APPLICATION NOTE

78K0/Ix2 Microcontrollers

78K0/Ix2 Microcontrollers

LED Lighting System with PFC Control

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Readers The target readers of this document are user engineers who design and develop LED lighting systems and power supply systems.

The target products are as follows:

- •78K0/IB2: μPD78F0745, 78F0746, 78F0755, 78F0756
- •78K0/IA2: μPD78F0743, 78F0744, 78F0753, 78F0754
- •78K0/IY2: μPD78F0740, 78F0741, 78F0742, 78F0750, 78F0751, 78F0752

Purpose The purpose of this document is to describe the features and the control methods for the LED lighting system with PFC control using the 78K0/Ix2 microcontroller.

Caution The sample programs are for reference only. We do not guarantee their operation. Before using the sample programs, evaluate them thoroughly on the user's set.

CONTENTS

CHAPTER 1 OVERVIEW

1.1 Introduction

Lighting accounts for about 16% of domestic household power consumption (Figure 1-1). The use of LED's in lighting has been increasingly popular in recent years due to the reduction of CO_2 emissions and the needs for energy saving. This is because LED lighting has higher luminance efficiency and a longer life than the conventional incandescent bulbs or fluorescent lights. For energy saving in systems, there are greater needs for optimal ON/OFF control and dimming control for lighting using communication and sensors, and lighting system control with microcontrollers is required. On the other hand, there are greater needs for low costs for promoting LED lighting. There have been many cases in which board platforms are used to reduce development man-hours or the functions of analog control IC's are built into a microcontroller.

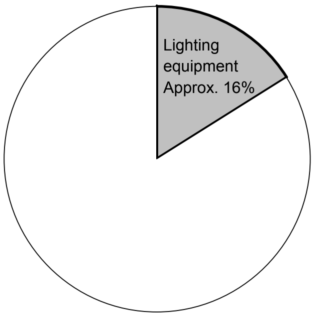


Figure 1-1. Percentage of Lighting Equipment in Domestic Household Power Consumption

With these needs, this application note describes the features, system configuration, and control methods of LED lighting system with the 78K0/Ix2 microcontroller by using the LED lighting evaluation board with PFC control EZ-0011 (Photo 1-1) as an example. To purchase the EZ-0011, contact Renesas Electronics sales office or distributor.

Photo 1-1. External Appearance of EZ-0011

1.2 Features of LED Lighting System Control with 78K0/Ix2

The LED lighting system with the 78K0/Ix2 microcontroller has the following features:

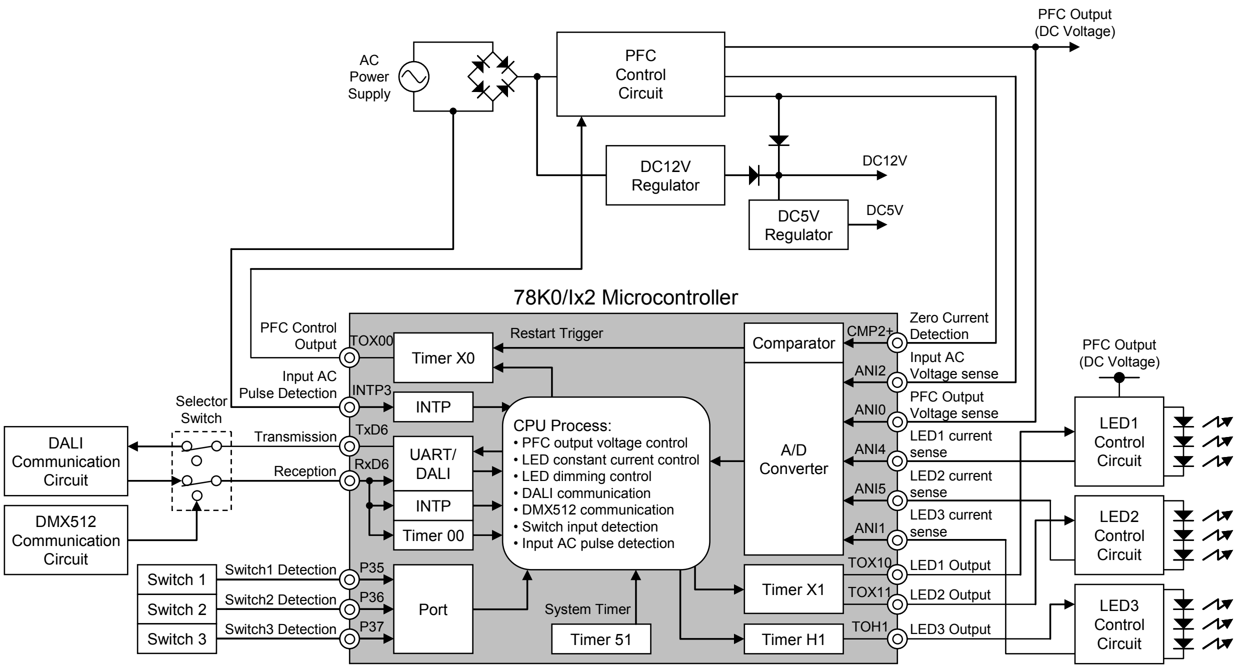
- Allows LED constant current/dimming control of up to 6 channels with the timer output function of the 16-bit timers X0, X1, 00 and 8-bit timer H1. This eliminates the need for an IC for LED constant current control, reducing the cost of the set.
- Allows power factor correction (PFC) control with the timer restart function that works with the comparator of the 16-bit timer X0. This eliminates the need for an IC for PFC control, reducing the cost of the set.
- Realizes the protective function that causes emergency stop of PWM output immediately (without the CPU) in case of a detection of overcurrent or overvoltage in the LED or PFC control part by using the high impedance output function that works with the comparator of the 16-bit timers X0 and X1. This eliminates the need for a dedicated protective circuit with an external comparator, reducing the cost of the set. Furthermore, operation after the emergency stop can be controlled by software, realizing a flexible protective function according to the system.
- Realizes transmission and reception of Manchester codes (transmission: 11 bits, reception: 19 bits) in compliance with the DALI communication standard with built-in hardware by using the DALI communication slave function of the serial interface UART6/DALI. This can reduce CPU load during data transmission and reception.
- The reception pin RxD6 of the serial interface UART6/DALI can be connected to the external interrupt pin INTP0 and the capture input pin TI000 of the 16-bit timer 00 inside the microcontroller. This realizes stand-by mode cancellation during the break period reception (low level for 88 μs to 1 s) of DMX512 communication as well as pulse width measurement during the break period.
- Realizes pulse width measurement during infrared remote control signal reception [Note] with hardware by using the pulse width measurement function of the 16-bit timer 00. This can reduce CPU load during data reception.
- Flexibly realizes time management and control during sensor detection [Note] with software processing of the microcontroller.

Note The EZ-0011 does not incorporate a reception circuit for infrared remote control signals or sensor detection circuit.

1.3 System Block Diagram

Figure 1-2 shows the system block diagram of the EZ-0011. This LED lighting system performs PFC control and LED×3ch control based on DALI communication, DMX512 communication, and switch input. The system has a feature of being able to achieve these controls with only one 78K0/Ix2 microcontroller without using any IC for PFC control or LED constant current control.

Figure 1-2. LED Lighting System Block Diagram with 78K0/Ix2 Microcontroller



1.4 Pin Functions of 78K0/Ix2

Table 1-1 shows the assignments of the major pins of the 78K0/Ix2 microcontroller in the EZ-0011.

Table 1-1. Port Pin Assignment of 78K0/Ix2 Microcontroller

Function	Description	Function name	Port name	I/O	78K0/ IY2 (16 pin)	78K0/ IA2 (20 pin)	78K0/ IB2 (30 pin/ 32 pin)
LED control	LED1 PWM output	TOX10	P33	O	√	√	√
	LED2 PWM output	TOX11	P34	O	√	√	√
	LED3 PWM output	TOH1	P30	O	—	√ Note 1	√ Note 1
	LED1 current monitoring analog input	ANI4	P24	I	√	√	√
	LED2 current monitoring analog input	ANI5	P25	I	√	√	√
	LED3 current monitoring analog input	ANI1	P21	I	√	√	√
	LED1 anode voltage monitoring analog input Note 2	ANI6	P26	I	—	—	√
	LED2 anode voltage monitoring analog input Note 2	ANI7	P27	I	—	—	√
	LED3 anode voltage monitoring analog input Note 2	ANI8	P70	I	—	—	√
PFC control	PFC output	TOX00	P31	O	√	√	√
	Zero current detection comparator input	CMP2+	P23	I	√	√	√
	DC output voltage monitoring analog input	ANI0	P20	I	√	√	√
	AC power supply voltage monitoring analog input	ANI2	P22	I	—	√	√
Communication	DALI communication transmission output	TxD6	P60	O	—	√	√
	DALI communication/DMX512 communication reception input	RxD6	P61	I	—	√	√
Other	Switch 1 input	P35	P35	I	—	—	√
	Switch 2 input	P36	P36	I	—	—	√
	Switch 3 input	P37	P37	I	—	—	√
	AC power supply monitoring interrupt input	INTP3	P32	I	√	√	√

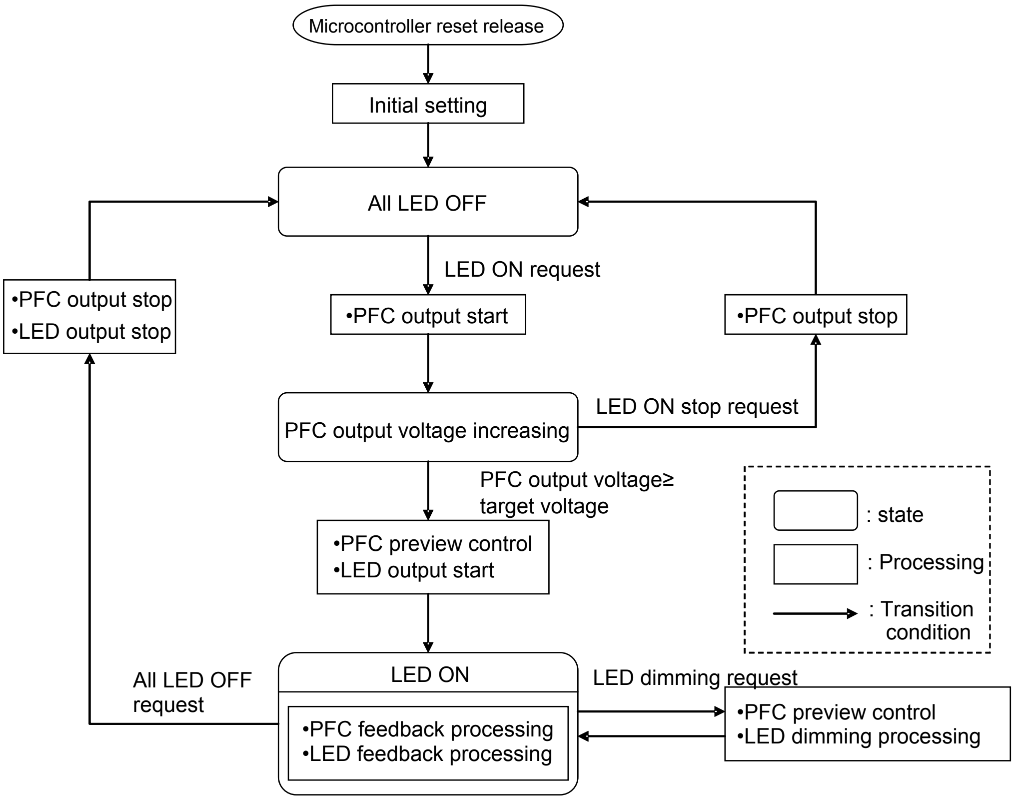
Notes 1. For 78K0/IA2 and 78K0/IB2 (32 pin), use the P00/TOH1 pin.

2. This pin is not required for LED constant current/dimming control. It can be used for open/short-circuit destruction detection of the LED.

1.5 System Operation Overview

Figure 1-3 shows the state transition diagram of LED lighting control with PFC control with the 78K0/Ix2 microcontroller. The states can be classified into 3 categories: All LED Off, PFC Output Voltage Increasing, and LED ON. These states may change mainly based on DALI communication, DMX512 communication, and switch input.

Figure 1-3. State Transition Diagram of LED Lighting Control with PFC Control with 78K0/Ix2 Microcontroller



<Definitions of transition conditions>

LED ON request: A request to turn on one or more LED's among LED's 1 to 3.

LED ON stop request: A request to turn off all the LED's that are planned to be turned ON, or a request to stop increasing of the PFC output voltage in case of an error (when the target voltage is not reached after a certain period of time from the start of increasing of the PFC output voltage, or when overvoltage of the PFC output voltage is detected)

PFC output voltage ≥ Target voltage:

The PFC output voltage reaches the target voltage (70V for the EZ-0011)

LED dimming request: A request to dim or turn off the LED's that are ON, or a request to turn on the LED's that are OFF

All LED OFF request: A request to turn off all the LED's that are ON

CHAPTER 2 CONTROL METHODS FOR VARIOUS FUNCTIONS

This chapter describes the overview and software design methods for LED control and PFC control with the 78K0/Ix2 microcontroller.

Remark For the protective function and the control method for DALI communication, refer to the following document.

- Controlling Fluorescent Lamp Ballasts by Using 78K0/Ix2 Application Note (U19665E)

For the control method for DMX512 communication, refer to the following document.

- Controlling high brightness LED by using 78K0/Ix2 Application Note (U19666E)

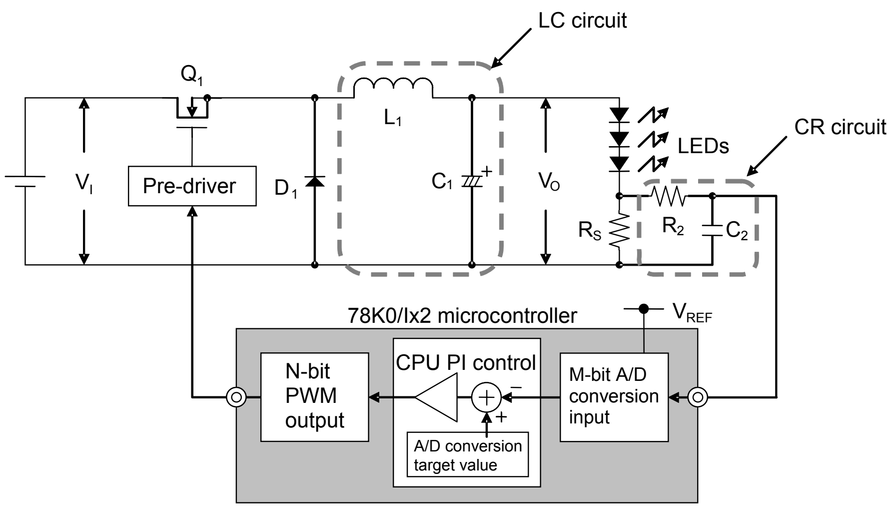
2.1 LED Control

2.1.1 LED control overview

The 78K0/Ix2 microcontroller can perform constant current control of the LED by using timer output and A/D converter input in combination. Therefore, no separate analog IC for constant current control is required in addition to the microcontroller.

Figure 2-1 shows the fly-back converter circuit for LED constant current control actually used in the EZ-0011.

Figure 2-1. Fly-back Converter Circuit for LED Constant Current Control



When Q1 is switched at a constant PWM frequency, the following relationship holds between the input voltage V_I and output voltage V_O according to the on duty D (=ON time of Q1/PWM switching cycle of Q1) Note:

$$V_O = V_I \cdot D$$

Note For simplicity, the formula does not include forward voltage of the diode D1 that has a small impact.

This means that output voltage V_O can be controlled by controlling the on duty D of PWM output. Actually, in the EZ-0011, when the on duty D of PWM output is about 71% when the input voltage V_I = 70V (=PFC output voltage), the output voltage V_O becomes about 50V.

Next, the current I_{LED} flowing through the LED can be obtained from the total forward voltage of the LED V_{FT} and sense resistance R_S as follows:

$$I_{LED} = \frac{V_O - V_{FT}}{R_S}$$
$$= \frac{V_I \cdot D - V_{FT}}{R_S}$$

This formula indicates that constant current control of the LED current I_{LED} can be achieved by controlling the voltage $V_O - V_{FT}$ to a constant value. If V_{FT} is a known constant value, it seems possible to check if the LED current I_{LED} is the target current value by monitoring the output voltage V_O at the A/D converter. However, in reality, V_{FT} varies among individual LED's, so it is necessary to monitor the voltage $V_O - V_{FT}$ of the sense resistance R_S rather than the output voltage V_O to check if the LED current I_{LED} is the target current value. In other words, constant current control is performed for the LED current I_{LED} to the target current value by feeding back the voltage value of the sense resistance R_S to the on duty D of PWM output.

Next, the peripheral hardware of the 78K0/Ix2 microcontroller used for LED constant current/dimming control in the EZ-0011 and their functions are shown below.

- 16-bit timer X1: PWM output ×2 channels
- 8-bit timer H1: PWM output ×1 channel
- A/D converter: LED current monitoring

The features of the peripheral hardware are as follows:

- 16-bit timer X1 can output two PWM's with different duties with the same cycle.
- Up to 40 MHz can be selected for count clock of the 16-bit timer X1, and up to 20 MHz can be selected for count clock of the 8-bit timer H1.
- Both 16-bit timer X1 and 8-bit timer H1 can change the duty of PWM output without stopping timer operation.
- LED current can be detected by the A/D converter with up to 10-bit resolution.

2.1.2 LED control software design

This section describes software design examples of LED control with 16-bit timer X1 output.

(1) Initial setting of LED control

Before starting LED control, the peripheral hardware of the 78K0/Ix2 microcontroller needs to be initialized. The following is an initial setting sample program for the 16-bit timer X1.

```
TX1CTL0 = 0b00000000;     /* Sets count clock to 40 MHz Note */
TX1CTL1 = 0b00001000;     /* Dual output (TOX10,TOX11 terminal output),TMX1-only single start
                             mode */
TX1IOC0 = 0b00001100;     /* Sets the default output state of TOX10 and TOX11 to LOW level
                             Permits output of TOX10 and TOX11*/
```

Note When the PLL clock mode is used and the supply clock to the 16-bit timer X1 is set to 40 MHz.

In the actual initial setting, clock setting, port setting, and interrupt setting are required in addition to the above. For details, refer to **78K0/Ix2 Hardware User's Manual (R01UH0010E)**.

(2) Starting LED control

An example of setting procedure to start LED control is shown below. In this example, PWM duty control for turning on the LED is done by using "D) Constant current control/dimming control of the LED" that will be described later. Immediately after the start of PWM output <3>, PWM output will be 0% duty, which is the default level output. The duty according to the LED current value will be output after feedback processing by PI control.

<1> Set the initial duty of PWM output to 0.
<2> Set the frequency of PWM output.
<3> Start PWM output.

Sample programs for <1> through <3> are shown below.

```
TX1CR0 = LED_CYCLE;     /* <1> Sets the duty of TOX10 output to 0. */
TX1CR1 = LED_CYCLE;     /* <1> Sets the duty of TOX10 output to 0. */
TX1CR2 = LED_CYCLE;     /* <1> Sets the duty of TOX11 output to 0. */
TX1CR3 = LED_CYCLE;     /* <2> Sets the timer X1 output frequency. */
TX1TMC = 1;             /* <3> Permits count operation of the timer X1. */
```

Remark "LED_CYCLE" in the sample program is actually defined to be "255." Therefore, as the count clock of the timer X0 is set to 40 MHz, the PWM output frequency of the timer X1 is 40[MHz]÷(255 + 1)=156[kHz].

(3) Stopping LED control

An example of setting procedure to stop LED control is shown below. PWM output stops with either <1> through <3>, <1> through <2>, or <3> only (default level output).

<1> Set the duty of PWM output to 0.
<2> Write the same value to the frequency of PWM output.
<3> Stop operation of the 16-bit timer X1.

Sample programs for <1> through <3> are shown below.

```
TX1CR0 = LED_CYCLE;     /* <1> Sets the duty of TOX10 output to 0. */
TX1CR1 = LED_CYCLE;     /* <1> Sets the duty of TOX10 output to 0. */
TX1CR2 = LED_CYCLE;     /* <1> Sets the duty of TOX11 output to 0. */
TX1CR3 = LED_CYCLE;     /* <2> Sets the timer X1 output frequency. */
TX1TMC = 0;             /* <3> Prohibits count operation of the timer X1. */
```

(4) Constant current control/dimming control of the LED

Both constant current control and dimming control (including turning on/off) of the LED can be realized by using feedback processing with PI control. The general formula for PI control is as follows. For information on how to derive the coefficients A_1 and A_2, refer to **2.1.3 Calculating coefficients of PI control formula**.

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

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)
A_1, A_2:	Coefficients

(a) Constant current control of the LED

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.

$$X_{TARGET} = INT\left(\frac{I_{LED} \cdot R_S}{V_{REF}} \cdot 2^M + 0.5\right)$$

Note In the sample program in this section, the A/D conversion target value X_{TARGET} is defined as "ucAdCled1Tgt."

For example, when constant current control is performed with the LED current I_{LED} = 350 mA, set A/D conversion target value X_{TARGET} = 337 assuming that the sense resistance R_S = 4.7Ω, A/D converter reference voltage V_{REF} = 5V, and A/D conversion resolution M = 10 bits. Also, this formula implies that changing the A/D conversion target value X_{TARGET} by 1 will change the LED current I_{LED} by about 1 mA. At the same time, there is an error of about ± 0.5 mA in the LED current I_{LED} due to the quantizing error of ±0.5 in X_{TARGET}.

(b) Dimming control of the LED

Current dimming 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 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 337 to 96.

The overview of the operation is as follows.

<1> Start A/D conversion of the LED current sense resistance voltage.
<2> Read the A/D conversion target value.
<3> During A/D conversion, calculate "A_2 x E(n-1)" of PI control.
<4> Read the A/D conversion value.
<5> As a result of A/D conversion, if overcurrent occurs in the LED, perform stop processing of LED output and PFC output.
(In this case, do not perform processing for PI control in <6> through <9> below.)
<6> As a result of A/D conversion, if overcurrent does not occur in the LED, calculate "A_1 x E(n)+A_2 x E(n-1)".
<7> Compare the current PWM output duty "D(n-1)" with the result of <6> "A_1 x E(n)+A_2 x E(n-1)." If the calculation result of "D(n-1)+A_1 x E(n)+A_2 x E(n-1)" is within the range between the upper limit value [Note 1] and lower limit value [Note 2] of the duty D(n), set the calculation result to the duty D(n), or set the upper limit value or lower limit value to the duty D(n) otherwise.
<8> Update the duty setting value of PWM output.
<9> To reflect the updated duty to the actual output, write the same value to the frequency setting value of PWM output.

Notes 1. Set the upper limit value in the range where the on duty of PWM output becomes 100% or less.

2. Set the lower limit value in the range where the on duty of PWM output becomes 0% or more.

Sample programs for <1> through <9> are shown below.

```
ADS = ADCH_VLED1;                                                   /* <1> */
ADIF = 0;
shAdCled1Tgt = ushReqLed1;                                          /* <2> */
shErrLED1 = cushA2 * (shAdCled1Tgt - ushAdLed1);                    /* <3> */
while (!ADIF){}
ushAdLed1 = ADCR;                                                   /* <4> */
if (ushAdLed1 > AD_CLED1_OVER)
{
        stop_pfcled();                                              /* <5> */
}
else
{
        shErrLED1 += cushA1 * (shAdCled1Tgt - ushAdLed1);           /* <6> */
        if (shErrLED1 >= 0)
        {
                if (LED_DUTY_MAX_SL10 - ulDutyLED1 >= shErrLED1)
                {
                        ulDutyLED1 += shErrLED1;                    /* <7> */
                }
                else
                {
                        ulDutyLED1 = LED_DUTY_MAX_SL10;             /* <7> */
                }
        }
        else
        {
                if (ulDutyLED1 > - shErrLED1)
                {
                        ulDutyLED1 += shErrLED1;                    /* <7> */
                }
                else
                {
                        ulDutyLED1 = 0;                             /* <7> */
                }
        }
        TX1CR0 = LED_CYCLE - (unsigned char)(ulDutyLED1 >> 10);     /* <8> */
        TX1CR3 = LED_CYCLE;                                         /* <9> */
}
```

2.1.3 Calculating coefficients of PI control formula

This section describes how to calculate the coefficients in the PI control formula shown in 2.1.2. The coefficients A_1 and A_2 can be obtained from the following formulas.

$$A_1 = (\pi \cdot f_Z \cdot T + 1) \cdot K_P$$
$$A_2 = (\pi \cdot f_Z \cdot T - 1) \cdot K_P$$

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

In other words, the coefficients A_1 and A_2 can be obtained by determining 3 parameters; f_Z, T, and K_P. These parameters can be obtained from the gain of the LED control circuit.

(1) Obtaining the zero point frequency f_Z from the pole point frequency of the control circuit

As shown in Figure 2-1, 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 cutoff frequencies. Assuming that the former is f_{C1} and the latter is f_{C2}, the following values can be obtained with L_1=820 μH, C_1=27 μF, C_2=0.1 μF, and R_2=1 kΩ.

$$f_{C1} = \frac{1}{2\pi\sqrt{L_1 \cdot C_1}} = 1[kHz]$$
$$f_{C2} = \frac{1}{2\pi \cdot C_2 \cdot R_2} = 1.6[kHz]$$

Set a zero point frequency lower than these frequencies. Here, set it as follows.

$$f_Z = 500[Hz]$$

(2) Obtaining the feedback cycle T from the zero point frequency f_Z

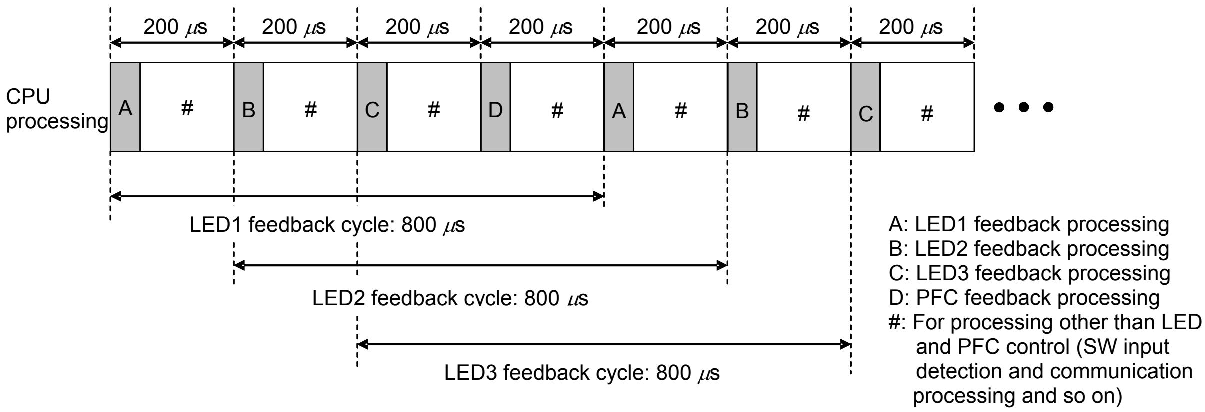
Because of the sampling theorem, the sampling frequency (=inverse of the feedback cycle T) must be twice or more of the zero point frequency f_Z. In other words, the relation between the feedback cycle T and zero point frequency f_Z can be described by the following formula.

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

Therefore, when f_Z=500 Hz is assigned from (1), the feedback cycle T is less than 1 [ms]. Next, consider CPU load to the feedback processing. Total of 4 channels require constant feedback: LED constant current control ×3 channels and PFC output constant voltage control ×1 channel. Here, CPU load is distributed by performing feedback in 200 [μs] cycles as shown in Figure 2-2, and the feedback cycle T is set as follows.

$$T = 800[\mu S]$$

Figure 2-2. Image of CPU Load Distribution for Feedback Processing



(3) Obtaining the proportional constant K_P from the gain of A/D converter input→PWM output of the microcontroller

The gain of A/D converter input→PWM output of the microcontroller can be obtained from the change in the LED current for the A/D conversion and PWM duty resolutions.

First, obtain the change in the LED current for the A/D conversion resolution. When the LED current is I_{LED}, the result of A/D conversion of the voltage of the sense resistance R_S is X, the A/D conversion resolution is M bits, and the reference voltage of the A/D converter is V_{REF}, the following relationship holds.

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

Here, when the change in the LED current by 1 bit of A/D conversion is i_{AD}, and X = 1 is assigned, the following is obtained.

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

Next, obtain the change in the LED current for the PWM duty resolution. When the LED current is I_{LED}, total of forward voltage of the LED is V_{FT}, the PWM output duty register setting value +1 is Y, and the PWM output resolution is N bits, the following relationship holds.

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

Here, when the change in the LED current by 1 bit of PWM duty is i_{PWM}, the LED's forward voltage is constant, and Y = 1 is assigned, the following is obtained.

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

Therefore, the gain i_{PWM} / i_{AD} of A/D converter input→PWM output is as follows.

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

When the A/D conversion resolution M = 8 bits, PWM output resolution N = 8 bits, input voltage V_I = 70 V, and A/D converter reference voltage V_{REF} = 5 V are assigned, the gain of A/D converter input→PWM output can be obtained as follows.

$$\frac{i_{PWM}}{i_{AD}} = 14$$

The proportional constant K_P must be set to a value smaller than the inverse of this gain. The relation is expressed by the following formula.

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

Here, set the following.

$$K_P = \frac{1}{16}$$

From the above, the PI control coefficients A_1 and A_2 can be obtained as follows.

$$A_1 = 0.141$$
$$A_2 = 0.016$$

2.2 PFC Control

2.2.1 PFC control overview

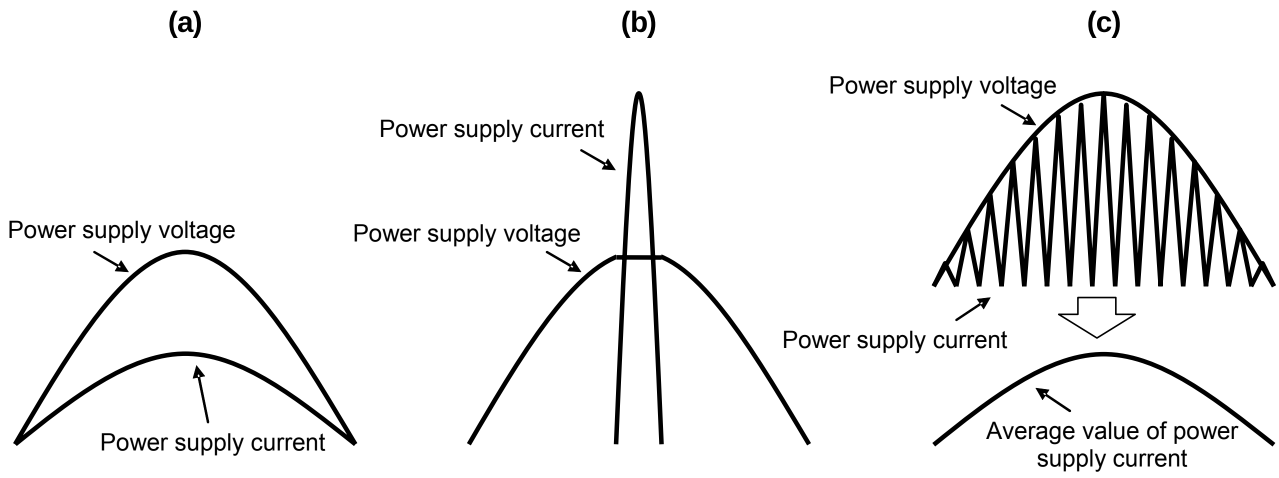
(1) What is PFC control?

Figure 2-3(a) shows ideal power supply voltage/current waveforms in AC power supply. The voltage and current have the same phase and sinusoidal waveforms, and the power factor is 1. Figure 2-3(b) shows actual power supply voltage/current waveforms in a power supply without PFC control. The current conducting time is short and the peak current value is high. As a result, the peak of the voltage waveform is flat. When the power factor is low, the following problems occur.

- Due to generation of harmonics, the product cannot conform to the standard, and may not be shipped.
- The peak current is large, requiring very thick wire for power line.
- The breaker will trip easily.

To improve the power factor, PFC control is required. In general LED lighting, the critical conduction mode (CRM) is used for PFC control because the number of parts is relatively small and it has low switching noise. Figure 2-3(c) shows the power supply voltage/current waveforms in AC power supply with PFC control. The distribution of current value is dispersed by turning on and off the power supply current repeatedly, and control is done so that the average value has the same phase as power supply voltage and sinusoidal waveforms. PFC control in the critical conduction mode can be realized by using the 78K0/Ix2 microcontroller.

Figure 2-3. Power Supply Voltage and Current Waveforms and PFC Control

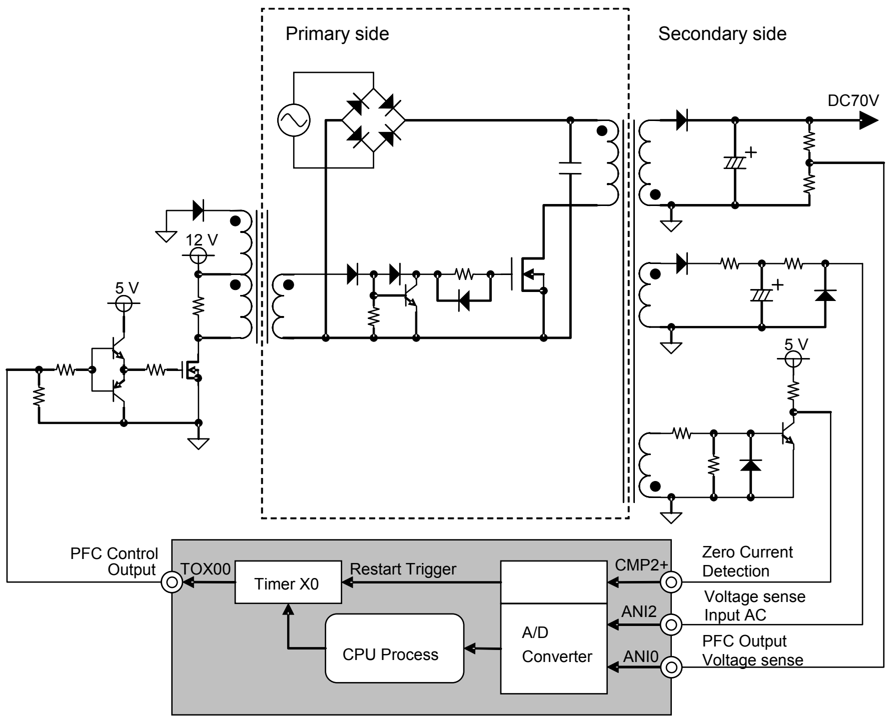


(2) PFC control with 78K0/Ix2

The 78K0/Ix2 microcontroller can perform PFC control in the critical conduction mode by using the timer restart function that works with the built-in comparator and the A/D converter in combination. Therefore, no separate analog IC for PFC control is required in addition to the microcontroller. Because the 78K0/Ix2 microcontroller performs LED control, i.e. load control of PFC output, as well as PFC control, preview control of load fluctuations can be done in advance. Therefore, voltage fluctuations during load changes can be less than the method that performs feedback after the load fluctuates.

Figure 2-4 shows an example of a fly-back converter type PFC circuit configuration with the 78K0/Ix2 microcontroller. The pins required for PFC control are PFC output (TOX00 pin), zero current detection input (CMP2+ pin), and DC output voltage monitoring input (ANI0 pin). The AC power supply voltage monitoring input (ANI2 pin) is required when control is done according to the AC power supply voltage, such as the environment in which AC power supply voltage is different.

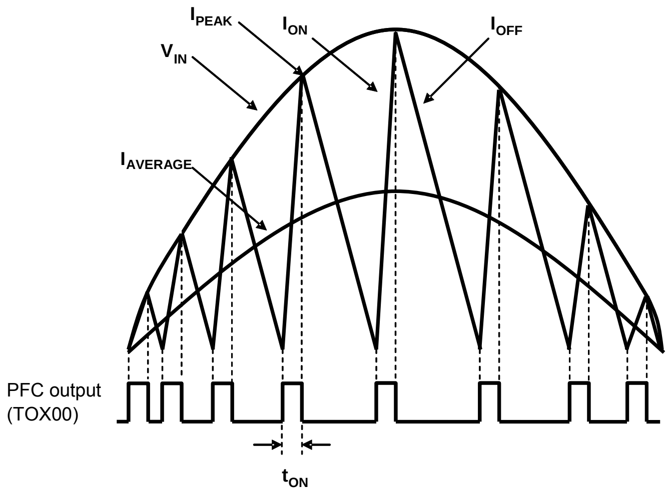
Figure 2-4. Example of Fly-back Converter Type PFC Circuit Configuration with 78K0/Ix2 Microcontroller



78K0/Ix2 Microcontroller

Figure 2-5 shows the waveform when PFC control is performed in this configuration. When PFC output (TOX00) is ON, $I_{ON} = (V_{IN}/L) \times t_{ON}$. Therefore, I_{ON} is proportional to V_{IN} when the time of the t_{ON} output is constant, the peak current I_{PEAK} of I_{ON} has a sinusoidal waveform with the same phase as the waveform of V_{IN}. Also, as the current waveform is triangular, the average current $I_{AVERAGE} = I_{PEAK} / 2$, which is also proportional to V_{IN}. Therefore, the average current waveform is sinusoidal and has the same phase as the power supply voltage waveform, realizing a waveform with a power factor close to 1.

Figure 2-5. PFC Control Waveform by 78K0/Ix2 Microcontroller



Next, the peripheral hardware of the 78K0/Ix2 microcontroller used for PFC control and their functions are shown below.

- 16-bit timer X0: PFC output
- Comparator: Zero current detection
- A/D converter: DC output voltage monitoring, AC power supply voltage monitoring [Note]

Note Used when control according to AC power supply voltage is performed.

The features of PFC control with the peripheral hardware are as follows.

- PFC output can be turned ON automatically (without software processing) at zero current detection by the timer restart function that works with the comparator of the 16-bit timer X0.
- 40 MHz can be selected for the count clock of the 16-bit timer X0 to control the ON time of PFC output in units of 25 ns. The PFC output restart cycle when zero current is not detected can be set flexibly in units of 25 ns up to about 1.6 ms.
- The 16-bit timer X0 can change the ON time of PFC output without stopping timer operation.
- PFC output voltage and AC power supply voltage input can be detected with the A/D converter of maximum of 10-bit resolution.

2.2.2 PFC control software design

(1) Initial setting of PFC control

Before starting PFC control, the peripheral hardware of the 78K0/Ix2 microcontroller needs to be initialized. The following is an initial setting sample program for the PFC output port, 16-bit timer X0, and comparator.

```
/* PFC output port setting */
P3.1 = 0;                  /* Sets the output latch of P31 to 0. */
PU3.1 = 0;                 /* Does not connect the internal pull-up resistor to P31. */
PM3.1 = 1;                 /* Sets P31 to the input mode Note 1 (default output is continued with the
                              external resistance). */

/* 16-bit timer X0 setting */
TX0CTL0 = 0b00000000;      /* Sets the count clock to 40 MHz Note 2 */
TX0CTL1 = 0b00000000;      /* Sets it to single output (output only from the TOX00 terminal). */
TX0CTL3 = 0b01100010;      /* Rewrites TX0CRn in batch at the restart due to Comparator 2 output.
                              Restarts the timer when Comparator 2 output is detected. */
TX0IOC0 = 0b00000101;      /* Sets the default state of TOX00 output to the high level Note1.
                              Permits TOX00 output (output doesn't change because of the P31
                              input mode). */

/* Comparator setting */
C2RVM   = 0b00011111;      /* Sets the voltage level of the internal reference voltage DA2 to 1.6V. */
CVRE    = 1;               /* Permits operation of internal reference voltage generation. */
C2CTL   = 0b00010000;      /* Sets the reference voltage to the internal reference voltage DA2.
                              Noise filter not used. */
```

Notes 1. Here, P31 is set to the input mode, and the default state of TOX00 output is set to high level. Alternately, the default state of TOX00 output can be set to low level and P31 can be set to the output mode. In that case, however, changes must be made in the start/stop programs for PFC control as described in B) and C) below.

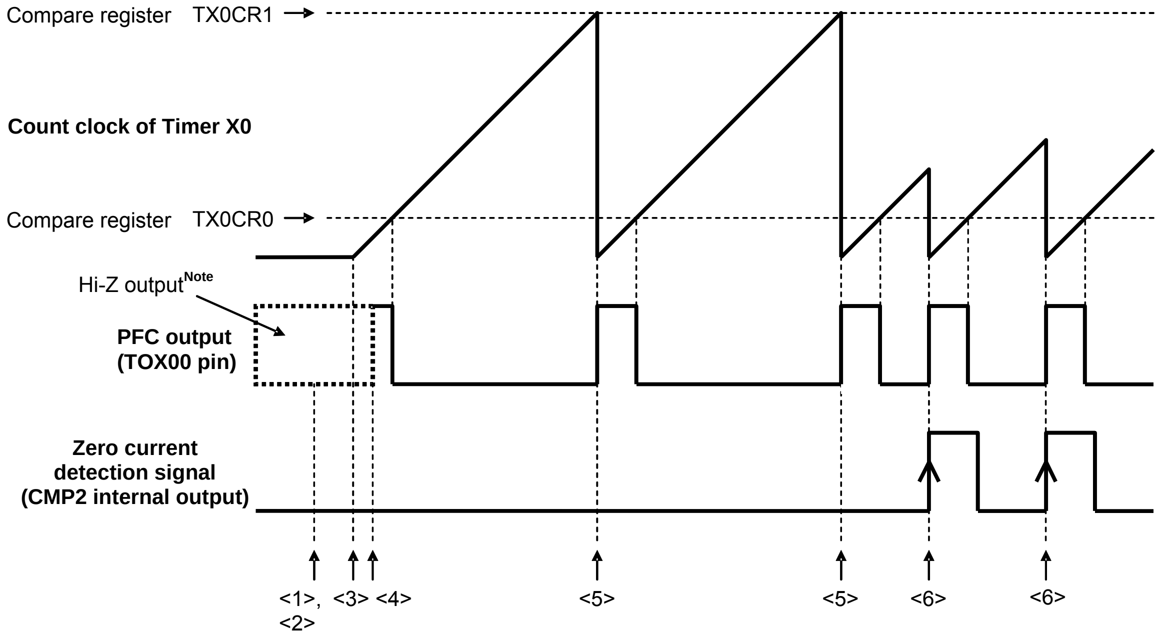
2. When the PLL clock mode is used and the supply clock to the 16-bit timer X0 is set to 40 MHz.

In the actual initial setting, clock setting, port setting, and interrupt setting are required in addition to the above. For details, refer to **78K0/Ix2 Hardware User's Manual (R01UH0010E)**.

(2) Starting PFC control

Figure 2-7 shows the waveforms at the start of PFC control.

Figure 2-7. Waveforms at Start of PFC Control



Note Actually low level output due to the external pull-down resistor.

Operation overview is as follows.

<1> Start operation of the comparator.
<2> Set the ON time of PFC output and the PFC output restart cycle when zero current is not detected.
<3> Start operation of the 16-bit timer X0.
<4> Set the PFC output pin to the output mode. As a result, high-impedance output is released, and PFC output is started.
<5> While zero current is not detected, PFC output restarts with the cycle set in the compare register TX0CR1 to turn on the MOSFET for a certain period of time repeatedly.
<6> After zero current is detected, PFC output restarts as zero current is detected, and the MOSFET enters the ON state for a certain period of time.

As described above, after PFC output is started in <4>, PFC output restart before zero current detection and PFC output immediate ON at zero current detection are executed by hardware without software processing. Therefore, any delay due to CPU processing or CPU load does not exist for these operations.

Sample programs for <1> through <4> are shown below.

```
/* Comparator setting */
CMP2EN = 1;            /* <1> Permits operation of the comparator 2. */
C2OE   = 1;            /* <1> Permits internal output of the comparator 2. */

/* 16-bit timer X0 setting */
TX0CR0  = 32 – 1;      /* <2> Sets the ON time at the start of PFC control (0.8 us in this example). */
TX0CR1  = PFC_CYCLE_RESTART;   /* <2> Sets the PFC output restart cycle when zero current is not detected (Example: 250 us). */
TX0TMC  = 1;           /* <3> Permits timer count operation. */
PM3.1   = 0;           /* <4> Sets the PFC output port to the output mode. */
```

Remark ”PFC_CYCLE_RESTART” in the sample program is actually defined to be “9999.” Therefore, as the count clock of the timer X0 is set to 40 MHz, the PFC output restart cycle is (9999 + 1) ÷ 40[MHz]=250[μs].

(3) Stopping PFC control

To stop PFC control, perform the settings as follows.

<1> Set the PFC output pin to the input mode. As a result, PFC output becomes high-impedance, and the MOSFET enters the OFF state because of the external pull-down resistance.
<2> Stop operation of the 16-bit timer X0.
<3> Stop operation of the comparator.

Sample programs for <1> through <3> are shown below.

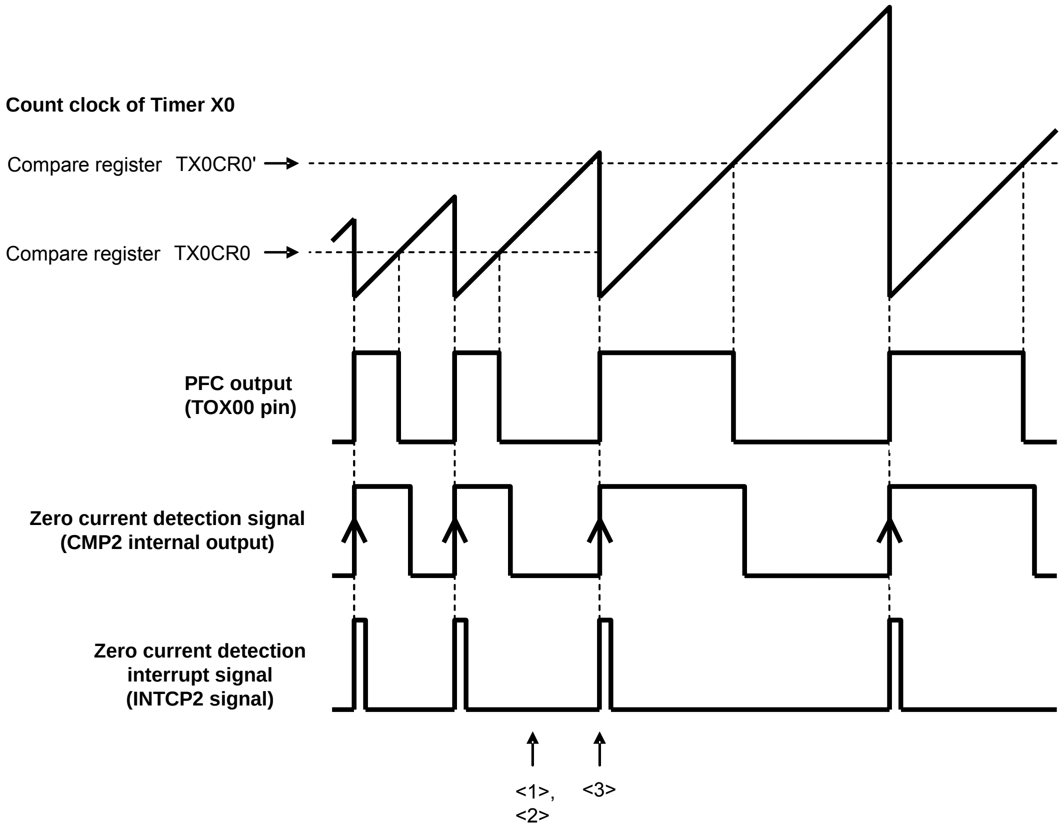
```
/* 16-bit timer X0 setting */
P3.1    = 1;           /* <1> Sets the PFC output port to the input mode. */
TX0TMC  = 0;           /* <2> Prohibits timer count operation. */

/* Comparator setting */
C2OE   = 0;            /* <3> Prohibits internal output of the comparator 2. */
CMP2EN = 0;            /* <3> Prohibits operation of the comparator 2. */
```

(4) PFC control when load changes (preview control)

Figure 2-8 shows the PFC control waveforms when load changes such as during dimming and turning on/off of the LED. LED lighting is controlled by the 78K0/Ix2 microcontroller, so it is possible to predict the timing of load change and the amount of load change. Therefore, when load changes significantly due to dimming, PFC output according to dimming, or preview control, can be done to reduce fluctuations in DC output voltage.

Figure 2-8. PFC Control Waveforms When Load Changes



The overview of the operation is as follows.

<1> Increase or decrease the ON time of PFC output (TX0CR0 in Figure 2-8) to a value according to the load (TX0CR0' in Figure 2-8).
<2> To reflect the update in <1> to the actual output, write the same value to the PFC output restart cycle (TX0CR1).
<3> The ON time of PFC output is updated when the next zero current detection interrupt is generated.

Sample programs for <1> through <2> are shown below.

<The following processing is executed near the timing when the load changes.>

```
TX0CR0 += shDpfcLed1;            /* <1> Increases or decreases the ON time of PFC output
                                    according to the load change.  */
TX0CR1 = PFC_CYCLE_RESTART;      /* <2> Writes the same value to the PFC output restart cycle. */
```

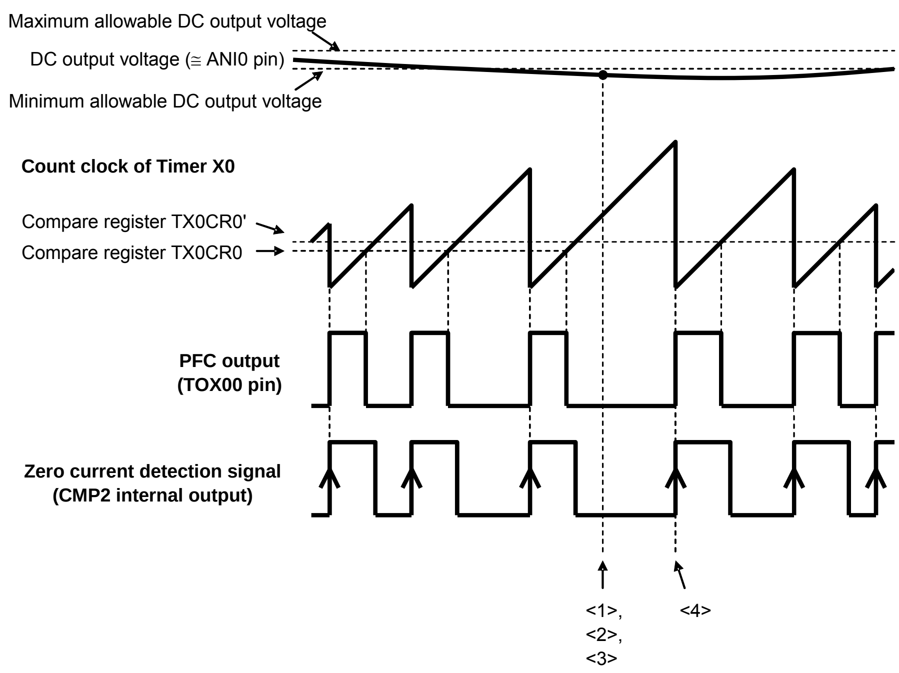
(5) DC output voltage feedback

The DC output voltage must be monitored by the A/D converter and fed back to the ON time of PFC output so that the DC output voltage is always constant. Because the load changes significantly only when the LED load is dimmed, turned on or off intentionally, the change in the DC output voltage can be suppressed by preview control as described in D) above. Therefore, feedback control is performed when the LED illuminates at a constant brightness, i.e. when LED load is almost constant, and simplified feedback control is performed here.

If the DC output voltage is greater than the allowable maximum value, DC output voltage can be lowered by decreasing the ON time of PFC output. On the other hand, if the DC output voltage is lower than the allowable minimum value, DC output voltage can be increased by increasing the ON time of PFC output. When the DC output voltage is within the range between the allowable minimum value and allowable maximum value, the ON time of PFC output is not to be changed. The feedback cycle is set to about the half cycle (approx. 9 to 10 ms) of the AC power frequency, and the average value of DC output voltage between the cycles is calculated and reflected to the ON time of PFC output.

Figure 2-9 shows an example of feedback control when the DC output voltage is lower than the allowable minimum value.

Figure 2-9. Example of DC Output Voltage Feedback Control



The overview of the operation is as follows.

<1> Calculate the average value of DC output voltage.
<2> Feedback judgment process:
If "DC output voltage is higher than the allowable maximum value" and "DC output voltage is increasing" and "ON time of PFC output is greater than the allowable minimum value," decrease the ON time of PFC output (TX0CR0) by 25 ns with software.
"DC output voltage is less than the allowable minimum value" and "DC output voltage is decreasing" and "ON time of PFC output is less than the allowable minimum value," increase the ON time of PFC output (TX0CR0) by 25 ns with software.
<3> To reflect the update in <2> to the actual output, write the same value to the PFC output restart cycle (TX0CR1).
<4> The ON time of PFC output is updated when the next zero current detection interrupt is generated.

Sample programs for <1> through <3> are shown below.

＜The following processing is executed near the timing when the load changes.＞

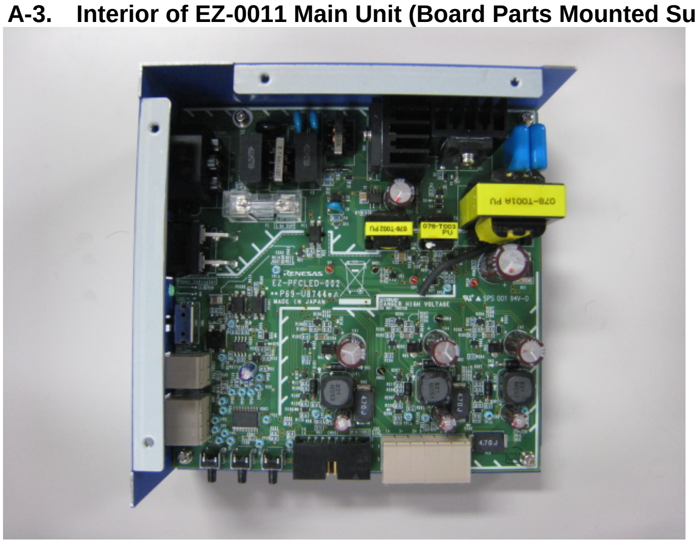
```
ushADtemp = (unsigned short)(ushAdSumVout / ucAdCntVout);    /* <1> Calculates the average of the DC output
                                                                voltage. */
if (ushADtemp > AD_VPFCO_MAX                      /* <2> Feedback judgment processing */
  && ushADtemp >= ushAdOldVout
  && TX0CR0 > 0)
{
            TX0CR0 -= 1;                          /* <2> Decreases the ON time of PFC output by 25 ns. */
            TX0CR1 = PFC_CYCLE_RESTART;           /* <3> Writes the same value to the PFC output restart cycle. */
}
else if (ushADtemp < AD_VPFCO_MIN                 /* <2> Feedback judgment processing */
        && ushADtemp <= ushAdOldVout
        && TX0CR0 < PFC_ON_MAX)
{
           TX0CR0 += 1;                           /* <2> Increases the ON time of PFC output by 25ns. */
           TX0CR1 = PFC_CYCLE_RESTART;            /* <3> Writes the same value to the PFC output restart cycle. */
}
```

APPENDIX A EZ-0011 EXTERNAL APPEARANCE

Figure A-1. Right Side of EZ-0011 Main Unit (Power Supply and Communication Side)

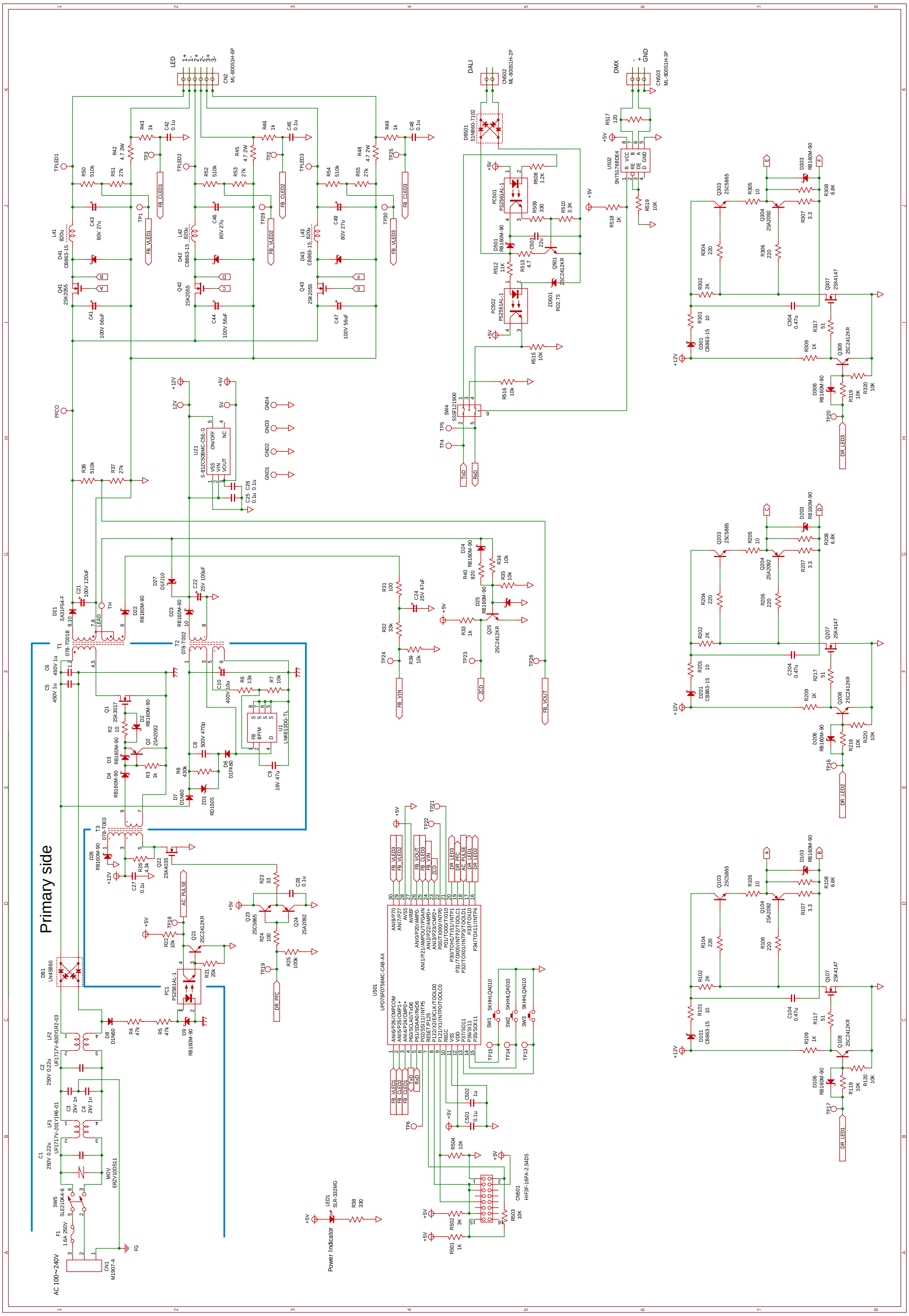
Figure A-2. Front Side of EZ-0011 Main Unit (Switch Input, MINICUBE2 Connection, and LED Connection Side)

Figure A-3. Interior of EZ-0011 Main Unit (Board Parts Mounted Surface)



APPENDIX B EZ-0011 CIRCUIT DIAGRAM

Figure B-1. EZ-PFCLED-002 Circuit Diagram



APPENDIX C EZ-0011 PARTS LIST

Table C-1. EZ-0011 Parts List (1/3)

Part	Part No.	Item name	Rating	Manufacturer	Model No. or Drawing No.	Remark
C	1	Film capacitor	AC250V 0.22uF	Panasonic	ECQU2A224ML	DIP
C	2	Film capacitor	AC250V 0.22uF	Panasonic	ECQU2A224ML	DIP
C	3	Ceramic capacitor	2kV 1nF	Murata Manufacturing	DEHR33D102KB3B	DIP
C	4	Ceramic capacitor	2kV 1nF	Murata Manufacturing	DEHR33D102KB3B	DIP
C	5	Film capacitor	450V 1uF	Nitsuko	MDX22W105K	DIP
C	6	Film capacitor	450V 1uF	Nitsuko	MDX22W105K	DIP
C	8	Ceramic capacitor	500V 470pF	Murata Manufacturing	DEHC32H471KA2B	DIP
C	9	Multilayer ceramic capacitor	16V 47uF	Murata Manufacturing	GRM32EB31C476ME15	3225
C	10	Electrolytic capacitor	400V 10uF	Nippon Chemi-Con	EKXJ401ELL100MJ16S	DIP
C	21	Electrolytic capacitor	100V 120uF	Nippon Chemi-Con	ELXV101ELL121MK25S	DIP
C	22	Electrolytic capacitor	25V 100uF	Nippon Chemi-Con	ELXZ250ELL101MFB5D	DIP
C	24	Electrolytic capacitor	25V 47uF	Nippon Chemi-Con	ELXZ250ELL470MEB5D	DIP
C	25	Multilayer ceramic capacitor	50V 0.1uF	Murata Manufacturing	GRM188B31H104KA92	1608
C	26	Multilayer ceramic capacitor	50V 0.1uF	Murata Manufacturing	GRM188B31H104KA92	1608
C	27	Multilayer ceramic capacitor	50V 0.1uF	Murata Manufacturing	GRM188B31H104KA92	1608
C	28	Multilayer ceramic capacitor	50V 0.1uF	Murata Manufacturing	GRM188B31H104KA92	1608
C	41	Electrolytic capacitor	100V 56uF	Nippon Chemi-Con	ELXV101ELL560MJ20S	DIP
C	42	Multilayer ceramic capacitor	50V 0.1uF	Murata Manufacturing	GRM188B31H104KA92	1608
C	43	Electrolytic capacitor	80V 27uF	Nippon Chemi-Con	ELXV800ELL270MF15D	DIP
C	44	Electrolytic capacitor	100V 56uF	Nippon Chemi-Con	ELXV101ELL560MJ20S	DIP
C	45	Multilayer ceramic capacitor	50V 0.1uF	Murata Manufacturing	GRM188B31H104KA92	1608
C	46	Electrolytic capacitor	80V 27uF	Nippon Chemi-Con	ELXV800ELL270MF15D	DIP
C	47	Electrolytic capacitor	100V 56uF	Nippon Chemi-Con	ELXV101ELL560MJ20S	DIP
C	48	Multilayer ceramic capacitor	50V 0.1uF	Murata Manufacturing	GRM188B31H104KA92	1608
C	49	Electrolytic capacitor	80V 27uF	Nippon Chemi-Con	ELXV800ELL270MF15D	DIP
C	104	Multilayer ceramic capacitor	50V 0.47uF	Murata Manufacturing	GRM31MR71H474KA01	3216
C	204	Multilayer ceramic capacitor	50V 0.47uF	Murata Manufacturing	GRM31MR71H474KA01	3216
C	304	Multilayer ceramic capacitor	50V 0.47uF	Murata Manufacturing	GRM31MR71H474KA01	3216
C	501	Multilayer ceramic capacitor	50V 0.1uF	Murata Manufacturing	GRM188B31H104KA92	1608
C	502	Multilayer ceramic capacitor	16V 1uF	Murata Manufacturing	GRM188B31C105KA92	3216
C	503	Multilayer ceramic capacitor	25V 22uF	Murata Manufacturing	GRM32EC81E226ME15	3225
CN	1	AC inlet 3-terminal connector	3-pole	EMUDEN	M1907-A	DIP
CN	2	Connector	6-pole	Sato Parts	ML-800-S1H-6P	DIP
CN	501	Straight type pin header	16-pole	Hirose Electric	HIF3F-16PA-2.54DS	DIP
CN	502	Screwless terminal block	2-pole	Sato Parts	ML-800-S1H-2P	DIP
CN	503	Screwless terminal block	3-pole	Sato Parts	ML-800-S1H-3P	DIP
D	2	Schottky Barrier diode	90V 1A	Rohm	RB160M-90	SMD
D	3	Schottky Barrier diode	90V 1A	Rohm	RB160M-90	SMD
D	4	Schottky Barrier diode	90V 1A	Rohm	RB160M-90	SMD
D	6	Fast recovery diode	600V 0.8A	Shindengen Electric Manufacturing	D1FK60	SMD
D	7	Rectifying diode	600V 1A	Shindengen Electric Manufacturing	D1N60	DIP
D	8	Rectifying diode	600V 1A	Shindengen Electric Manufacturing	D1N60	DIP
D	9	Schottky Barrier diode	90V 1A	Rohm	RB160M-90	SMD
D	21	Fast recovery diode	400V 3A	Nihon Inter Electronics	EA31FS4-F	TO-252
D	22	Schottky Barrier diode	90V 1A	Rohm	RB160M-90	SMD
D	23	Schottky Barrier diode	90V 1A	Rohm	RB160M-90	SMD
D	24	Schottky Barrier diode	90V 1A	Rohm	RB160M-90	SMD
D	25	Schottky Barrier diode	90V 1A	Rohm	RB160M-90	SMD
D	26	Schottky Barrier diode	90V 1A	Rohm	RB160M-90	SMD
D	27	Schottky Barrier diode	100V 1.0A	Shindengen Electric Manufacturing	D1FJ10	SMD
D	41	Schottky Barrier diode	150V 2A	Fuji Electric	CB863-15	SMD
D	42	Schottky Barrier diode	150V 2A	Fuji Electric	CB863-15	SMD
D	43	Schottky Barrier diode	150V 2A	Fuji Electric	CB863-15	SMD
D	101	Schottky Barrier diode	150V 2A	Fuji Electric	CB863-15	SMD
D	103	Schottky Barrier diode	90V 1A	Rohm	RB160M-90	SMD
D	106	Schottky Barrier diode	90V 1A	Rohm	RB160M-90	SMD
D	201	Schottky Barrier diode	150V 2A	Fuji Electric	CB863-15	SMD
D	203	Schottky Barrier diode	90V 1A	Rohm	RB160M-90	SMD
D	206	Schottky Barrier diode	90V 1A	Rohm	RB160M-90	SMD
D	301	Schottky Barrier diode	150V 2A	Fuji Electric	CB863-15	SMD
D	303	Schottky Barrier diode	90V 1A	Rohm	RB160M-90	SMD
D	306	Schottky Barrier diode	90V 1A	Rohm	RB160M-90	SMD
D	501	Schottky Barrier diode	90V 1A	Rohm	RB160M-90	SMD
DB	1	Rectifying stack	600V 4A	Shindengen Electric Manufacturing	LN4SB60	DIP
		Heat sink		Mizutani Electric	PUE26-25	
DB	501	Rectifying stack	600V 1A	Shindengen Electric Manufacturing	S1NB60-7102	SMD
F	1	Fuse holder	250V	BULGIN	FX0321	DIP
		Fuse holder cover		BULGIN	12760	
		Fuse	1.6A 250V	Littlefuse	021701.6HXP	
L	41	Coil	820uH 0.75A	Sumida	CDRH127/LDNP-821M	DIP
L	42	Coil	820uH 0.75A	Sumida	CDRH127/LDNP-821M	DIP
L	43	Coil	820uH 0.75A	Sumida	CDRH127/LDNP-821M	DIP
LED	1	LED		Rohm	SLR-332MG	DIP
LF	1	Common mode choke	0.2mH 1.6A	TDK	UF1717V-201Y1R6-01	DIP
LF	2	Common mode choke	30uH 1.2A	TDK	UF1717V-300Y1R2-03	DIP

Table C-1. EZ-0011 Parts List (2/3)

Part	Part No.	Item name	Rating	Manufacturer	Model No. or Drawing No.	Remark
MOV		Absorber		Panasonic	ERZV10D511	DIP
PC	1	Photocoupler		Renesas Electronics	PS2561AL-1	SMD
PC	501	Photocoupler		Renesas Electronics	PS2561AL-1	SMD
PC	502	Photocoupler		Renesas Electronics	PS2561AL-1	SMD
Q	1	Power MOSFET	900V 8.5A	Toshiba	2SK3017	TO-3P(N)IS
		Heat sink		Mizutani Electric	PUE26-25	
Q	2	Transistor	60V 1A	Rohm	2SA2092	SMD
Q	21	Transistor	60V 0.15A	Rohm	2SC2412KR	SMD
Q	22	Power MOSFET	250V 0.5A	Renesas Electronics	2SK4035	SMD
Q	23	Transistor	60V 1A	Rohm	2SC5865	SMD
Q	24	Transistor	60V 1A	Rohm	2SA2092	SMD
Q	25	Transistor	60V 0.15A	Rohm	2SC2412KR	SMD
Q	41	Power MOSFET	100V 2A	Renesas Electronics	2SK2055	SC-84
Q	42	Power MOSFET	100V 2A	Renesas Electronics	2SK2055	SC-84
Q	43	Power MOSFET	100V 2A	Renesas Electronics	2SK2055	SC-84
Q	103	Transistor	60V 1A	Rohm	2SC5865	SMD
Q	104	Transistor	60V 1A	Rohm	2SA2092	SMD
Q	107	Power MOSFET	250V 0.5A	Renesas Electronics	2SK4147	SMD
Q	108	Transistor	60V 0.15A	Rohm	2SC2412KR	SMD
Q	203	Transistor	60V 1A	Rohm	2SC5865	SMD
Q	204	Transistor	60V 1A	Rohm	2SA2092	SMD
Q	207	Power MOSFET	250V 0.5A	Renesas Electronics	2SK4147	SMD
Q	208	Transistor	60V 0.15A	Rohm	2SC2412KR	SMD
Q	303	Transistor	60V 1A	Rohm	2SC5865	SMD
Q	304	Transistor	60V 1A	Rohm	2SA2092	SMD
Q	307	Power MOSFET	250V 0.5A	Renesas Electronics	2SK4147	SMD
Q	308	Transistor	60V 0.15A	Rohm	2SC2412KR	SMD
Q	501	Transistor	60V 0.15A	Rohm	2SC2412KR	SMD
R	2	Chip type resistor	0.125W 10Ω	KOA	RK73H2ATTD10R0F (KOA)	2012
R	3	Chip type resistor	0.125W 1kΩ	KOA	RK73H2ATTD1001F (KOA)	2012
R	4	Chip type resistor	0.25W 47kΩ	KOA	RK73H2BTTD4702F (KOA)	3216
R	5	Chip type resistor	0.25W 47kΩ	KOA	RK73H2BTTD4702F (KOA)	3216
R	6	Chip type resistor	0.125W 13KΩ	KOA	RK73H2ATTD1302F (KOA)	2012
R	7	Chip type resistor	0.125W 10KΩ	KOA	RK73H2ATTD1002F (KOA)	2012
R	8	Chip type resistor	0.25W 430kΩ	KOA	RK73H2BTTD4303F (KOA)	3216
R	21	Chip type resistor	0.125W 20kΩ	KOA	RK73H2ATTD2002F (KOA)	2012
R	22	Chip type resistor	0.125W 10kΩ	KOA	RK73H2ATTD1002F (KOA)	2012
R	23	Chip type resistor	0.125W 33Ω	KOA	RK73H2ATTD33R0F (KOA)	2012
R	24	Chip type resistor	0.125W 100Ω	KOA	RK73H2ATTD1000F (KOA)	2012
R	25	Chip type resistor	0.125W 100kΩ	KOA	RK73H2ATTD1003F (KOA)	2012
R	26	Chip type resistor	0.125W 4.3kΩ	KOA	RK73H2ATTD4301F (KOA)	2012
R	31	Chip type resistor	0.125W 100Ω	KOA	RK73H2ATTD1000F (KOA)	2012
R	32	Chip type resistor	0.125W 33kΩ	KOA	RK73H2ATTD3302F (KOA)	2012
R	33	Chip type resistor	0.125W 1kΩ	KOA	RK73H2ATTD1001F (KOA)	2012
R	34	Chip type resistor	0.125W 10kΩ	KOA	RK73H2ATTD1002F (KOA)	2012
R	35	Chip type resistor	0.125W 10kΩ	KOA	RK73H2ATTD1002F (KOA)	2012
R	36	Chip type resistor	0.125W 510kΩ	KOA	RK73H2ATTD5103F (KOA)	2012
R	37	Chip type resistor	0.125W 27kΩ	KOA	RK73H2ATTD2702F (KOA)	2012
R	38	Chip type resistor	0.125W 330Ω	KOA	RK73H2ATTD3300F (KOA)	2012
R	39	Chip type resistor	0.125W 12kΩ	KOA	RK73H2ATTD1202F (KOA)	2012
R	40	Chip type resistor	0.125W 820Ω	KOA	RK73H2ATTD8200F (KOA)	2012
R	42	Metal oxide film resistor	2W 4.7Ω	KOA	SL2TBK4R7J	DIP
R	43	Chip type resistor	0.125W 1kΩ	KOA	RK73H2ATTD1001F (KOA)	2012
R	45	Metal oxide film resistor	2W 4.7Ω	KOA	SL2TBK4R7J	DIP
R	46	Chip type resistor	0.125W 1kΩ	KOA	RK73H2ATTD1001F (KOA)	2012
R	48	Metal oxide film resistor	2W 4.7Ω	KOA	SL2TBK4R7J	DIP
R	49	Chip type resistor	0.125W 1kΩ	KOA	RK73H2ATTD1001F (KOA)	2012
R	50	Chip type resistor	0.125W 510kΩ	KOA	RK73H2ATTD5103F (KOA)	2012
R	51	Chip type resistor	0.125W 27kΩ	KOA	RK73H2ATTD2702F (KOA)	2012
R	52	Chip type resistor	0.125W 510kΩ	KOA	RK73H2ATTD5103F (KOA)	2012
R	53	Chip type resistor	0.125W 27kΩ	KOA	RK73H2ATTD2702F (KOA)	2012
R	54	Chip type resistor	0.125W 510kΩ	KOA	RK73H2ATTD5103F (KOA)	2012
R	55	Chip type resistor	0.125W 27kΩ	KOA	RK73H2ATTD2702F (KOA)	2012
R	101	Chip type resistor	0.125W 10Ω	KOA	RK73H2ATTD10R0F (KOA)	2012
R	102	Chip type resistor	0.125 2kΩ	KOA	RK73H2ATTD2001F (KOA)	2012
R	104	Chip type resistor	0.125W 220Ω	KOA	RK73H2ATTD2200F (KOA)	2012
R	105	Chip type resistor	0.125W 10Ω	KOA	RK73H2ATTD10R0F (KOA)	2012
R	106	Chip type resistor	0.125W 220Ω	KOA	RK73H2ATTD2200F (KOA)	2012
R	107	Chip type resistor	0.125W 3.3Ω	KOA	RK73B2ATTD3R3J	2012
R	108	Chip type resistor	0.125W 6.8kΩ	KOA	RK73H2ATTD6801F (KOA)	2012
R	109	Chip type resistor	0.125W 1kΩ	KOA	RK73H2ATTD1001F (KOA)	2012
R	117	Chip type resistor	0.125W 51Ω	KOA	RK73H2ATTD51R0F (KOA)	2012
R	119	Chip type resistor	0.125W 10kΩ	KOA	RK73H2ATTD1002F (KOA)	2012
R	120	Chip type resistor	0.125W 10kΩ	KOA	RK73H2ATTD1002F (KOA)	2012
R	201	Chip type resistor	0.125W 10Ω	KOA	RK73H2ATTD10R0F (KOA)	2012
R	202	Chip type resistor	0.125 2kΩ	KOA	RK73H2ATTD2001F (KOA)	2012
R	204	Chip type resistor	0.125W 220Ω	KOA	RK73H2ATTD2200F (KOA)	2012
R	205	Chip type resistor	0.125W 10Ω	KOA	RK73H2ATTD10R0F (KOA)	2012

Table C-1. EZ-0011 Parts List (3/3)

Part	Part No.	Item name	Rating	Manufacturer	Model No. or Drawing No.	Remark
R	206	Chip type resistor	0.125W 220Ω	KOA	RK73H2ATTD2200F (KOA)	2012
R	207	Chip type resistor	0.125W 3.3Ω	KOA	RK73B2ATTD3R3J	2012
R	208	Chip type resistor	0.125W 6.8kΩ	KOA	RK73H2ATTD6801F (KOA)	2012
R	209	Chip type resistor	0.125W 1kΩ	KOA	RK73H2ATTD1001F (KOA)	2012
R	217	Chip type resistor	0.125W 51Ω	KOA	RK73H2ATTD51R0F (KOA)	2012
R	219	Chip type resistor	0.125W 10kΩ	KOA	RK73H2ATTD1002F (KOA)	2012
R	220	Chip type resistor	0.125W 10kΩ	KOA	RK73H2ATTD1002F (KOA)	2012
R	301	Chip type resistor	0.125W 10Ω	KOA	RK73H2ATTD10R0F (KOA)	2012
R	302	Chip type resistor	0.125 2kΩ	KOA	RK73H2ATTD2001F (KOA)	2012
R	304	Chip type resistor	0.125W 220Ω	KOA	RK73H2ATTD2200F (KOA)	2012
R	305	Chip type resistor	0.125W 10Ω	KOA	RK73H2ATTD10R0F (KOA)	2012
R	306	Chip type resistor	0.125W 220Ω	KOA	RK73H2ATTD2200F (KOA)	2012
R	307	Chip type resistor	0.125W 3.3Ω	KOA	RK73B2ATTD3R3J	2012
R	308	Chip type resistor	0.125W 6.8kΩ	KOA	RK73H2ATTD6801F (KOA)	2012
R	309	Chip type resistor	0.125W 1kΩ	KOA	RK73H2ATTD1001F (KOA)	2012
R	317	Chip type resistor	0.125W 51Ω	KOA	RK73H2ATTD51R0F (KOA)	2012
R	319	Chip type resistor	0.125W 10kΩ	KOA	RK73H2ATTD1002F (KOA)	2012
R	320	Chip type resistor	0.125W 10kΩ	KOA	RK73H2ATTD1002F (KOA)	2012
R	501	Chip type resistor	0.125W 1kΩ	KOA	RK73H2ATTD1001F (KOA)	2012
R	502	Chip type resistor	0.125W 3kΩ	KOA	RK73H2ATTD3001F (KOA)	2012
R	503	Chip type resistor	0.125W 10kΩ	KOA	RK73H2ATTD1002F (KOA)	2012
R	504	Chip type resistor	0.125W 10kΩ	KOA	RK73H2ATTD1002F (KOA)	2012
R	508	Chip type resistor	0.125W 1.2kΩ	KOA	RK73H2ATTD1201F (KOA)	2012
R	509	Chip type resistor	0.125W 330Ω	KOA	RK73H2ATTD3300F (KOA)	2012
R	510	Chip type resistor	0.125W 3.3kΩ	KOA	RK73H2ATTD3301F (KOA)	2012
R	512	Chip type resistor	0.125W 11kΩ	KOA	RK73H2ATTD1102F (KOA)	2012
R	513	Chip type resistor	0.125W 4.7Ω	KOA	RK3B2ATTD4R7G	2012
R	515	Chip type resistor	0.125W 10kΩ	KOA	RK73H2ATTD1002F (KOA)	2012
R	516	Chip type resistor	0.125W 10kΩ	KOA	RK73H2ATTD1002F (KOA)	2012
R	517	Chip type resistor	0.125W 120Ω	KOA	RK73H2ATTD1200F (KOA)	2012
R	518	Chip type resistor	0.125W 1kΩ	KOA	RK73H2ATTD1001F (KOA)	2012
R	519	Chip type resistor	0.125W 10kΩ	KOA	RK73H2ATTD1002F (KOA)	2012
SW	1	Push type switch		Alps Electric	SKHHLQA010	DIP
SW	2	Push type switch		Alps Electric	SKHHLQA010	DIP
SW	3	Push type switch		Alps Electric	SKHHLQA010	DIP
SW	4	Slide switch		Alps Electric	SSSF121900	DIP
SW	5	Rocker switch		Fujisoku	SLE210K4-6	DIP
T	1	Transformer		Pony Electric	078-T001A	DIP
T	2	Transformer		Pony Electric	078-T002	DIP
T	3	Transformer		Pony Electric	078-T003	DIP
U	1	Power supply IC		Power Integrations	LNK613DG-TL	SMD
U	21	Power supply IC		Seiko Instruments	S-812C50BMC-C5E-G	SMD
U	501	CPU		Renesas Electronics	UPD78F0756MC-CAB-AX	SMD
U	502	Interface IC		Texas Instruments	SN75176BDE4	SMD
ZD	1	Zener diode		Renesas Electronics	RD150S	SMD
ZD	501	Zener diode		Renesas Electronics	RD2.7S	SMD
TP	1	Test tap		Mac8	LC-2-G-Skyblue	DIP
TP	2	Test tap		Mac8	LC-2-G-Skyblue	DIP
TP	3	Test tap		Mac8	LC-2-G-Skyblue	DIP
TP	4	Test tap		Mac8	LC-2-G-Skyblue	DIP
TP	5	Test tap		Mac8	LC-2-G-Skyblue	DIP
TP	6	Test tap		Mac8	LC-2-G-Skyblue	DIP
TP	13	Test tap		Mac8	LC-2-G-Skyblue	DIP
TP	14	Test tap		Mac8	LC-2-G-Skyblue	DIP
TP	15	Test tap		Mac8	LC-2-G-Skyblue	DIP
TP	16	Test tap		Mac8	LC-2-G-Skyblue	DIP
TP	17	Test tap		Mac8	LC-2-G-Skyblue	DIP
TP	18	Test tap		Mac8	LC-2-G-Skyblue	DIP
TP	19	Test tap		Mac8	LC-2-G-Skyblue	DIP
TP	20	Test tap		Mac8	LC-2-G-Skyblue	DIP
TP	21	Test tap		Mac8	LC-2-G-Skyblue	DIP
TP	22	Test tap		Mac8	LC-2-G-Skyblue	DIP
TP	23	Test tap		Mac8	LC-2-G-Skyblue	DIP
TP	24	Test tap		Mac8	LC-2-G-Skyblue	DIP
TP	25	Test tap		Mac8	LC-2-G-Skyblue	DIP
TP	26	Test tap		Mac8	LC-2-G-Skyblue	DIP
TP	29	Test tap		Mac8	LC-2-G-Skyblue	DIP
TP	30	Test tap		Mac8	LC-2-G-Skyblue	DIP
TPLED	1	Test tap		Mac8	LC-2-G-Skyblue	DIP
TPLED	2	Test tap		Mac8	LC-2-G-Skyblue	DIP
TPLED	3	Test tap		Mac8	LC-2-G-Skyblue	DIP
GND	1	Test tap		Mac8	LC-2-G-Black	DIP
GND	2	Test tap		Mac8	LC-2-G-Black	DIP
GND	3	Test tap		Mac8	LC-2-G-Black	DIP
GND	4	Test tap		Mac8	LC-2-G-Black	DIP
PFCO		Test tap		Mac8	LC-2-G-Red	DIP
12V		Test tap		Mac8	LC-2-G-Red	DIP
5V		Test tap		Mac8	LC-2-G-Red	DIP

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Revision Record

Rev.	Date	Description	
		Page	Summary
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NOTES FOR CMOS DEVICES

(1) 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 VIL (MAX) and VIH (MIN) due to noise, etc., 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 VIL (MAX) and VIH (MIN).

(2) HANDLING OF UNUSED INPUT PINS: Unconnected CMOS device inputs can be cause of malfunction. If an input pin is unconnected, it is possible that an internal input level may be generated due to noise, etc., causing malfunction. CMOS devices behave differently than Bipolar or NMOS devices. Input levels of CMOS devices must be fixed high or low by using pull-up or pull-down circuitry. Each unused pin should be connected to VDD or GND via a resistor if there is a possibility that it will be an output pin. All handling related to unused pins must be judged separately for each device and according to related specifications governing the device.

(3) PRECAUTION AGAINST ESD: A strong electric field, when exposed to a MOS device, can cause destruction of the gate oxide and ultimately degrade the device operation. Steps must be taken to stop generation of static electricity as much as possible, and quickly dissipate it when it has occurred. Environmental control must be adequate. When it is dry, a humidifier should be used. It is recommended to avoid using insulators that 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 should be grounded. The operator should be grounded using a wrist strap. Semiconductor devices must not be touched with bare hands. Similar precautions need to be taken for PW boards with mounted semiconductor devices.

(4) STATUS BEFORE INITIALIZATION: Power-on does not necessarily define the initial status of a MOS device. Immediately after the power source is turned ON, devices with reset functions have not yet been initialized. Hence, power-on does not guarantee output pin levels, I/O settings or contents of registers. A device is not initialized until the reset signal is received. A reset operation must be executed immediately after power-on for devices with reset functions.

(5) POWER ON/OFF SEQUENCE: In the case of a device that uses different power supplies for the internal operation and external interface, as a rule, switch on the external power supply after switching on the internal power supply. When switching the power supply off, as a rule, switch off the external power supply and then the internal power supply. Use of the reverse power on/off sequences may result in the application of an overvoltage to the internal elements of the device, causing malfunction and degradation of internal elements due to the passage of an abnormal current. The correct power on/off sequence must be judged separately for each device and according to related specifications governing the device.

(6) INPUT OF SIGNAL DURING POWER OFF STATE : Do not input signals or an I/O pull-up power supply while the device is not powered. 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. Input of signals during the power off state must be judged separately for each device and according to related specifications governing the device.

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