

RL78/I1A

R01AN1087EJ0201

LED Control Using RL78/I1A

Rev. 2.01

Mar. 26, 2013

Purpose

The purpose of this application note is to describe the control method for LED lighting systems using the RL78/I1A microcontroller features.

Readers

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

The target products are as follows:

- 20-pin: R5F1076C
- 30-pin: R5F107AE, R5F107AC
- 38-pin: R5F107DE

<R>

Table of Contents

1. Introduction.....	3
2. Overview of LED Control Using RL78/I1A	4
2.1 RL78/I1A Features for LED System Control	4
2.2 System Block Diagram	5
2.3 Pin Functions of RL78/I1A	6
3. LED Control Software Description	7
3.1 File Configuration	7
3.2 Initialization of the Internal Peripheral Functions	8
3.3 Constant Current and Dimming Control	10
3.4 PI Control Method	13
3.5 Calculation of the PI Control Formula's Coefficients.....	16
3.6 Software Flow Charts	19
4. Get Started Quickly with the RL78/I1A DC/DC LED Control Evaluation Board.....	23
APPENDIX A Pictures	25
APPENDIX B Schematic	26

1. Introduction

<R> This application note describes a sample program that controls high brightness LEDs by using the RL78/I1A microcontroller. This sample program uses a constant current control technique to control three LEDs independently, and supports individual dimming by using variable resistors. Feedback processing during constant current control is based on the proportional-integral (PI) method.

<R> This program can be evaluated using the RL78/I1A DC/DC LED Control Evaluation Board (EZ-0012). See the circuit diagram for the pin configuration on the RL78/I1A DC/DC LED control board.

2. Overview of LED Control Using RL78/I1A

2.1 RL78/I1A Features for LED System Control

The RL78/I1A microcontroller embeds comprehensive features enabling efficient LED lighting system control:

- <R> – RL78/I1A MCU allows LED constant current and PWM dimming control of up to 6 channels using the timer output functions of the 16-bit timers KB0, KB1, KB2 and 16-bit timer KC0. This eliminates the need for an external IC dedicated to LED constant current control, thus reducing the design cost. These 16-bit timers KBn include several powerful functions, one of them used in the sample program is Dithering function which contributes to increasing the average PWM resolution to 0.98 ns.
- <R> – RL78/I1A allows power factor correction (PFC) control in critical conduction mode (CRM) using the timer restart function, which is based on comparators and external interrupts that operate together with 16-bit timers KBn. This also eliminates the need for a dedicated PFC control IC, thus reducing design cost even further.
- <R> – RL78/I1A embeds protective functions that stop PWM output (without requiring control via the CPU) when an overcurrent or overvoltage is detected in an LED or PFC control circuit. This is realized by using the forced output stop function triggered by comparators and external interrupts that operate together with 16-bit timers KBn. Furthermore, operation restart after the emergency stop can be controlled by software, thus realizing a flexible protective function according to the system requirements.
- <R> – The RL78/I1A MCU incorporates a serial array unit (UART4/DALI) that supports the DALI communication slave function to enable transmission and reception of Manchester codes (transmission: 11, 19 or 27 bits, reception: 19, 20 or 27 bits), which is the communication method prescribed by the DALI communication standard. This allows reducing the CPU load during data transmission and reception.
- <R> – RL78/I1A also supports DMX512 communication via its UART0 serial interface. The input signal pulse width measurement function of Timer Array Unit channel 7 can be used to detect the falling edge of a break period on the RxD0 reception pin and to measure its length (low level for at least 88 μ s), and the interval timer function of the 16-bit Timer Array Unit can be used to calculate and acknowledge the MARK AFTER BREAK signal width (high level for 8 μ s to 1 s) and also to measure the MARK TIME BETWEEN SLOTS.
- <R> – The pulse interval measurement function of the 16-bit timer array unit can also be used to receive infrared (IR) remote control signals. This can reduce the CPU load during data reception.

Note: PWM dimming using the 16-bit Timer KC0 gate control function is not used in the sample program 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/I1A DC/DC LED Control Evaluation Board (EZ-0012 board). This LED lighting system performs 3-channel LED control using 16-bit Timers KB0 and KB1 and supports dimming control via:

- <R> • Volume control by using on-board variable resistors that use the 10-bit A/D converter. This application note only describes this dimming interface.
- DALI communication (using DALI/UART4 interface),
- DMX512 communication (using UART0 interface and Timer Array Unit channels in interval timer mode and low-level width measurement mode),
- IR communication (using Timer Array Unit channels in interval timer mode and high-level width measurement mode)

The full control is realized by only using the RL78/I1A microcontroller and doesn't need any additional external ICs.

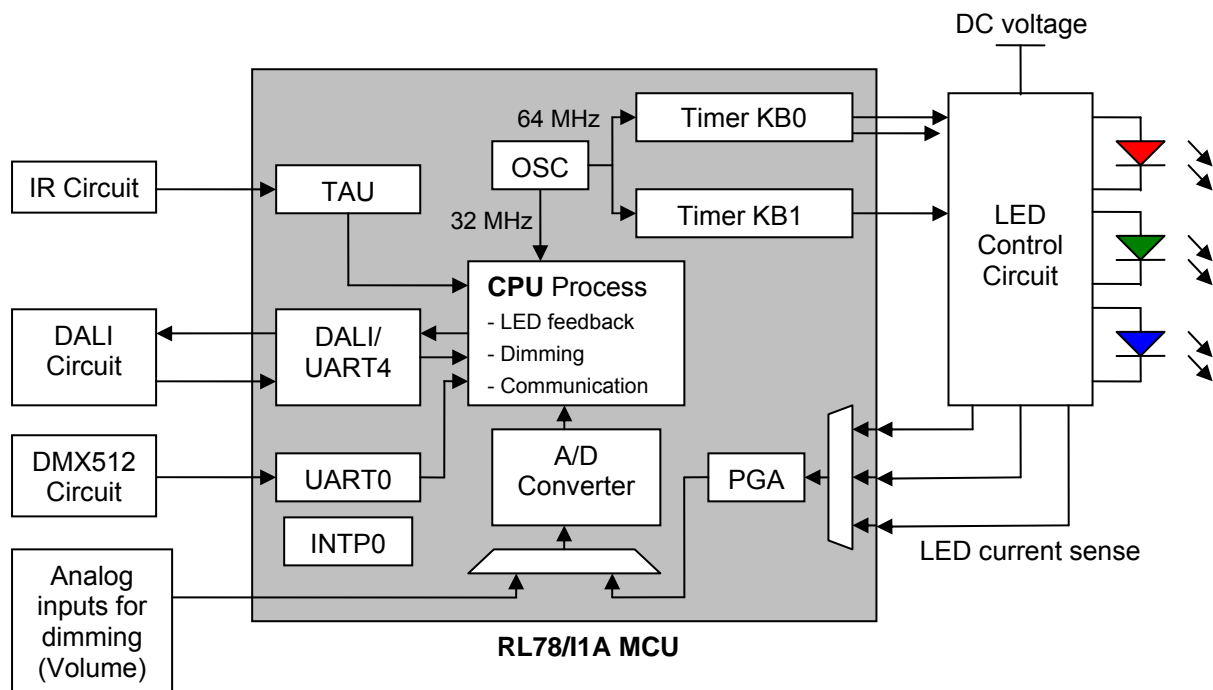


Figure 2-1. RL78/I1A DC/DC LED Control Evaluation Board Block Diagram

2.3 Pin Functions of RL78/I1A

The table below presents the different pins which are used, and gives a brief description of their functions within the LED control system.

Table 2-1. Pin Functions

Function	Function Name	Pin Name	I/O	Description
LED Control	TKBO00	P200	O	PWM output of LED1
	TKBO01	P201	O	PWM output of LED2
	TKBO10	P203	O	PWM output of LED3
	ANI2	P22	I	Feedback current input of LED1
	ANI4	P24	I	Feedback current input of LED2
	ANI5	P25	I	Feedback current input of LED3
	ANI6	P120	I	Volume input for dimming of LED2
	ANI7	P26	I	Volume input for dimming of LED3
Communication	ANI19	P27	I	Volume input for dimming of LED1
	TXD0	P10	O	DALI transmission output
	RXD0	P11	I	DALI / DMX512 reception input
	TI05	P05	I	IR reception input

3. LED Control Software Description

<R> This chapter describes the files included in the compressed files the user needs to download from the Renesas website, the internal peripheral functions of the RL78/I1A to be used, and their initial settings. This chapter also gives an overview of the overall operation (constant current and dimming control) of this sample program, as well as a comprehensive explanation about the PI method implemented for feedback control, and also includes flow charts of the different processing.

3.1 File Configuration

This sample program is split into several files:

- **r_init.asm:** holds the option byte settings
- **r_main.c:** contains the main function
- **r_usermain.c:** implements the LED dimming functions
- **r_userinit.c:** contains top function for peripheral initialization settings
- **r_adc.c:** contains general functions for LED volume reading
- **r_adc19.c:** contains initialization and implementation functions for ANI19 analog input pin reading (LED1 volume: VR1)
- **r_adc6.c:** contains initialization and implementation functions for ANI6 analog input pin reading (LED2 volume: VR2)
- **r_adc7.c:** contains initialization and implementation functions for ANI7 analog input pin reading (LED3 volume: VR3)
- **r_timer.c:** contains timer functions (interval mode) for LED volume analog sampling
- **r_led.c:** contains initialization functions for port and timers as well as LED feedback processing function
- **r_led1.c:** contains functions for LED1 channel control
- **r_led2.c:** contains functions for LED2 channel control
- **r_led3.c:** contains functions for LED3 channel control
- **r_led_user.c:** contains the data table for dimming level conversion
- **r_systeminit.c:** contains system initialization functions
- **r_cgc.c:** contains clock initialization function
- **r_lvd.c:** contains LVI initialization function
- **r_wdt.c:** contains watchdog initialization function
- **r_user.h:** contains parameter definitions used for clock and ADC configurations

3.2 Initialization of the Internal Peripheral Functions

The following internal peripheral functions of the RL78/I1A microcontroller are used in this sample program:

- Dimming processing interval control: 16-bit TAU Channel 0
- Feedback processing interval control: 16-bit TAU Channel 1
- PWM output with dithering function: 16-bit timer KB0 and KB1
- Volume input: 10-bit A/D converter channel n (n = 19, 6, 7)
- Feedback input amplification: PGA channel n (n = 2, 4, 5)
- LED current feedback input (from PGA output): 10-bit A/D converter channel n (n = 3)

Table 3-1. A/D Converter Channel Allocation

Analog Input Channel	Function
ANI0	AVREFP
ANI1	AVREFM
ANI2	Feedback current input of LED1
ANI4	Feedback current input of LED2
ANI5	Feedback current input of LED3
ANI6	Volume input for dimming of LED2
ANI7	Volume input for dimming of LED3
ANI16	Unused
ANI17	Unused
ANI19	Volume input for dimming of LED1

The hardware initialization includes the following settings:

1) Option Byte Setting

- Stopping watchdog timer operation
- Setting of LVD (Low-voltage detector) operation mode and detection level
 - Setting V_{LVI} (low-voltage detection voltage) to 4.06 V
 - Setting LVD in reset mode (Generating an internal reset when V_{DD} is less than V_{LVI})
- Selecting the high-speed internal oscillator (4 MHz) as the system clock source
- Enabling on-chip debugging

2) Peripheral Setting

- Setting CPU clock frequency to 32 MHz using PLL (16 times the internal high-speed oscillation clock $f_{IH} \times 1/2$)
- Peripheral function clock supply setting
- I/O port setting
- 16-bit TAU Channel 0 setting
 - Setting count clock to f_{CLK} (32 MHz)
 - Setting the interval time to 1 ms $((TDR00 + 1) / f_{CLK})$
 - Unmasking the interrupt INTTM00
- 16-bit TAU Channel 1 setting
 - Setting count clock to f_{CLK} (32 MHz)
 - Setting the interval time to 100 μ s $((TDR01 + 1) / f_{CLK})$
 - Unmasking the interrupt INTTM01
- A/D converter setting
 - Setting A/D converting time to 2.97 μ s
 - Masking the interrupt INTAD
- Programmable Gain Amplifier (PGA) setting
 - Setting PGA amplification factor to x 8
 - Setting input channel to ANI2
- 16-bit Timer KB setting
 - Setting count clock to $f_{PLL} = 64$ MHz
 - Enabling TKBO00, TKBO01 and TKBO10 PWM output dithering function
 - Setting operation mode of TKBO and TKB1 to standalone mode
 - Setting output default level of TKBO00, TKBO01 and TKBO10 to low level and active level to active high
 - Setting frequency of PWM output to 250 kHz $(f / (TKBCRn0 + 1), n = 0, 1)$
- 64 MHz counting clock source with a resolution of 8 bits $(64 \text{ MHz} / 2^8)$
 - Masking the interrupts INTTMKB0, INTTMKB1

After initialization, the 250 kHz PWM signal is output from the 16-bit timer KB0 & KB1 to drive the LEDs. Basically, the A/D converter detects the sense voltages from the feedback input pins, compares them with the ADC target levels and adjusts the duty of the PWM outputs to maintain a constant current.

3.3 Constant Current and Dimming Control

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

When the operation starts, the main loop program gets the latest LED volume levels from the on-board variable resistors and then calculates the dimming target levels ('VRn'^{Note 1}) for each LED channel.

The TAU channel 0 interrupt (INTTM00) occurs every 1 ms. The interrupt service routine increments a 'count_ms' variable, when the variable reaches 5 ms, the program proceeds with new A/D conversions for the 3 LED volume channels.

As for the feedback processing, the interrupt of TAU 1 (INTTM01) occurs every 100 μ s and the MCU enters the interrupt service routine to proceed with the constant current control of LEDn^{Note 1} by adjusting the duty of the PWM outputs.

The result of the A/D conversion 'FB_LEDADn'^{Note 2} is compared with the last result 'FB_LEDADn_old' and the target level 'VRn' using the PI (Proportional-Integral) feedback method. Please refer to section 3.4 for a full explanation about the PI method.

By using this feedback process, the sense voltage can get close to the target level voltage. If the target level radically changed, the feedback process is executed more than once before the sense voltage reaches the target.

In the calculation of volume n^{Note 1}, the result of the A/D conversion is used to calculate the dimming level which is the target level 'VRn', and which represents the brightness of the LEDs.

In this sample program, we convert the A/D conversion result of the selected volume channel in order to get a 'VRn' range (originally between values corresponding to 0 to 5 V) equivalent to the 'FB_LEDADn' range, which is 0 to 0.45 V.

*note1: n = 1, 2, 3 (on the board EZ-0012, LED1 is Red, LED2 is Green, LED3 is Blue)

*note2: the single quotation mark contents show some global variables in the sample program.

When the TM00 interrupt (INTTM00) occurs and the count has reached 5 ms, the analog input channel is set to be the LED1 volume channel and then shifts to the LED2 and LED3 volume channels within the same interrupt service routine iteration.

The analog input channel is changed to one of the feedback channels when the TM01 interrupt occurs (every 100 μ s). The program then updates the 'feedback' variable in order to shift the input channel to the next feedback channel at the next interrupt service routine iteration.

<R> The figure below is a diagram of the circuit used for constant current control of LED1. The RL78/I1A PWM output is used to switch the buck converter MOSFET by using a pre-driver, then the ADC input is used to measure the LED feedback current. The RL78/I1A CPU implements PI control to maintain a constant current in the LED. The ADC target value is read from the on-board variable resistor VR1.

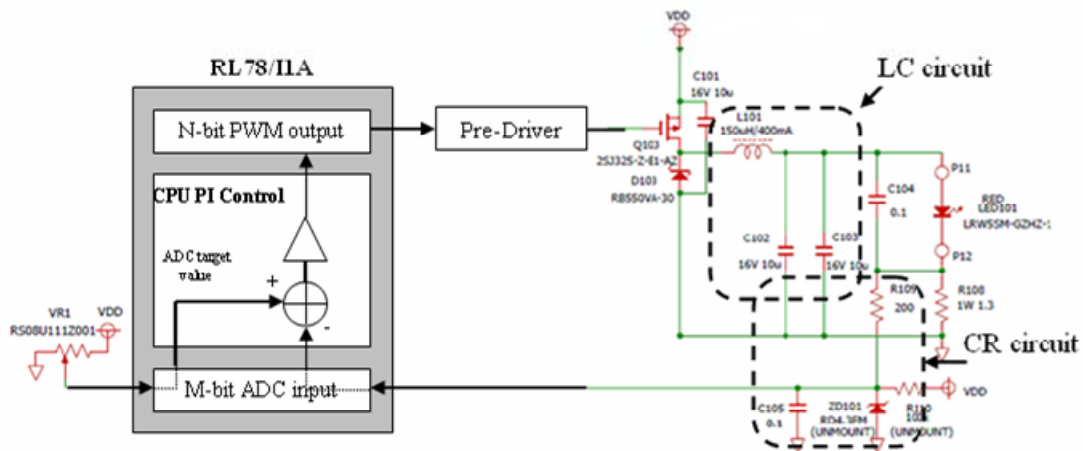


Figure 3-1. Buck Converter Circuit for LED1 Constant Current Control

The analog input channel shifting flow follows the below diagram.

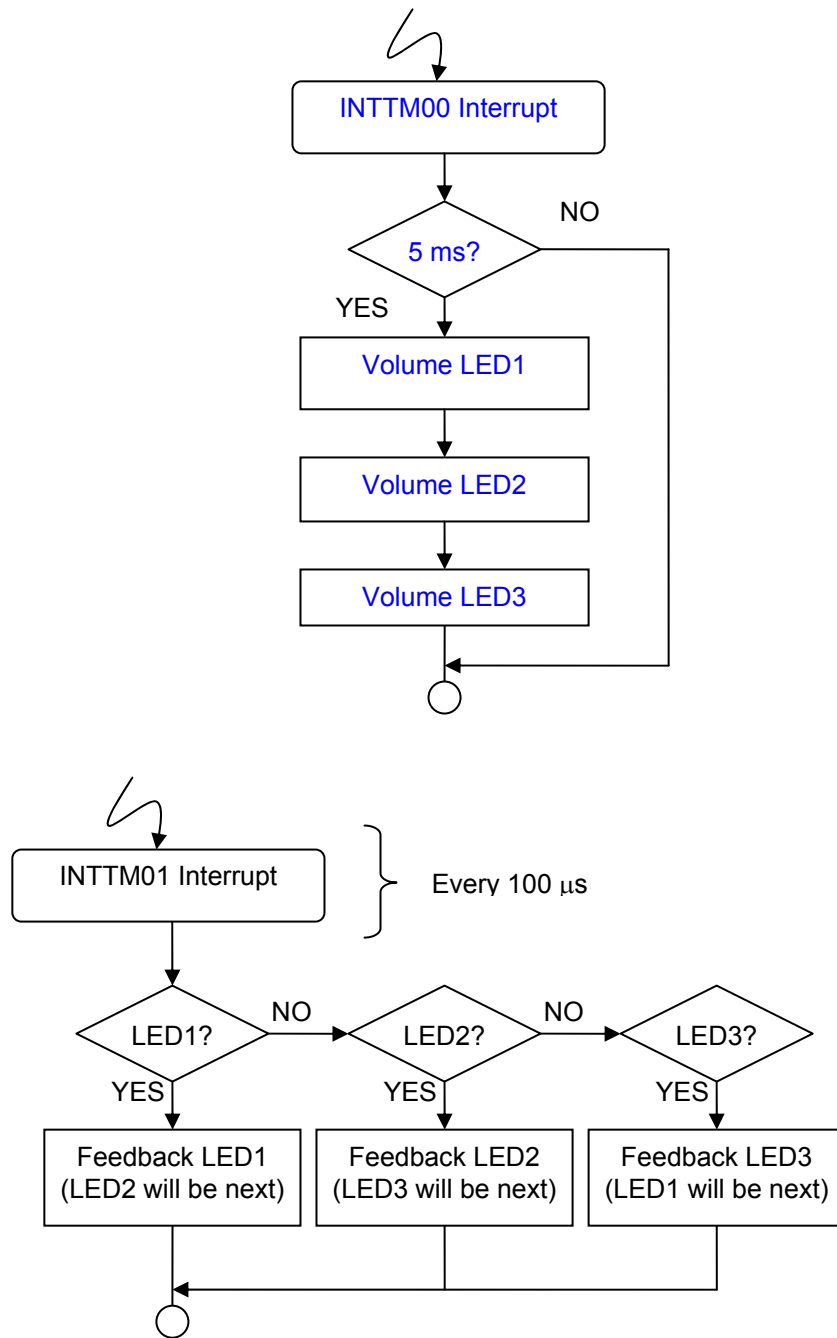


Figure 3-2. Shifting Flow of Analog Input Channels

3.4 PI Control Method

Both constant current control and dimming control (including turning on/off) of the LEDs can be realized by using feedback processing based on the PI control method.

The general equation for PI feedback is as follows.

For information on how to calculate the coefficients A1 and A2, please refer to section 3.5 Calculation of the PI Control Formula's Coefficients.

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

D(n): Latest PWM output duty

D(n-1): Previous PWM output duty

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

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

A1, A2: Coefficients

1) Constant Current Control of the LEDs

The target value of LED current I_{LED} is determined based on the A/D conversion target value. When the A/D conversion target value is X_{TARGET} ^{Note}, the setting method is as follows.

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

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

For example, when constant current control is performed with the LED current $I_{LED} = 350$ mA, set A/D conversion target value $X_{TARGET} = 744$ assuming that the sense resistor $R_s = 1.3$ Ω , A/D converter reference voltage $V_{REF} = 5$ V, and A/D conversion resolution $M = 10$ bits.

The LED current feedback measurement value is amplified through the Programmable Gain Amplifier with a gain of 8, therefore the A/D conversion target value X_{TARGET} needs to be multiplied by 8.

2) Dimming Control of the LEDs

Current dimming control can be performed by changing the target value of the LED constant current. In other words, the A/D conversion target value X_{TARGET} can be changed for dimming. The target value of PI control is changed as a result, and the RL78/I1A microcontroller will perform 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 744 to 216.

3) PGA Input Offset Voltage Compensation

<R>

When using the programmable gain amplifier (PGA), introducing an input offset voltage might cause the input voltage to be amplified to increase or decrease by 5 mV to 10 mV. In this case, the PGA will not supply an accurate voltage to the feedback loop. The sample program takes a positive offset voltage into account and compensates for it.

During the first LED feedback iteration on each channel, that is, when LEDs are still off, the sample program calculates the LED feedback voltage values and saves these values as "offsetLEDn" variables. These values represent the offset voltages induced by the PGA when no current is flowing through the LEDs. In the LED feedback processing, we then subtract these values from the next LED feedback voltage values, when LEDs are lit, to cancel the offset voltage.

Furthermore, the RL78/I1A DC/DC LED Control Evaluation Board has been designed to counteract the effect of positive offset voltages by means of pull-up resistors on each channel feedback circuit (R110, R210 and R310).

The overview of the operation is as follows.

- <1> Start PGA amplification
- <2> Start A/D conversion of the LED feedback voltage (measured through the sense resistor)
- <3> Read the A/D conversion target value.
- <4> Calculate " $A2 \times E(n-1)$ " of PI control taking the offset voltage into account.
- <5> As a result of A/D conversion, if over-current occurs in the LED, stop processing of LED output.
(In this case, do not perform processing for PI control from <6> to <8> below.)
- <6> As a result of A/D conversion, if over-current does not occur in the LED, calculate " $A1 \times E(n) + A2 \times E(n-1)$ " of PI control still taking the offset voltage into account.
- <7> Compare the last PWM output duty " $D(n-1)$ " with the result of <6> " $A1 \times E(n) + A2 \times E(n-1)$." If the calculation result of " $D(n-1) + A1 \times E(n) + A2 \times E(n-1)$ " is within the range between the maximum PWM duty value and the minimum PWM duty value, set the duty $D(n)$ according to the error calculation result, or set the duty $D(n)$ to the maximum or minimum value otherwise.
- <8> Update the duty setting value of PWM output.
- <9> Save the A/D conversion value of the LED feedback voltage as the last one.

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

<R>

```

PGAINS = FEEDBACK_LED1;
PGAEN = ON; /* <1> */
for( ucCount=0; ucCount<20; ucCount++ )
{
    NOP();
}
ADS = PGA_OUTPUT;
ADCS = ON; /* <2> */
while (!ADIF){}
getvalue = ADCR; /* <3> */
ADCS = OFF;
ADIF = 0;
temp11 = VR1 - (FB_LEDAD1_old - offsetLED1); /* <4> */
ErrLED1 = A2 * temp11;
FB_LEDAD1 = (getvalue >> 6) & 0x03FE;
if (feedback_offset == 0)
{
    offsetLED1 = FB_LEDAD1;
}
If ((FB_LEDAD1 - offsetLED1) >= MAXCHECK) /* <5> */
{
    TKBCRLD00 = 0;
    TKBTRG0 = 1;
}
else
{
    temp12 = VR1 - (FB_LEDAD1 - offsetLED1); /* <6> */
    ErrLED1 += A1 * temp12;
    if (ErrLED1 > 0) /* <7> */
    {
        if (0xFFFF000 - Duty_LED1 >= ErrLED1)
        {
            Duty_LED1 += ErrLED1;
        }
        else
        {
            Duty_LED1 = 0xFFFF000;
        }
    }
    else if (ErrLED1 < 0)
    {
        if (Duty_LED1 > - ErrLED1)
        {
            Duty_LED1 += ErrLED1;
        }
        else
        {
            Duty_LED1 = 0;
        }
    }
    else if (VR1 == 0)
    {
        Duty_LED1 = 0;
    }
}
TKBCRLD00 = (unsigned short)(Duty_LED1 >> 8); /* <8> */
}
FB_LEDAD1_old = FB_LEDAD1; /* <9> */
TKBTRG0 = 1;
NOP();

```

3.5 Calculation of the PI Control Formula's Coefficients

This section describes how to calculate the coefficients in the PI control formula shown in section 3.4. The coefficients A1 and A2 can be obtained from the following equations.

$$\begin{aligned} A_1 &= (\pi \times f_z \times T + 1) \times K_P \\ A_2 &= (\pi \times f_z \times T - 1) \times K_P \end{aligned}$$

π : Pi

f_z : Zero point frequency

T: Feedback cycle

K_P : Proportional constant

In other words, the coefficients A1 and A2 can be calculated by determining the 3 parameters: f_z , T and K_P . These parameters can be obtained from the gain of the LED control circuit.

1) Calculation of the zero point frequency (f_z) from the pole point frequencies of the control circuit

As shown in Figure 3-1, this control circuit has two pole points, one for the LC circuit and one for the CR circuit.

These pole point frequencies can be regarded as being equal to the respective cut-off frequencies. Assuming that the former is f_{C1} and the latter is f_{C2} , the following values can be obtained with:

$L_1 = 150 \mu\text{H}$, $C_1 = 20 \mu\text{F}$, $C_2 = 0.1 \mu\text{F}$ and $R_2 = 200 \Omega$.

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

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

We then choose a zero point frequency which is lower than these 2 frequencies, as shown below.

$$f_z = 1.5\text{KHz}$$

2) Calculation of the feedback cycle (T) from the zero point frequency (f_z)

Because of the sampling theorem, the sampling frequency (which is equal to the inverse of the feedback cycle T) must be twice or more than the zero point frequency f_z .

In other words, the relation between the feedback cycle T and the zero point frequency f_z can be described with the following equation.

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

Therefore, as $f_z = 1.5 \text{ kHz}$, the feedback cycle T must be less than $333 \mu\text{s}$.

We also need to consider the CPU load dedicated to the feedback processing. A total of 3 LED channels require constant current feedback control. In this sample program, the CPU load is thus shared in cycles of $100 \mu\text{s}$ to perform feedback control for each LED channel as shown in Figure 3-3 below.

The feedback cycle T is then set as follows.

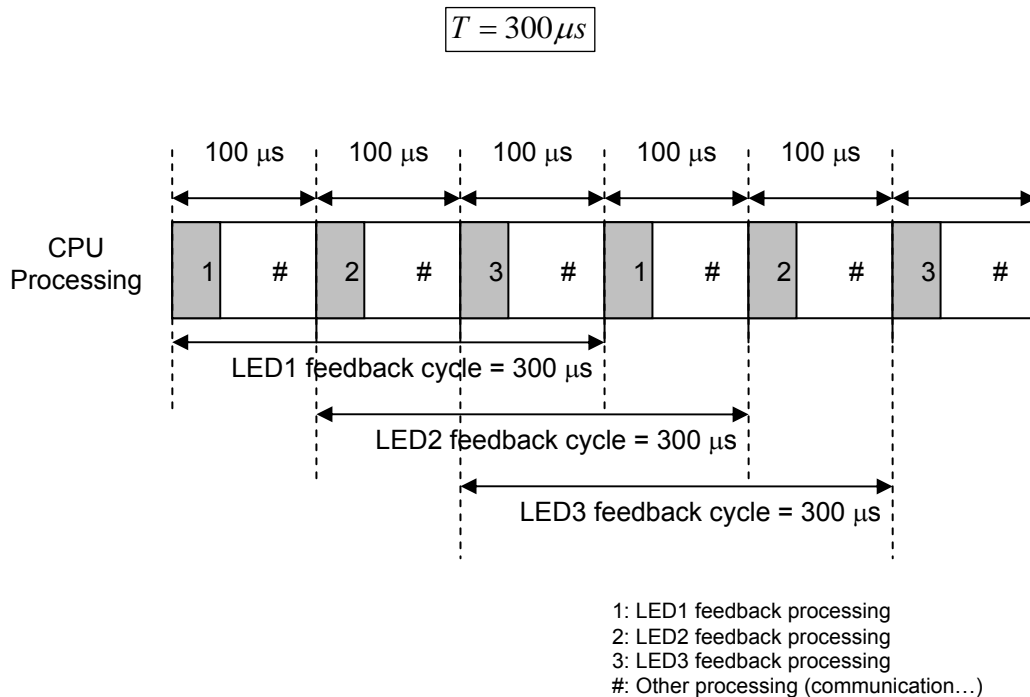


Figure 3-3. Image of the CPU Load Distribution for Feedback Processing

3) Calculation of the proportional constant K_p from the gain (ADC input / PWM output) of the microcontroller

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

First, we need to determine the change in LED current for a specific A/D conversion resolution. When the LED current is I_{LED} , the A/D conversion result of the feedback voltage (through the sense resistor R_S) is X , the A/D conversion resolution is M bits, and the ADC reference voltage is V_{REF} , we can establish the following equation.

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

Here, we call i_{AD} the change in LED current for an A/D conversion value equal to 1 ($X = 1$), and we get the below result.

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

Next, we need to determine the change in LED current for a specific PWM resolution. When the LED current is I_{LED} , total LED forward voltage is V_{FT} , the input voltage is V_I , the (PWM output duty register value +1) is Y , and the PWM output resolution is N bits, we can establish the following equation.

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

Here, we call i_{PWM} the change in LED current for a PWM duty value equal to 1 ($Y = 1$), furthermore the LED forward voltage remains constant, so we get the below result.

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

Therefore, the gain i_{PWM} / i_{AD} can be deduced from the above equations.

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

Considering that the A/D conversion resolution M is 13 bits (10 bits of the ADC + 3 bits of the PGA because of the $2^3 = 8$ amplification gain), the PWM output resolution N is 12 bits (8 bits of the PWM + 4 more bits because of the dithering function), the input voltage V_I is 5 V, and the A/D converter reference voltage V_{REF} is 5 V, we then get the following gain result (A/D converter input / PWM output).

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

The proportional constant K_P must be set to a value smaller than the inverse of this gain.

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

We choose K_P as follows.

$$K_P = 0.3$$

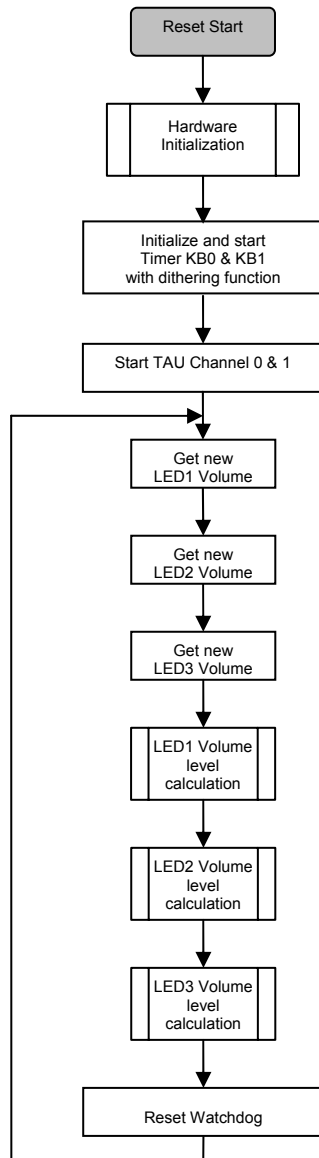
From the above results, we can then calculate the PI control coefficients A_1 and A_2 .

$$\begin{matrix} A_1 = 0.724 \\ A_2 = 0.124 \end{matrix}$$

In the sample program, both coefficients are multiplied by 2^8 (= 256) as well as the PWM duty and error values in order to get integer variables and make computations easier.

$$\begin{matrix} A_1 = 185 \\ A_2 = 32 \end{matrix}$$

3.6 Software Flow Charts



Get new LEDn Volume:
function gets the 8-bit A/D conversion result from the variable resistors (variable 'chn*_level' in the sample program)

LEDn Volume level processing:
function converts the 8-bit A/D conversion result (variable 'level' in the sample program) into a 16-bit variable within the feedback A/D conversion range (variable 'VRn*' in the sample)

*n = 1, 2 or 3

Figure 3-4. Main Program Loop Flow Chart

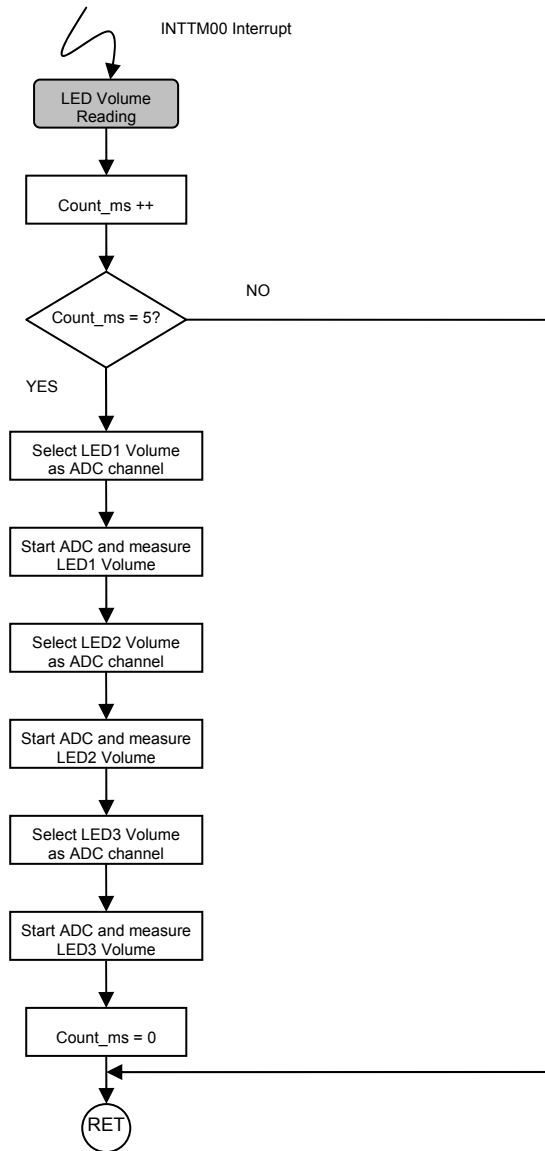


Figure 3-5. LEDn Volume Reading Flow Chart

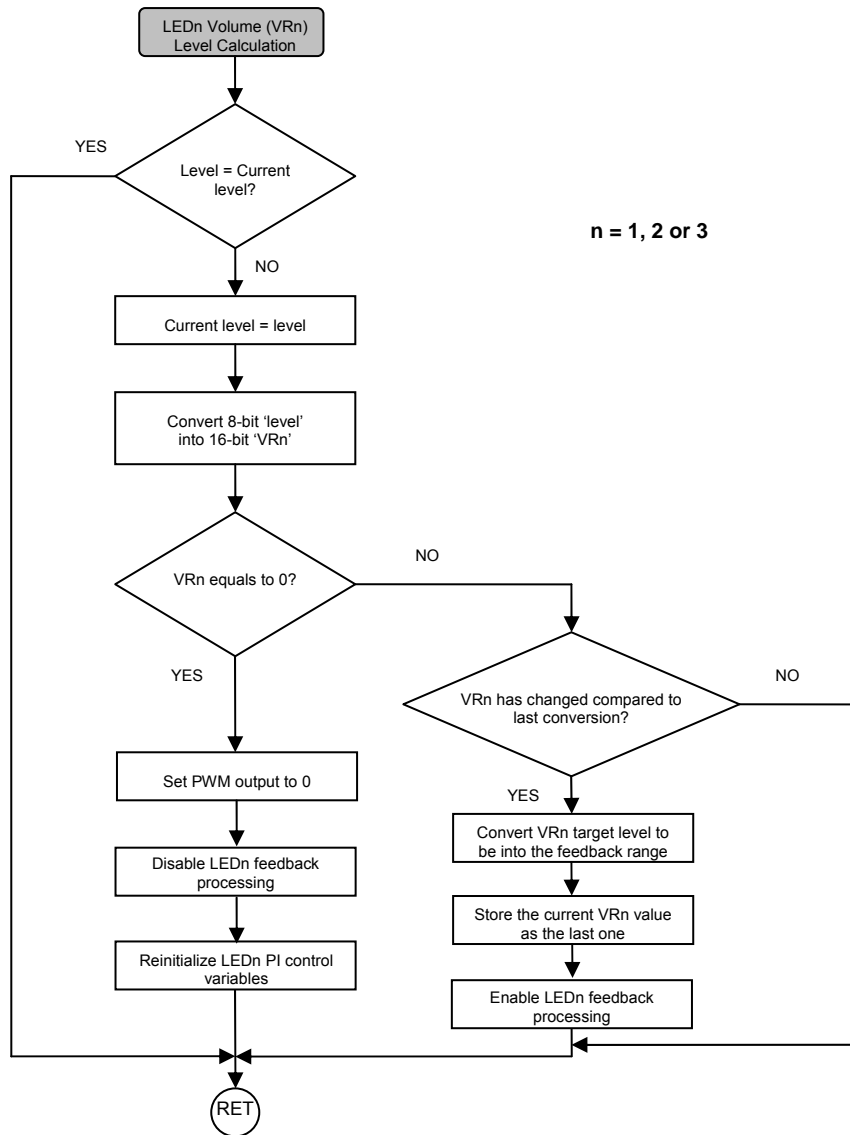


Figure 3-6. LEDn Volume (VRn) Processing Flow Chart (n = 1, 2, 3)

<R>

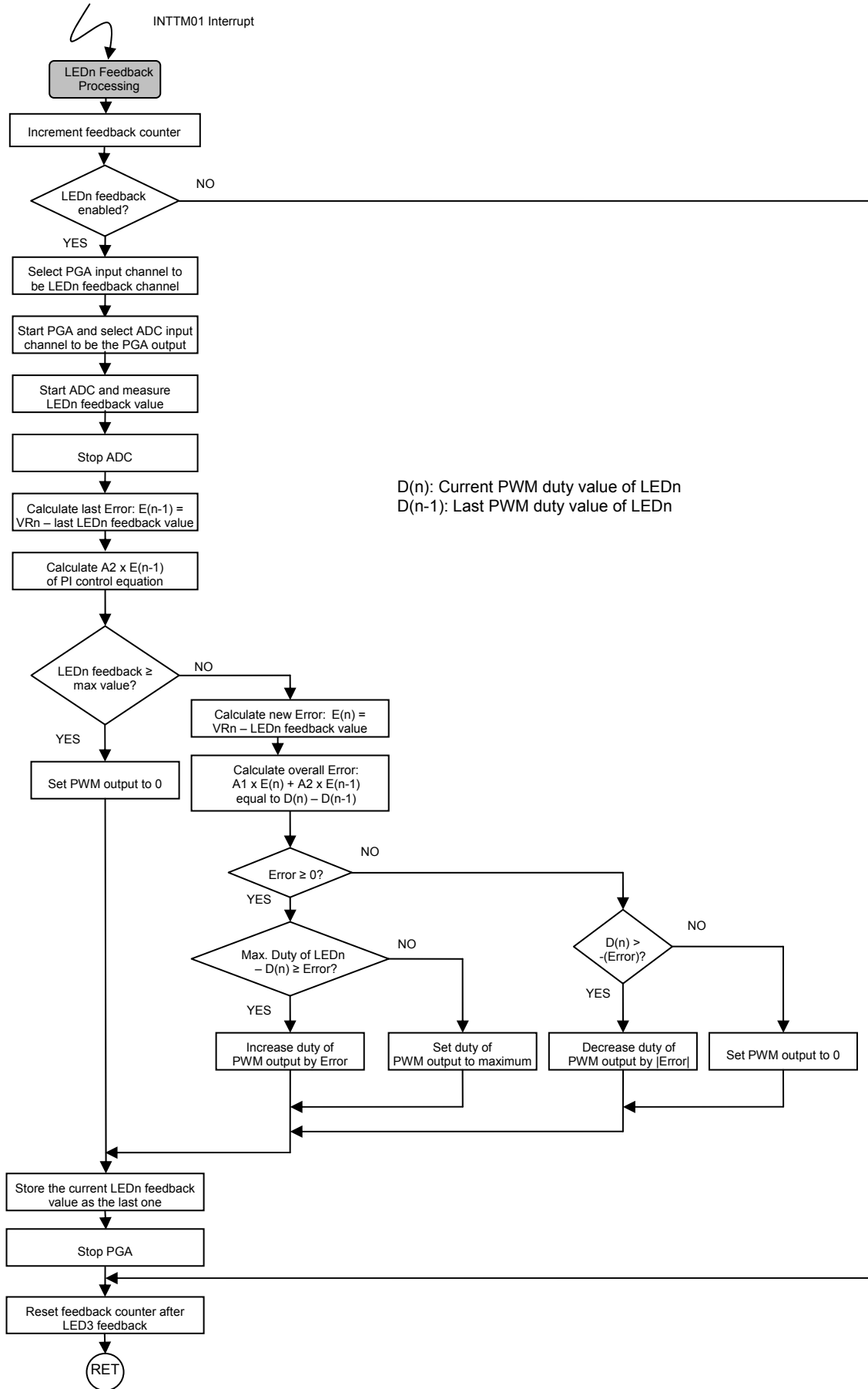


Figure 3-7. LEDn Feedback Processing Flow Chart (n = 1, 2, 3)

4. Get Started Quickly with the RL78/I1A DC/DC LED Control Evaluation Board

Follow the steps below before starting evaluating the RL78/I1A DC/DC LED Control Evaluation Board using the sample program provided.

<R> The below steps will guide you through the process of downloading the sample program into the RL78/I1A flash memory using the RFP (Renesas Flash Programmer) software tool.

1. Select the "Flash Programming Mode" by set SW2 bit 3-5-7 to ON position to allow Flash programming (all other bits must be set to OFF position).
2. Connect a 5 V power supply to the CN1 DC jack connector.
3. Connect the RL78/I1A DC/DC LED Control Evaluation Board to a PC USB port using a Type A - Mini-B USB cable.

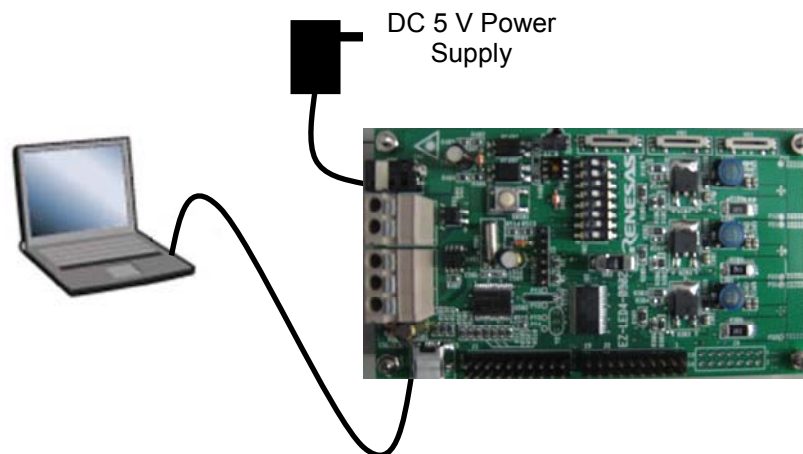


Figure 4-1. System Environment

<R> 4. Open the RFP Flash Programmer tool.

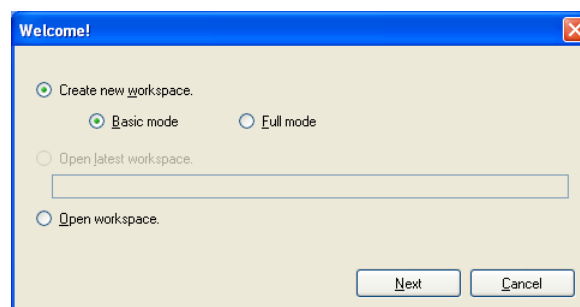


Figure 4-2. RFP Main Window

<R> 5. Select **Create new workspace** and then click **Next**. The **Create new workspace** dialog box opens. Select R5F017DE under **Device Name**. Specify the COM port used for communication between the host computer and the evaluation board.

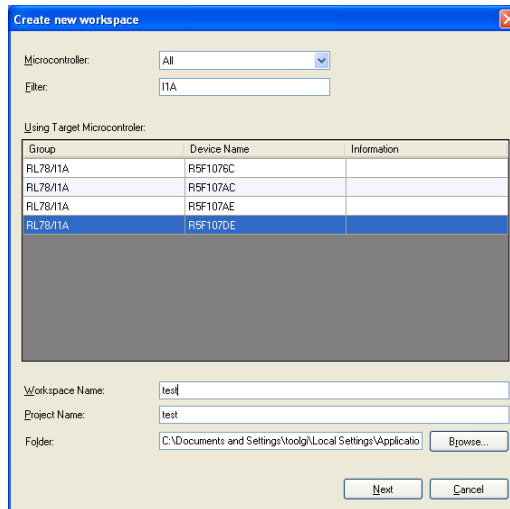


Figure 4-3. RFP Flash Programmer Tool - Create new workspace Dialog Box

- <R> 6. Select the hex file of the sample program to be written.
- <R> 7. Click **Next** to start writing the sample program to the flash memory in the RL78/I1A.
- <R> 8. Exit RFP when flash programming finishes.

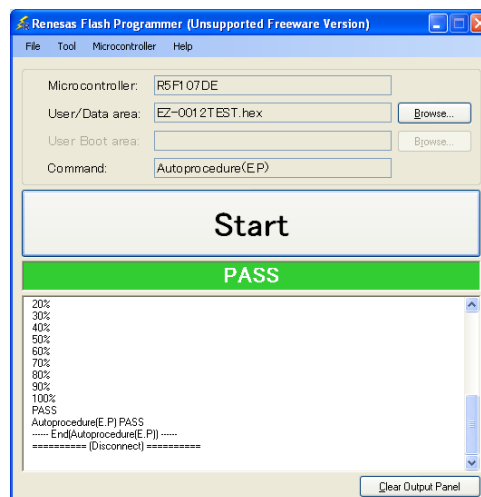
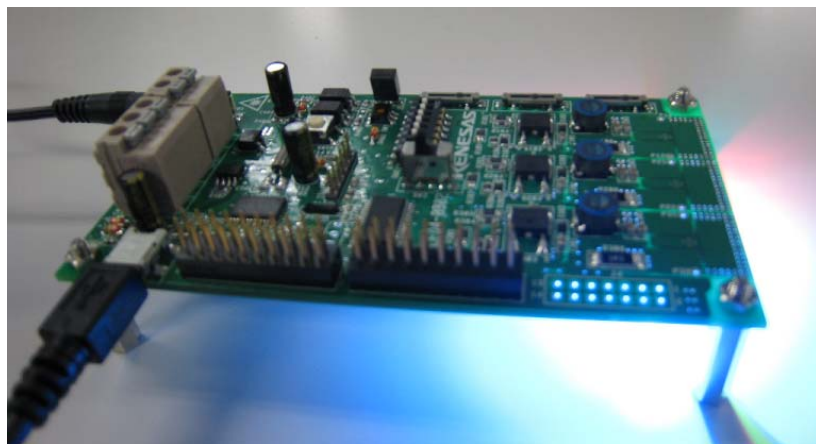


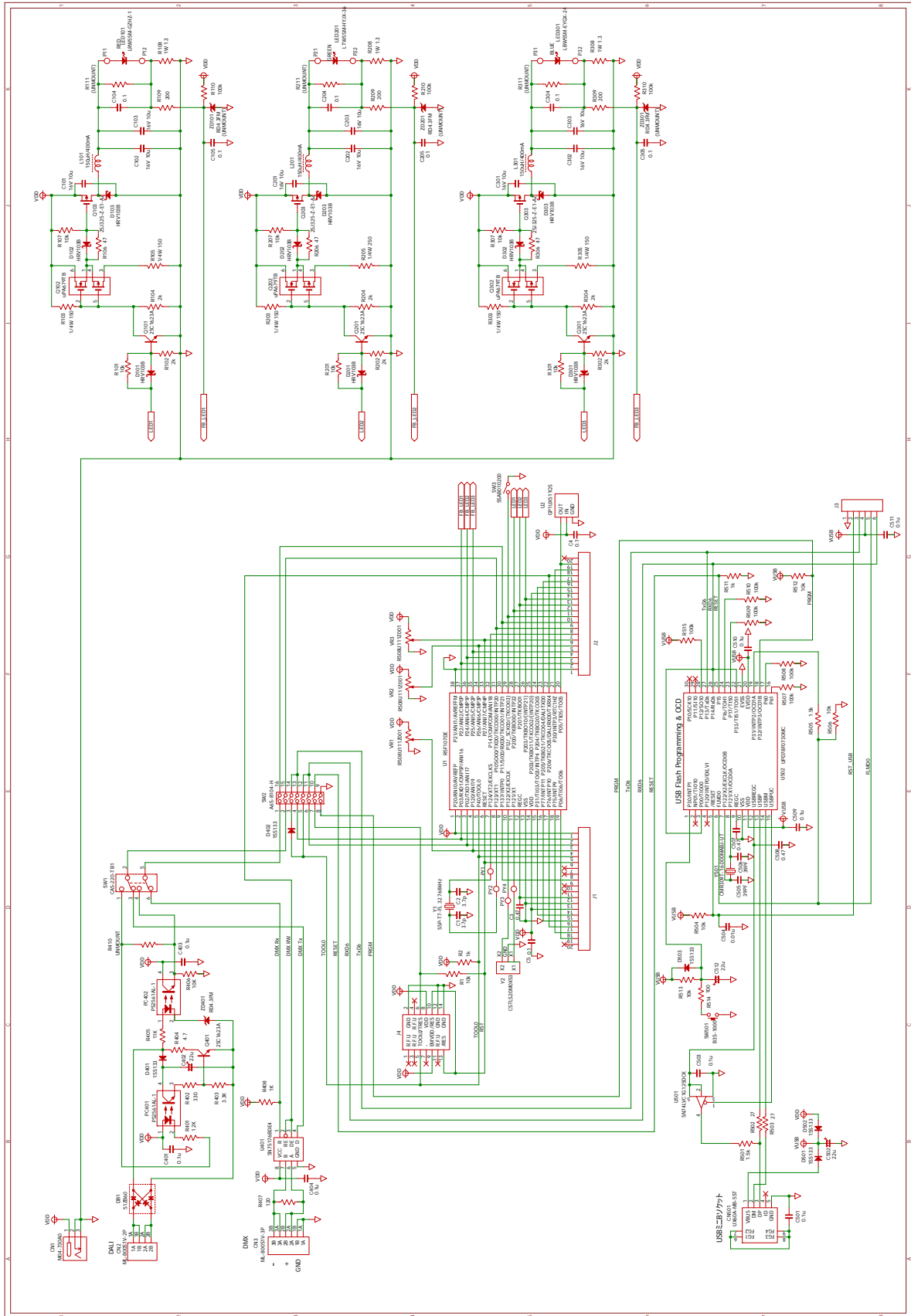
Figure 4-4. RFP Flash Programmer Tool - Programming Complete Window

9. Disconnect the 5 V power supply and the USB cable.
10. Select the "Run Mode" by set SW2 bits 7-8 to "ON" position (all other bits must be set to OFF position).
11. Plug the DC 5 V power supply again to CN1 connector.
12. Move slide switches VR1 to VR3 (variable resistors), and observe that the brightness of the LEDs is changing.
13. Disconnect the DC 5 V power supply from the CN1 connector when evaluation is complete.

APPENDIX A Pictures



APPENDIX B Schematic



Website and Support

Renesas Electronics Website

<http://www.renesas.com/>

Inquiries

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

REVISION HISTORY	RL78/I1A – LED Control Using RL78/I1A Application Note
-------------------------	---

Rev.	Date	Description	
		Page	Summary
1.00	Mar. 23, 2012	—	First edition issued
2.01	Mar. 26, 2013	p. 1	Change of description in Readers
		p. 3	Change of description in 1. Introduction
		p. 4	Change of description in 2.1 RL78/I1A Features for LED System Control
		p. 5	Change of description in 2.2 System Block Diagram
		p. 7	Change of description in 3. LED Control Software Description
		p. 11	Change of description in 3.3 Constant Current and Dimming Control
		p. 14	Change of description in 3.4 3) PGA Input Offset Voltage Compensation
		p. 15	Modification of code in 3.4 3) PGA Input Offset Voltage Compensation
		p. 22	Change of Figure 3-7. LEDn Feedback Processing Flow Chart (n = 1, 2, 3)
		pp. 23, 24	4. Get Started Quickly with the RL78/I1A DC/DC LED Control Evaluation Board Change of WriteEZ6 to REP Change of description and screenshots in steps 4 to 8

All trademarks and registered trademarks are the property of their respective owners.

General Precautions in the Handling of MPU/MCU Products

The following usage notes are applicable to all MPU/MCU products from Renesas. For detailed usage notes on the products covered by this manual, refer to the relevant sections of the manual. If the descriptions under General Precautions in the Handling of MPU/MCU Products and in the body of the manual differ from each other, the description in the body of the manual takes precedence.

1. Handling of Unused Pins

Handle unused pins in accord 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 unused pin in the open-circuit state, extra electromagnetic noise is induced in the vicinity of 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. Unused pins should be handled as described under Handling of Unused Pins in the manual.

2. Processing at Power-on

The state of the product is undefined at the moment 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 moment 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 moment 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 moment when power is supplied until the power reaches the level at which resetting has been specified.

3. Prohibition of Access to Reserved Addresses

Access to reserved addresses is prohibited.

- The reserved addresses are provided for the possible future expansion of functions. Do not access these addresses; the correct operation of LSI is not guaranteed if they are accessed.

4. Clock Signals

After applying a reset, only release the reset line after the operating clock signal has become stable. When switching the clock signal during program execution, wait until the target clock signal has 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. Moreover, 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.

5. Differences between Products

Before changing from one product to another, i.e. to one with a different part number, confirm that the change will not lead to problems.

- The characteristics of MPU/MCU in the same group but having different part numbers may differ because of the differences in internal memory capacity and layout pattern. When changing to products of different part numbers, implement a system-evaluation test for each of the products.

Notice

1. Descriptions of circuits, software and other related information in this document are provided only to illustrate the operation of semiconductor products and application examples. You are fully responsible for the incorporation of these circuits, software, and information in the design of your equipment. Renesas Electronics assumes no responsibility for any losses incurred by you or third parties arising from the use of these circuits, software, or information.
 2. Renesas Electronics has used reasonable care in preparing the information included in this document, but Renesas Electronics does not warrant that such information is error free. Renesas Electronics assumes no liability whatsoever for any damages incurred by you resulting from errors in or omissions from the information included herein.
 3. Renesas Electronics does not assume any liability for infringement of patents, copyrights, or other intellectual property rights of third parties by or arising from the use of Renesas Electronics products or technical information described in this document. No license, express, implied or otherwise, is granted hereby under any patents, copyrights or other intellectual property rights of Renesas Electronics or others.
 4. You should not alter, modify, copy, or otherwise misappropriate any Renesas Electronics product, whether in whole or in part. Renesas Electronics assumes no responsibility for any losses incurred by you or third parties arising from such alteration, modification, copy or otherwise misappropriation of Renesas Electronics product.
 5. Renesas Electronics products are classified according to the following two quality grades: "Standard" and "High Quality". The recommended applications for each Renesas Electronics product depends on the product's quality grade, as indicated below.
"Standard": Computers; office equipment; communications equipment; test and measurement equipment; audio and visual equipment; home electronic appliances; machine tools; personal electronic equipment; and industrial robots etc.
"High Quality": Transportation equipment (automobiles, trains, ships, etc.); traffic control systems; anti-disaster systems; anti-crime systems; and safety equipment etc.
Renesas Electronics products are neither intended nor authorized for use in products or systems that may pose a direct threat to human life or bodily injury (artificial life support devices or systems, surgical implantations etc.), or may cause serious property damages (nuclear reactor control systems, military equipment etc.). You must check the quality grade of each Renesas Electronics product before using it in a particular application. You may not use any Renesas Electronics product for any application for which it is not intended. Renesas Electronics shall not be in any way liable for any damages or losses incurred by you or third parties arising from the use of any Renesas Electronics product for which the product is not intended by Renesas Electronics.
 6. You should use the Renesas Electronics products described in this document within the range specified by Renesas Electronics, especially with respect to the maximum rating, operating supply voltage range, movement power voltage range, heat radiation characteristics, installation and other product characteristics. Renesas Electronics shall have no liability for malfunctions or damages arising out of the use of Renesas Electronics products beyond such specified ranges.
 7. Although Renesas Electronics endeavors to improve the quality and reliability of its products, semiconductor products have specific characteristics such as the occurrence of failure at a certain rate and malfunctions under certain use conditions. Further, Renesas Electronics products are not subject to radiation resistance design. Please be sure to implement safety measures to guard them against the possibility of physical injury, and injury or damage caused by fire in the event of the failure of a Renesas Electronics product, such as safety design for hardware and software including but not limited to redundancy, fire control and malfunction prevention, appropriate treatment for aging degradation or any other appropriate measures. Because the evaluation of microcomputer software alone is very difficult, please evaluate the safety of the final products or systems manufactured by you.
 8. Please contact a Renesas Electronics sales office for details as to environmental matters such as the environmental compatibility of each Renesas Electronics product. Please use Renesas Electronics products in compliance with all applicable laws and regulations that regulate the inclusion or use of controlled substances, including without limitation, the EU RoHS Directive. Renesas Electronics assumes no liability for damages or losses occurring as a result of your noncompliance with applicable laws and regulations.
 9. Renesas Electronics products and technology may not be used for or incorporated into any products or systems whose manufacture, use, or sale is prohibited under any applicable domestic or foreign laws or regulations. You should not use Renesas Electronics products or technology described in this document for any purpose relating to military applications or use by the military, including but not limited to the development of weapons of mass destruction. When exporting the Renesas Electronics products or technology described in this document, you should comply with the applicable export control laws and regulations and follow the procedures required by such laws and regulations.
 10. It is the responsibility of the buyer or distributor of Renesas Electronics products, who distributes, disposes of, or otherwise places the product with a third party, to notify such third party in advance of the contents and conditions set forth in this document, Renesas Electronics assumes no responsibility for any losses incurred by you or third parties as a result of unauthorized use of Renesas Electronics products.
 11. This document may not be reproduced or duplicated in any form, in whole or in part, without prior written consent of Renesas Electronics.
 12. Please contact a Renesas Electronics sales office if you have any questions regarding the information contained in this document or Renesas Electronics products, or if you have any other inquiries.
- (Note 1) "Renesas Electronics" as used in this document means Renesas Electronics Corporation and also includes its majority-owned subsidiaries.
(Note 2) "Renesas Electronics product(s)" means any product developed or manufactured by or for Renesas Electronics.



SALES OFFICES

Renesas Electronics Corporation

<http://www.renesas.com>

Refer to "<http://www.renesas.com/>" for the latest and detailed information.

Renesas Electronics America Inc.
2880 Scott Boulevard Santa Clara, CA 95050-2554, U.S.A.
Tel: +1-408-588-6000, Fax: +1-408-588-6130

Renesas Electronics Canada Limited
1101 Nicholson Road, Newmarket, Ontario L3Y 9C3, Canada
Tel: +1-905-898-5441, Fax: +1-905-898-3220

Renesas Electronics Europe Limited
Dukes Meadow, Millboard Road, Bourne End, Buckinghamshire, SL8 5FH, U.K.
Tel: +44-1628-651-700, Fax: +44-1628-651-804

Renesas Electronics Europe GmbH
Arcadiastrasse 10, 40472 Düsseldorf, Germany
Tel: +49-211-65030, Fax: +49-211-6503-1327

Renesas Electronics (China) Co., Ltd.
7th Floor, Quantum Plaza, No.27 ZhiChunLu Haidian District, Beijing 100083, P.R.China
Tel: +86-10-8235-1155, Fax: +86-10-8235-7679

Renesas Electronics (Shanghai) Co., Ltd.
Unit 204, 205, AZIA Center, No.1233 Lujiazui Ring Rd., Pudong District, Shanghai 200120, China
Tel: +86-21-5877-1818, Fax: +86-21-6887-7858 / -7898

Renesas Electronics Hong Kong Limited
Unit 1601-1613, 16/F., Tower 2, Grand Century Place, 193 Prince Edward Road West, Mongkok, Kowloon, Hong Kong
Tel: +852-2886-9318, Fax: +852 2886-9022/9044

Renesas Electronics Taiwan Co., Ltd.
13F, No. 363, Fu Shing North Road, Taipei, Taiwan
Tel: +886-2-8175-9600, Fax: +886 2-8175-9670

Renesas Electronics Singapore Pte. Ltd.
80 Bendemeer Road, Unit #06-02 Hyflux Innovation Centre Singapore 339949
Tel: +65-6213-0200, Fax: +65-6213-0300

Renesas Electronics Malaysia Sdn.Bhd.
Unit 906, Block B, Menara Amcorp, Amcorp Trade Centre, No. 18, Jln Persiaran Barat, 46050 Petaling Jaya, Selangor Darul Ehsan, Malaysia
Tel: +60-3-7955-9390, Fax: +60-3-7955-9510

Renesas Electronics Korea Co., Ltd.
11F., Samik Laved' or Bldg., 720-2 Yeoksam-Dong, Kangnam-Ku, Seoul 135-080, Korea
Tel: +82-2-558-3737, Fax: +82-2-558-5141