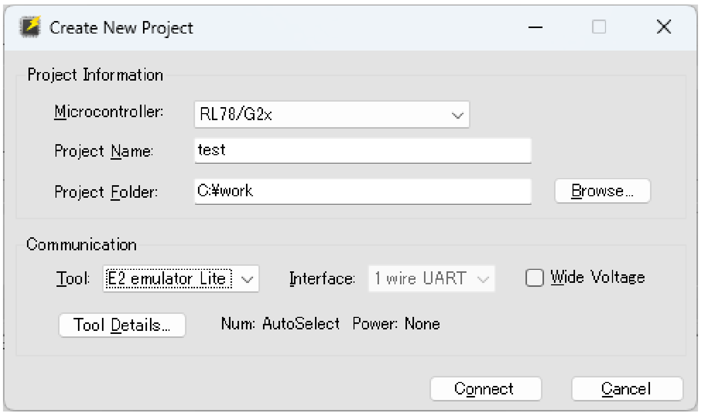


Figure 4-3 RFP Flash Programming Tool - "Create new Project" window

6. Select the "hex" file of the sample program to be programmed.
7. Click the "Next" button to flash program the sample program into the RL78/G24 flash memory.
8. After the flash programming is completed, close "RFP".

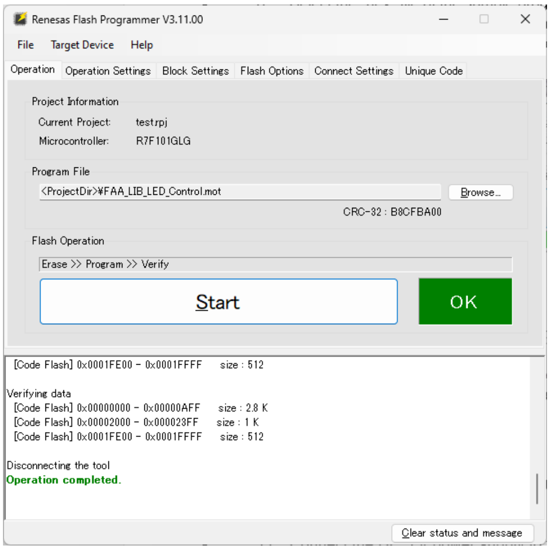


Figure 4-4 RFP Flash Programming Tool - "Execution" window

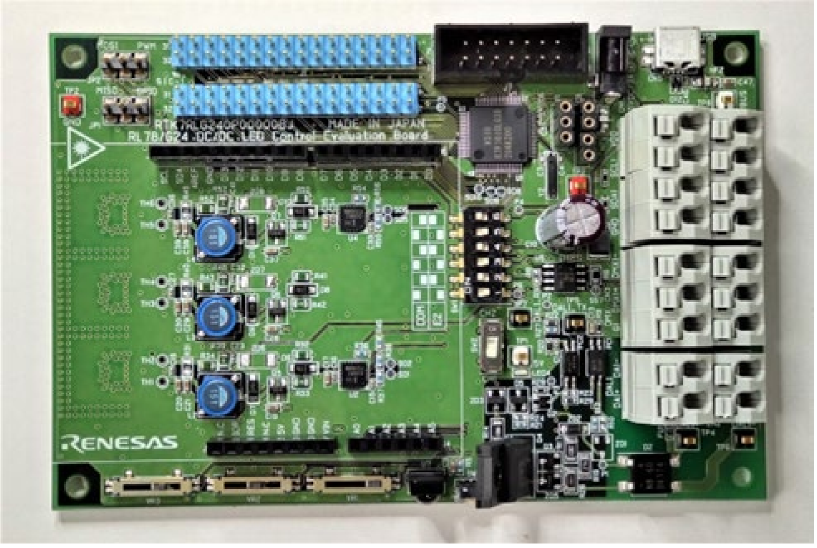
9. Disconnect the 5 V power supply and USB cable.

10. Connect the DC 5 V power supply to the CN1 connector again.

11. Confirm the dimming of the LED using DALI communication.

12. After evaluation is complete, disconnect the 5 V DC power supply from the CN1 connector.

Appendix A Photos



Appendix B Schematics

Please see below document.

RTK7RLG240P00000BJ Schematics (R12TU0260)

Website and Support

Renesas Electronics Website

http://www.renesas.com/

Contact information

http://www.renesas.com/contact/

Revision History

Rev.	Date	Description	
		Page	Summary
1.00	Sep. 1st, 23	—	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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Corporate Headquarters

TOYOSU FORESIA, 3-2-24 Toyosu,
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