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Application Note

Controlling High Brightness LED by using 78K0/Ix2

This document describes a reference design for controlling a high brightness LED by using various functions mounted onto the 78K0/Ix2 microcontroller. Specifically, the document describes methods for driving a constant current and dimming LED by using the PWM output and internal analog peripherals (comparator and A/D converter) of 78K0/Ix2 microcontroller.

Target devices

78K0/IY2 microcontroller

78K0/IA2 microcontroller

78K0/IB2 microcontroller

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CONTENTS

CHAPTER 1 INTRODUCTION

This document describes a reference design for a high brightness LED control application using the 78K0/Ix2 microcontroller.

1.1 78K0/Ix2 Features for High Brightness LED Control

High brightness LED control using the 78K0/Ix2 microcontroller has the following features:

- The LED constant current drive can be controlled by using a PWM timer (TMXn: n = 0, 1) and analog peripheral (comparator or A/D converter) mounted onto the 78K0/Ix2. This will help you to remove the LED driver IC.
  Two constant current feedback methods can be used for the 78K0/Ix2:
  - Comparator feedback
  - 10-bit A/D converter feedback

- Dimming can be controlled by using a comparator or PWM timer mounted onto the 78K0/Ix2.
  Two LED dimming methods can be used for the 78K0/Ix2:
  - DC dimming by changing the internal programmable reference voltage for the comparator
  - PWM dimming by using the PWM timer (TMH1)

- The high brightness LED be controlled by using the A/D converter or communication functions mounted onto the 78K0/Ix2.
  Three control methods can be used for the 78K0/Ix2:
  - Volume control by using the 10-bit A/D converter
  - DMX512 protocol communication control by using UART (78K0/IA2 and 78K0/IB2 only)
  - DALI protocol communication control by using UART (in DALI mode) (78K0/IA2 and 78K0/IB2 only)

Remark The control method introduced in this application note can be evaluated using the 78K0/IB2 HBLED evaluation board (EZ-0005) offered by NEC Electronics. Please visit to the following website for details about the evaluation board:
- URL: http://www.necel.com/micro/en/solution/lighting/index.html

1.2 System Overview

Figures 1-1 and 1-2 show block diagrams for three-channel LED control by using the 78K0/Ix2 microcontroller.

Figure 1-1. Block Diagram of 3-Channel LED Control Using 78K0/Ix2 Microcontroller (Feedback by Comparators)

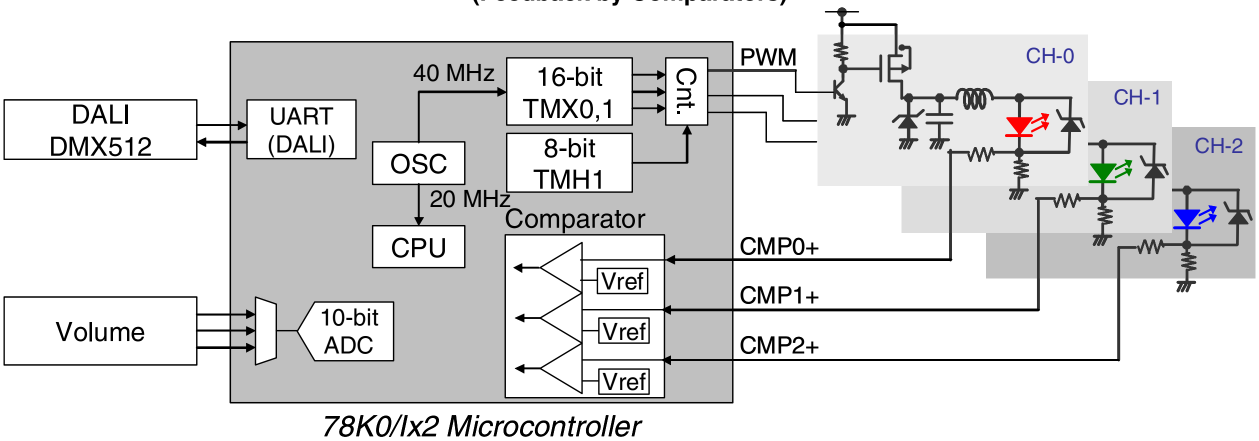
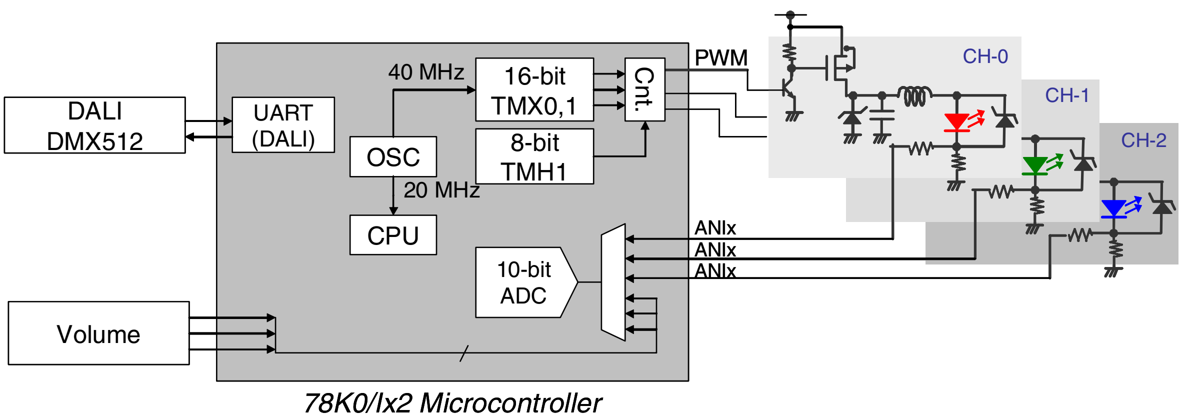


Figure 1-2. Block Diagram of 3-Channel LED Control Using 78K0/Ix2 Microcontroller (Feedback by10-bit A/D Converter)



CHAPTER 2 CONTROL THEORY

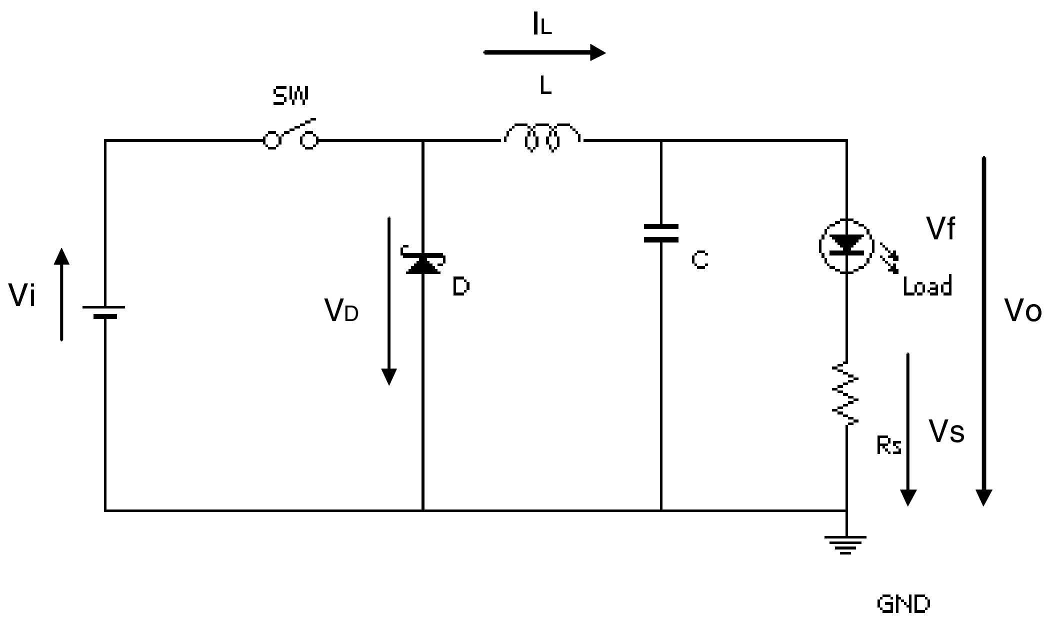
2.1 Buck Converter Basics

By using the timer and either the comparators or A/D converter integrated into 78K0/Ix2 microcontroller, constant current control is possible.

This enables high brightness LED control without using a separate LED-dedicated constant current driver IC.

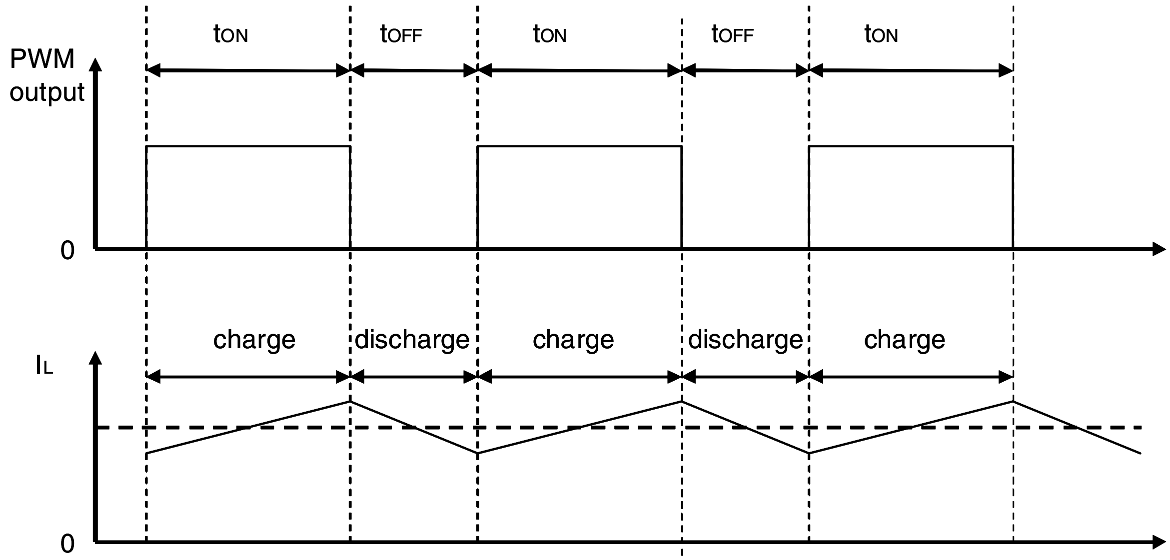
Figure 2-1 shows the basic of buck converter configuration.

Figure 2-1. Buck Converter Basics



A buck converter operates using an inductor (L), a switch (SW), and a diode (D). Figure 2-2 shows an example of constant current control using a buck converter while PWM output controls the switch (SW).

Figure 2-2. Constant Current Control



When the switch (SW) is on, the voltage bias on the inductor becomes (Vi – Vo), and the current increases according to following equation:

$| I_{L(ON)} | = [(Vi – Vo) \times t_{ON}] / L$

While the switch (SW) is off, the current through the inductor (L) decreases according to the following equation during the off period (t_{OFF}):

$| I_{L(OFF)} | = [(Vo – V_D) \times t_{OFF}] / L$

Assuming the converter operates in a steady state, the current is constant and can be calculated the following equation:

$| I_{L(ON)} | = | I_{L(OFF)} |$

These two periods repeat. The converter is regulated by varying the duty cycle of the power switch according to the load conditions. To achieve this, the power switch requires electronic control for proper operation. It is possible to determine the duty cycle as follows:

Duty = t_{ON} / t (switching cycle (t): $t_{ON} + t_{OFF}$)

Duty = Vo / Vi

An example of selecting an inductor (L) and a sense resistor (R_S) is shown here.

When using a constant current to control LEDs, the forward current must be kept constant. When detecting the forward current using a sense resistor, the sense voltage (Vs) is as follows:

$V_S = I_L \times R_S$

To drive LEDs at a better power efficiency, the sense voltage (Vs) must be minimized. In contrast, to achieve higher dimming resolution, higher sense voltage (Vs) is required. In addition, to reduce the error margin for the sense voltage, accurate sense resistors must be selected.

Suppose the typical forward current of a selected LED is 300 mA. Select the sense voltage (V_S) as 1.4 V during full output. The sense resistor (R_S) should be 4.7 Ω (1 W).

1.4 (V) = 0.3 (A) × R_S

R_S = 1.4 (V) / 0.3 (A) ≈ 4.7 Ω

The inductor value can be decided by the following equations:

$V_L = L \times di / dt$

$L = (Vi – V_O) \times Duty \times t / Iripple$

$Duty = Vo / Vi$

$Iripple (target) < I_L \times 1.5$ [%]

To realize 8-bit resolution for switching duty when using PWM output, the 78K0/Ix2 microcontroller can output a 156.25 kHz PWM signal (40 MHz/2^8) from 16-bit timers X0 and X1 by using a 40 MHz clock source.

So, t =1 / f =1 / 156.25 kHz

For an input voltage (Vi) of 5 V, the LED forward voltage (Vf) of 3.5 V, and a sense voltage (V_S) of 1.4 V, an inductor (L) larger than 140 μH is suitable for this feedback circuit.

$L > (Vi – V_O) \times Duty \times t / Iripple$

$L > (5.0 – 4.9) \times (4.9/5) \times (1/156250) \times (1/0.3 \times 1.5$ % or $0.015)$

$L > 139.38$ [μ H]

2.2 Constant Current Control Method

As shown in Figure 2-2, to perform control at a constant current, it is necessary to keep the sense voltage (Vs) through the sense resistor (Rs) the same as the target reference voltage. If the sense voltage (V_S) is higher than the reference voltage, the PWM output duty must be reduced to reduce a mount of time that the MOSFET switch is on and the current (sense voltage). In contrast, if the sense voltage (V_S) is lower than the reference voltage, the PWM output duty must be increased to increase the mount of time that the MOSFET switch is on and the current (sense voltage).

To compare the sense voltage and reference voltage adjusted by controlling PWM output, a method that uses the 78K0/Ix2 comparators and one that uses the 78K0/Ix2 A/D converter are available. The features of these methods are as follows:

- Comparator feedback:
  Because the CPU is not accessed before comparator interrupts occur, the software load can be reduced.
- A/D converter feedback:
  Because converted values are immediately compared, the ripple of current is smaller and the dimming resolution can be higher. However, the CPU is used to perform all channel switching and comparison for A/D converter.

PWM output for MOSFET switching is performed using the 16-bit timers X0 and X1. A 156.25 kHz switching frequency is available because these timers use a 40 MHz clock as a counting source with a resolution of 8 bits (40 MHz/2^8).

2.2.1 Internal comparator feedback

The 78K0Ix2 microcontroller has three internal comparators with programmable internal voltage references, so that three channels of LEDs can be driven independently using a comparator feedback method.

Specify the valid edge of the comparator interrupt to be both edges. The comparator interrupt occurs while the sense voltage (Vs) is higher or lower than the reference voltage. When this interrupt occurs, execute constant current feedback control by adjusting the PWM duty cycle.

When a comparator interrupt occurs, use the CMPnF flag to compare the comparator output level with expected value to avoid misjudgment caused by noise. Set the expected level of comparator output to the high level when increasing the duty. Set the expected level to the low level when reducing the duty.

By comparing the comparator output level with the expected value, changes in the duty due to unexpected noise can be avoided.

Figure 2-3. Example of Internal Comparator feedback

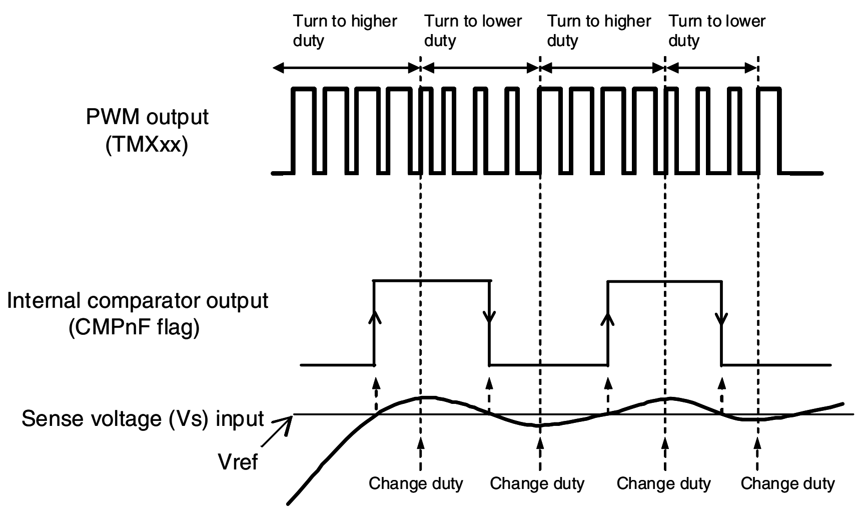
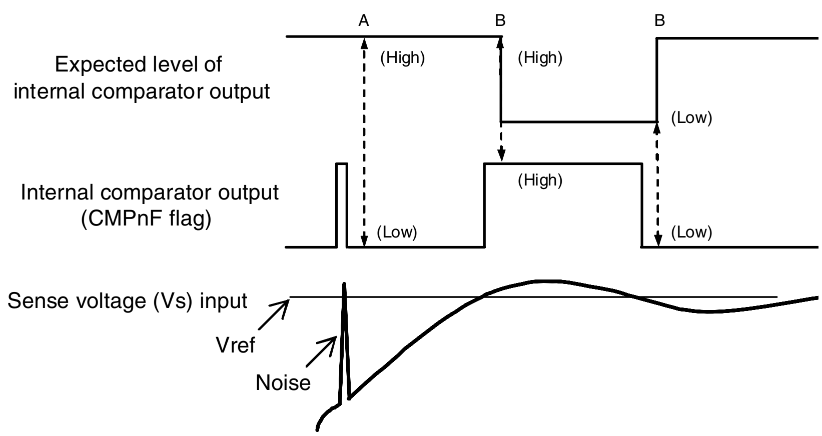


Figure 2-4. Example of Avoiding Misjudgment Caused by Noise



A: CMPnF does not match the expected level. Adjust the wave as noise.

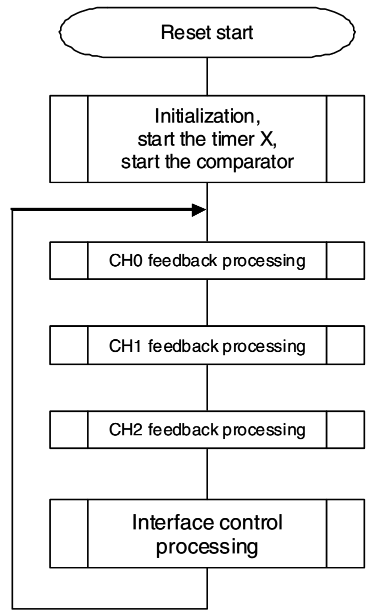
B: CMPnF matches the expected level. Feedback processing is required.

The higher duty and lower duty parameters are stored beforehand. For the higher duty, a sense voltage over the target level is output. A lower duty causes a sense voltage under the target level. It is possible to determine these two parameters by experimenting.

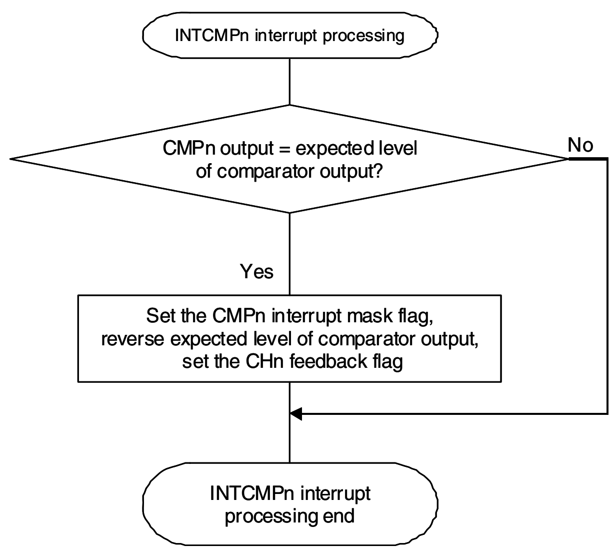
An example of data table based on the evaluation board (EZ-0005) is provided in Appendix C.

Figure 2-5. Flowchart of Comparator Feedback (1/2)

(Main processing)



(Comparator n interrupt processing: n = 0 to 2)

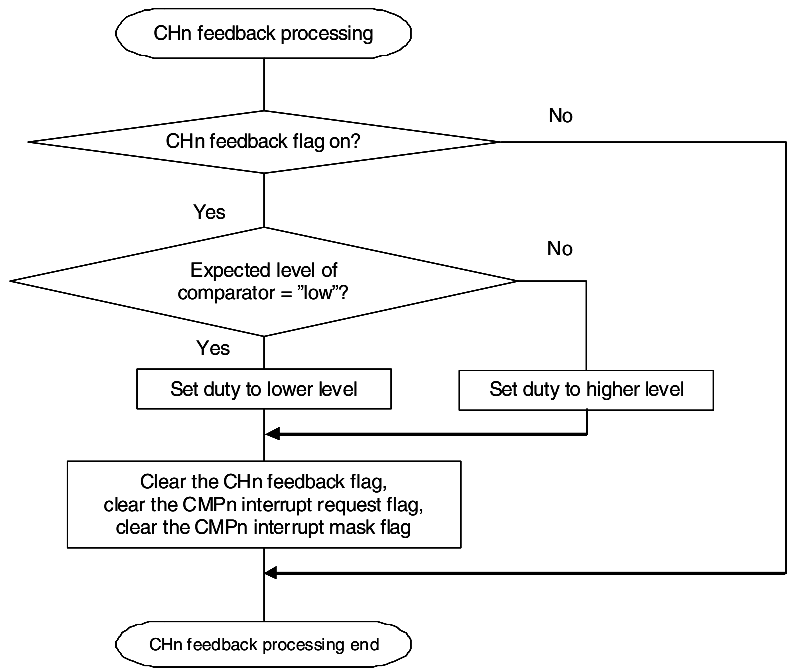


Caution **Feedback processing is executed according to the results of comparator interrupt processing.**

Remark The CHn feedback flag is used to indicate whether the PWM output changing processing is enabled or disabled.

Figure 2-5. Flowchart of Comparator Feedback (2/2)

(Comparator n feedback processing: n = 0 to 2)

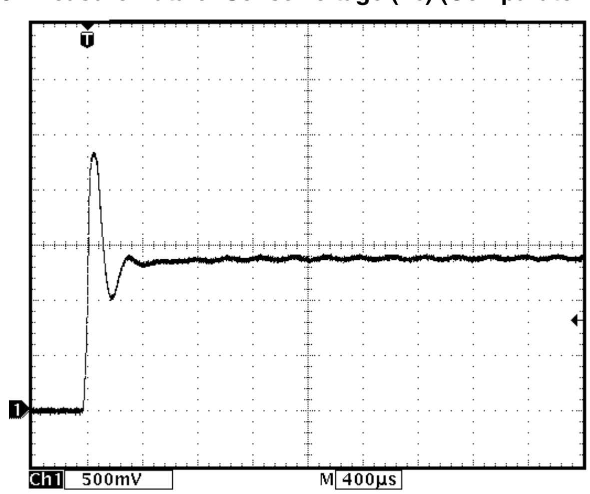


Caution Feedback processing is executed according to the results of comparator interrupt processing.

Remark The CHn feedback flag is used to indicate whether the PWM output changing processing is enabled or disabled.

Figure 2-6 shows the data measured using the comparator feedback.

Figure 2-6. Measure Data of Sense Voltage (V_S) (Comparator Feedback)



Remark The circuit constants are below.

- Inductor (L): 150 μH
- Sense resistor (R_S): 4.7 Ω
- LED forward current: 300 mA

2.2.2 Internal A/D converter feedback

The 78K0Ix2 microcontroller has an A/D converter that consists of up to 9 channels with a resolution of 10 bits, so that several LEDs can be driven independently using an A/D converter feedback method.

If the A/D converter is set up to operate at the shortest conversion time which is 3.3 μs, feedback processing for each channel can be executed every 20 μs.

The maximum and minimum target values of the A/D conversion results (the reference value for the sense voltage (Vs)) can be decided based on the detection accuracy of the target current. If the input voltage (Vi) = V_{DD} = 5 V, the sense voltage (Vs) = 1.4 V, and the ratio to define is 2%, the target range of A/D conversion result is supposed to approximately equal to the target level ±5LSB.

When the A/D conversion result is over the maximum while increasing compared with the last result, step down the duty. When the A/D conversion result becomes smaller than the minimum while decreasing compared with the last result, step up the duty.

To speed up the startup period of LEDs, set the duty of PWM output to the target duty related to the target A/D converter level before starting the timer X and the A/D converter.

While the A/D conversion result is almost 0, directly set the duty to the target value corresponding to the target A/D converter level.

The target duty related to each target level can be determined by experimenting.

An example of data table based on the evaluation board (EZ-0005) is provided in Appendix D.

Figure 2-7. Example of Internal A/D Converter Feedback

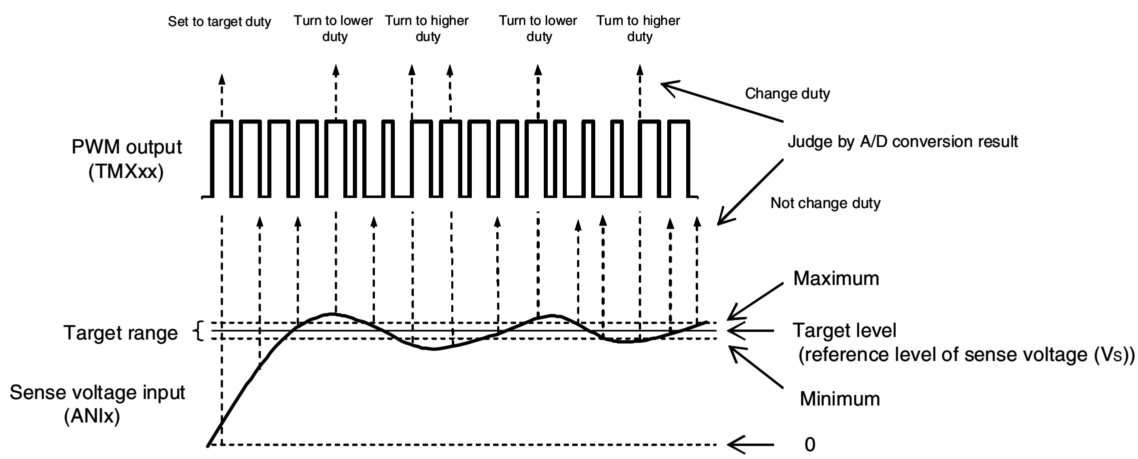
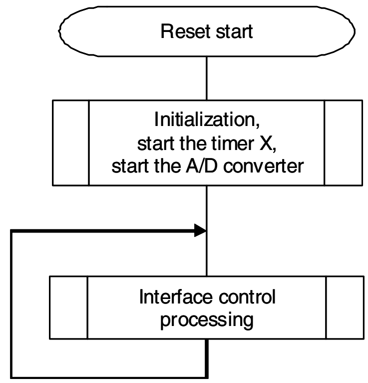


Figure 2-8. Flowchart of A/D Converter Feedback (1/2)

(Main processing)



(A/D Converter interrupt processing)

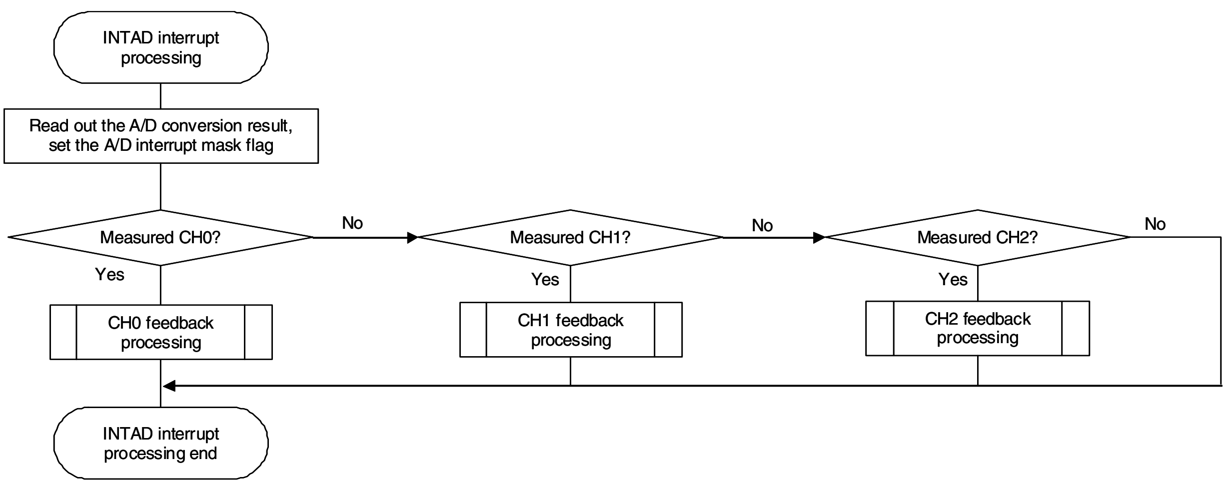


Figure 2-8. Flowchart of A/D Converter Feedback (2/2)

(CHn feedback processing)

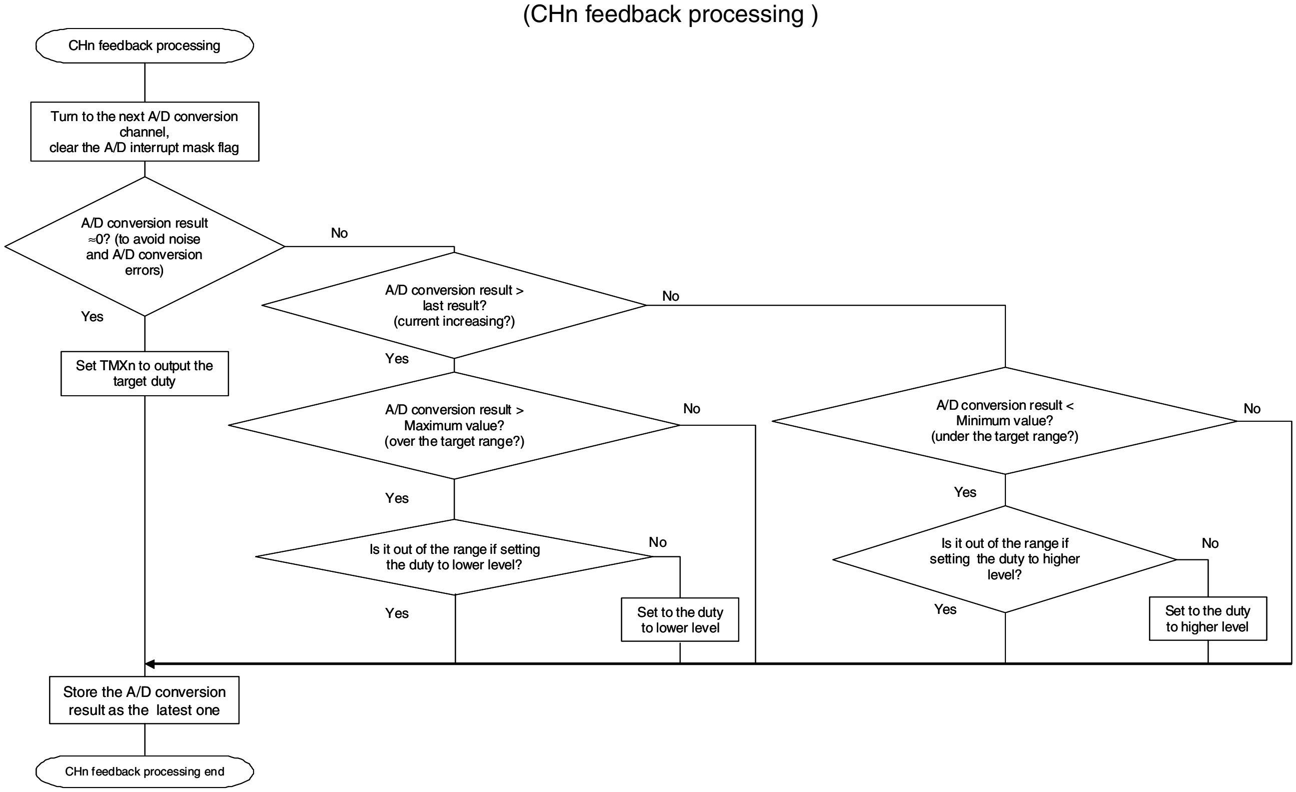
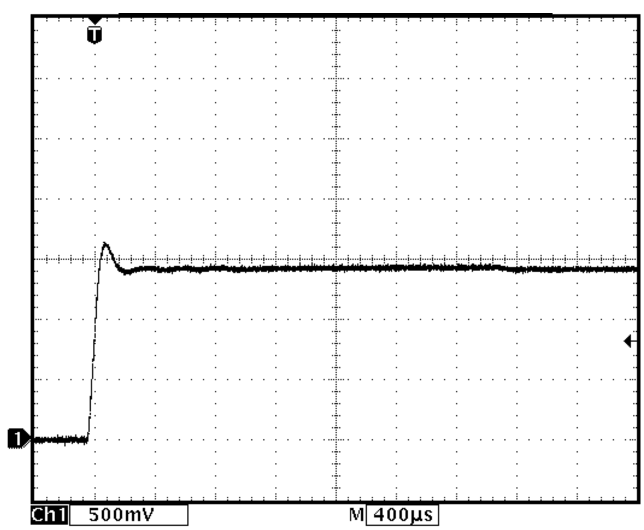


Figure 2-9 shows the data measured using A/D converter feedback.

Figure 2-9. Measure Data of Sense Voltage (Vs) (A/D Converter Feedback)



Remark The circuit constants are below.

- Inductor (L): 150 μH
- Sense resistor (Rs): 4.7 Ω
- LED forward current: 300 mA

2.3 Dimming Control

Dimming means change the brightness of LED. Dimming can be controlled by changing the LED forward current. Here, two dimming methods for the 78K0/Ix2 microcontroller are introduced: DC dimming and PWM dimming.

2.3.1 DC dimming

(1) Dimming by changing the internal reference voltage

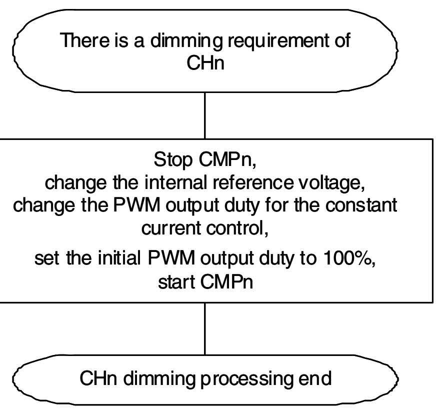
The 78K0/Ix2 microcontroller can generate 3 internal reference voltages independently for each internal comparator, which can be divided into 32 steps.

As expressed in **2.2**, the 78K0/Ix2 microcontroller monitors the sense voltage (V_S) and compares it to a stable reference to keep the current constant. Changing the reference voltage helps the circuit constantly keep the current as a different level. Dimming requirements depend on communication and user setting.

For the comparator feedback, change the internal reference voltage of each comparator. Also change higher duty and lower duty parameters.

The internal reference voltage can be changed in 32 steps in the range from 0.05 V (typ.) to 1.6 V (typ.). To increase the dimming resolution, set the sense voltage (Vs) when driving current at the maximum brightness to as high a value as possible in the range of the internal reference voltage.

Figure 2-10. Flowchart of Dimming for Changing Internal Reference Voltage



(2) Dimming by changing the target level for the A/D conversion result

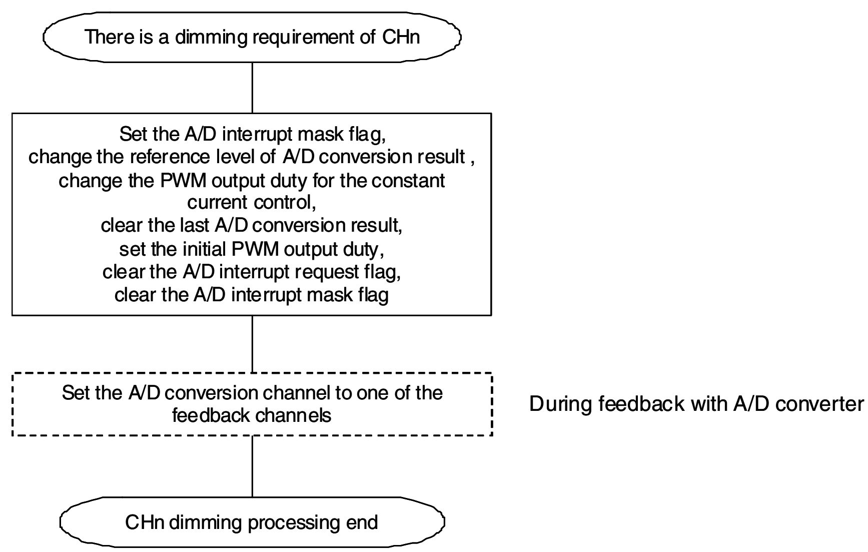
The 78K0Ix2 microcontroller has an A/D converter with a resolution of 10 bits.

For the A/D converter feedback, change the parameter target level. Also change the target duty.

The Reference voltage for the maximum brightness is selected by considering the hardware design and the limit of the A/D converter reference voltage. The dimming step number is decided by using maximum reference voltage and error margin for the target level.

To increase the dimming resolution, set the sense voltage (Vs) when driving current at the maximum brightness to as high a value as possible within the range of voltages for which A/D conversion is possible (AV_{REF} or less).

Figure 2-11. Flowchart of DC Dimming by Changing Target Level for A/D conversion Result



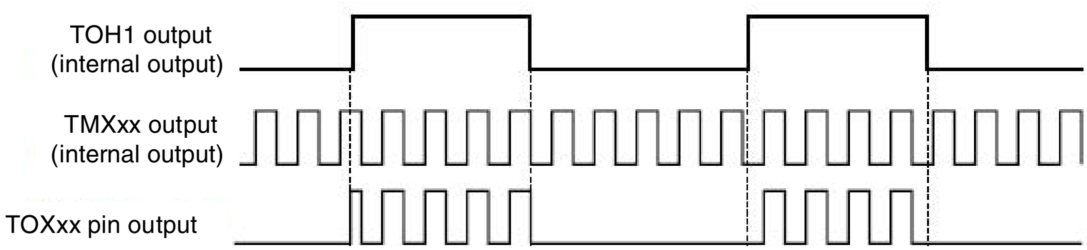
2.3.2 PWM dimming

78K0/Ix2 microcontroller includes a function that performs gate control for the signals output by the 16-bit timers X0 and X1 by using the output of the 8-bit timer H1.

Keeping the reference voltage at the maximum level, LEDs can be dimmed in 255 steps by using the TMXn output gate function via the TMH1 output. A square PWM wave output by the 8-bit timer H1 can be set to control all 4 TMXn outputs. If TOH1 is combined with the outputs of 16-bit timers X0 and X1, the TMXn output is only enabled when the TOH1 output is at high level or low level.

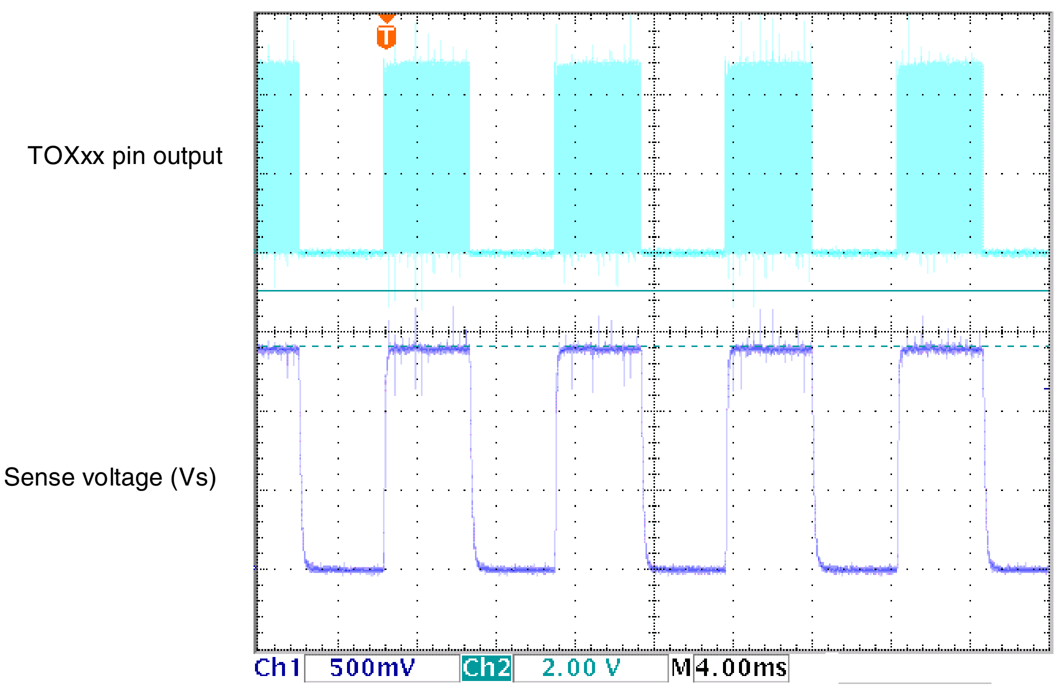
While using PWM dimming via TMH1, all TMX outputs will start or stop at the same time. Therefore, this method can be used to dim the LEDs of all channels at the same time.

Figure 2-12. Example Timing Chart of TMX0 and TMX1 Output Gate Function via TMH1 Output



Considering the startup speed of each channel, it seems the TMH1 output frequency should be selected to be as low as possible. However, the limitations of the human eye also affect this decision. A 100 Hz frequency is usually assumed to be sufficient for avoiding flicker, which means the frequency should be higher than 100Hz.

Figure 2-13. Sense Voltage and TOXxx Output Measurement Data (PWM Dimming via TMH1 Output)



2.4 User Interface

The user can assign dimming requirements by using the user interface mounted onto the 78K0/Ix2 microcontroller. Three interfaces are introduced here:

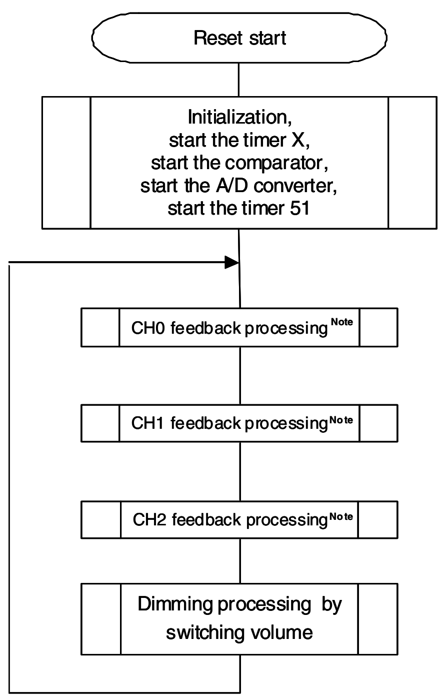
A/D converter control interface, DMX512 control interface, and DALI (Digital Addressable Lighting Interface) control interface

2.4.1 Internal A/D converter control interface

The 78K0Ix2 microcontroller has an A/D converter that consists of up to 9 channels. Volume switches, sensors or some other analog inputs can be connected to these analog input pins as the dimming requirement trigger.

Except the ones used for the feedback input, all A/D converter input pins are available. While using the A/D converter feedback, the feedback channels and the user interface channels use the same the A/D converter interrupt. This results in different flowcharts for the A/D converter interface with the comparator feedback as opposed to the A/D converter feedback.

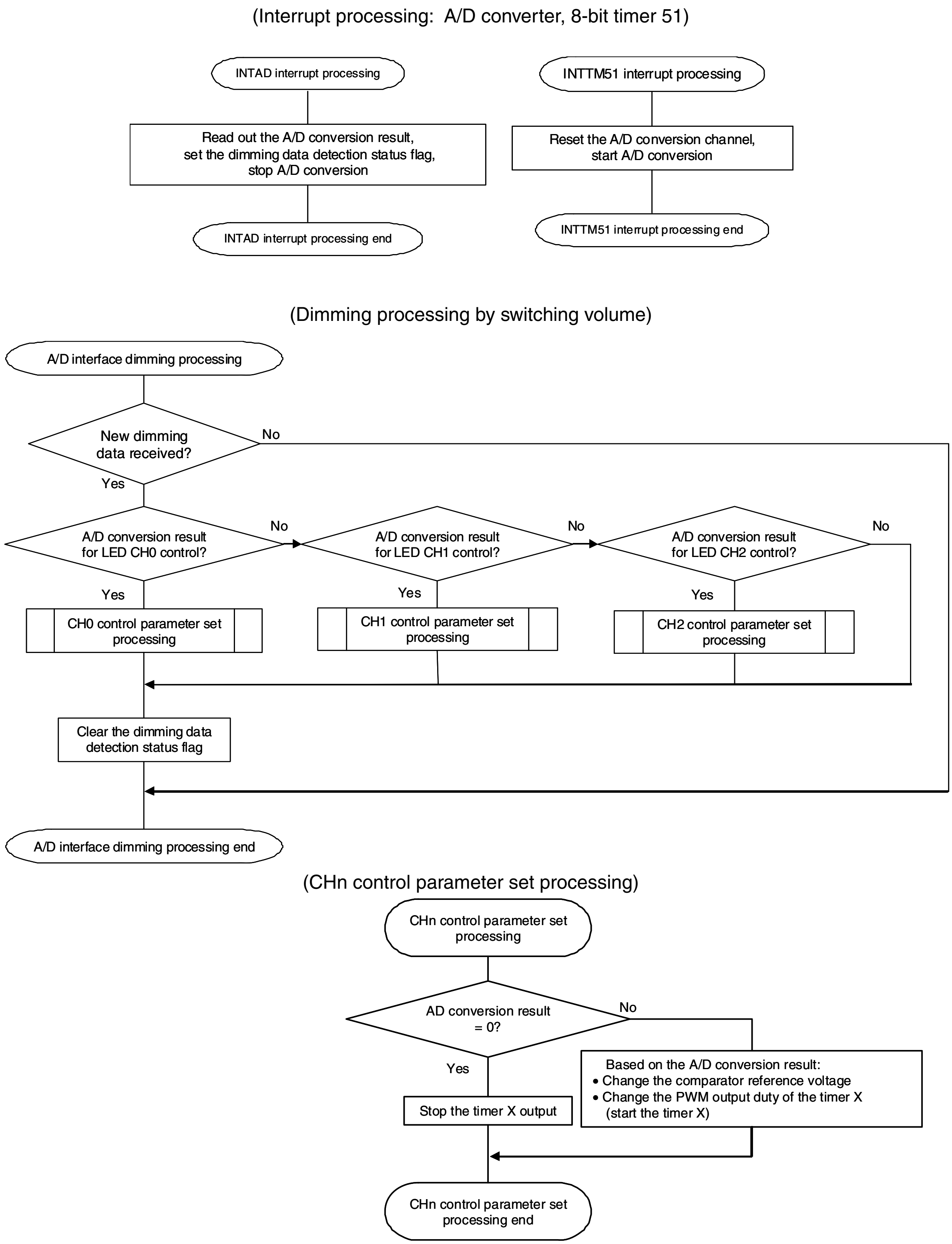
Figure 2-14. Flowchart of A/D Converter Control Interface (Comparator Feedback) (1/2)



Note For the comparator feedback, see 2.2.1 Internal comparator feedback.

Caution A/D conversion starts when the interrupt of 8-bit timer 51 occurs. LEDs are dimmed using the volume switches according to the result of A/D converter interrupt servicing.

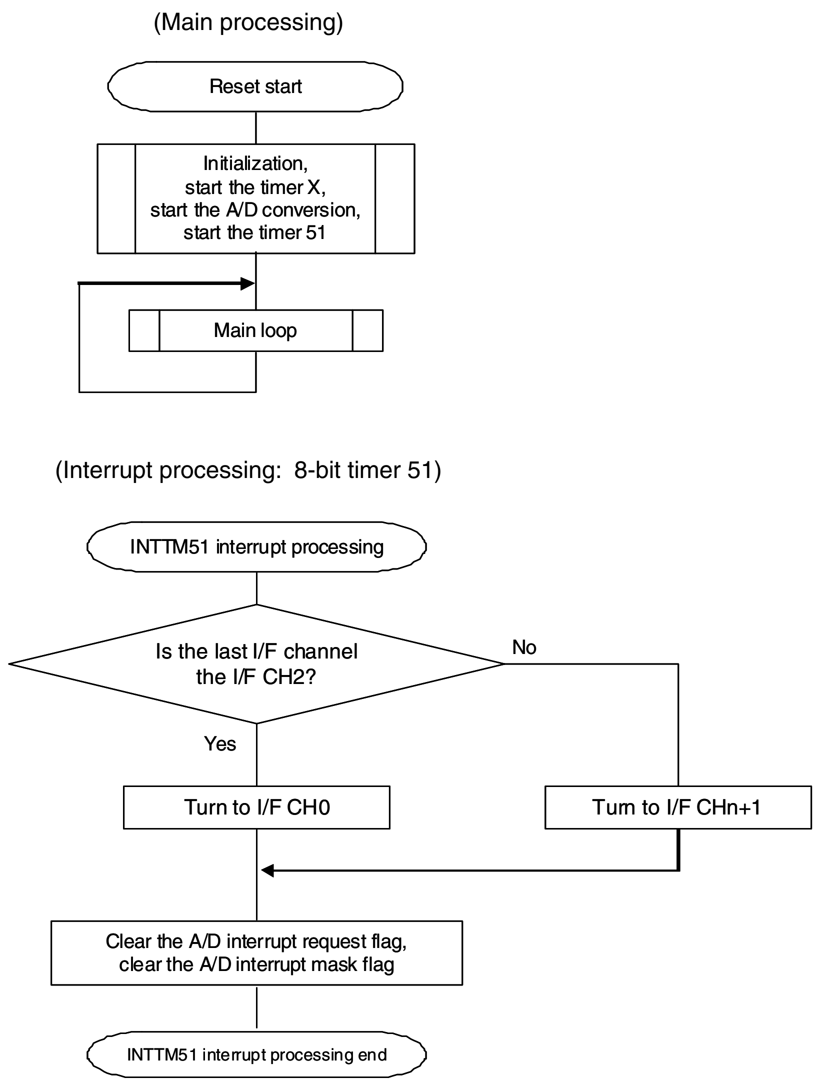
Figure 2-14. Flowchart of A/D Converter Control Interface (Comparator Feedback) (2/2)



Caution **A/D conversion starts when the interrupt of 8-bit timer 51 occurs. LEDs are dimmed using the volume switches according to the result of A/D converter interrupt servicing.**

Remark The dimming data detection status flag is used to indicate whether the dimming processing by switching volume is enable or disable.

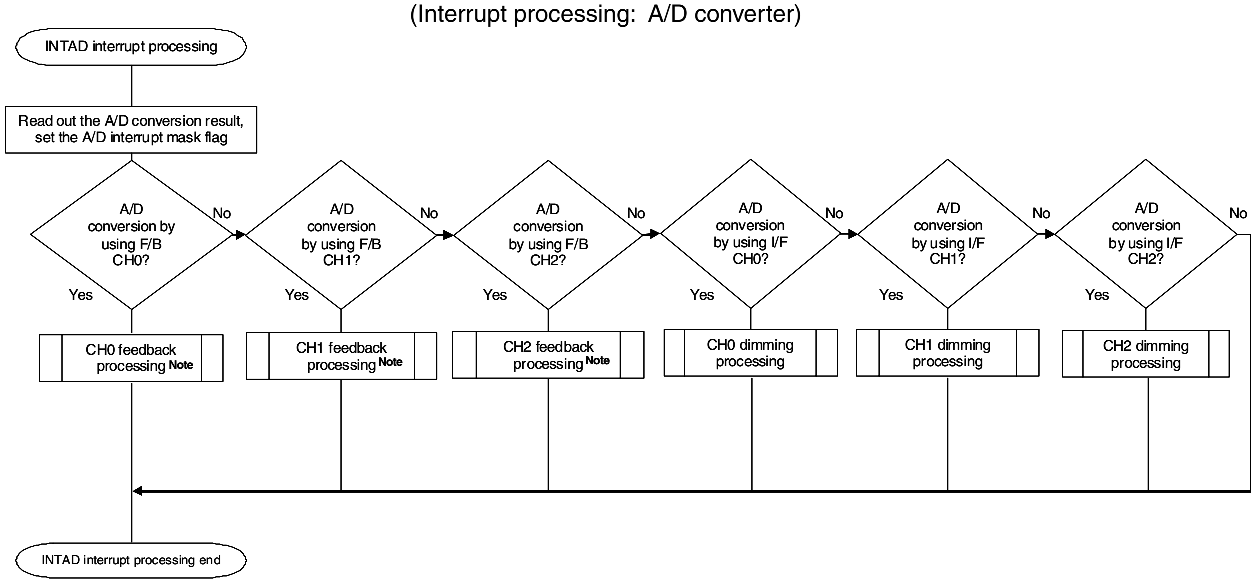
Figure 2-15. Flowchart of A/D Converter Control Interface (A/D Converter Feedback) (1/2)



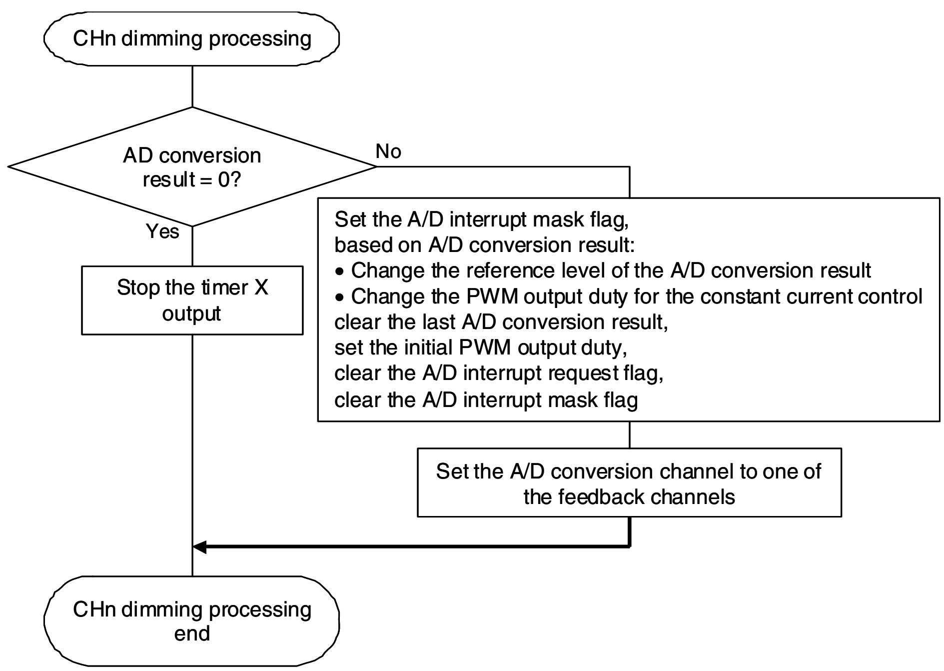
Remark I/F CHn: A/D conversion channels for LED CHn control interface

Figure 2-15. Flowchart of A/D Converter Control Interface (A/D Converter Feedback) (2/2)

(Interrupt processing: A/D converter)



(CHn dimming processing)



Note For the CHn feedback processing, see **2.2.2 Internal A/D converter feedback**.

Remark F/B CHn: A/D conversion channels for LED CHn feedback processing
I/F CHn: A/D conversion channels for LED CHn control interface

2.4.2 DMX512 protocol communication control interface

The DMX data stream clocks out at a rate of 250 kHz, which means each bit is measured in 4 microseconds. The DMX512 signal is transmitted via RS485, which is the industry standard interface.

The RS485 standard uses two or three wires to transmit digital HIs and LOs:

- The +signal wire (+s)
- The –signal wire (–s)
- The 0 wire or ground wire (0 V)

Figure 2-16 shows the DMX receiver hardware interface.

Figure 2-16. DMX512 Receiver Hardware Interface

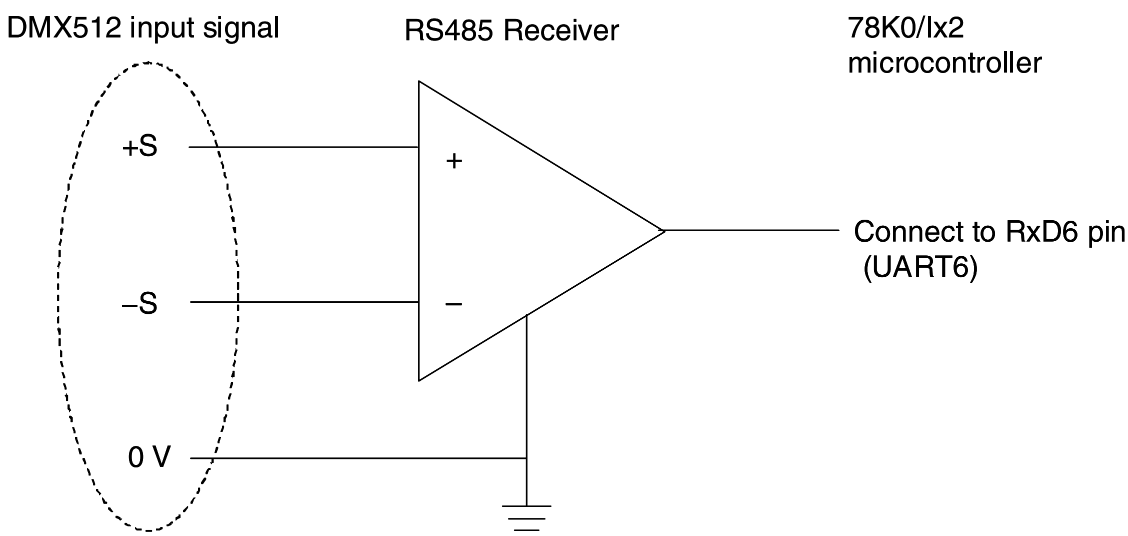
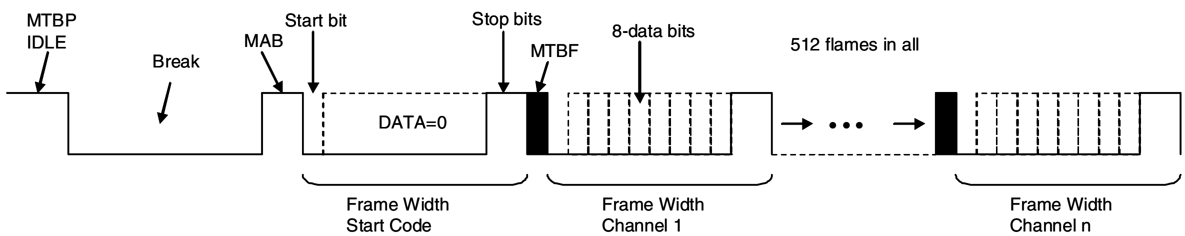


Figure 2-17 shows the DMX timing chart.

Figure 2-17. DMX512 Timing Chart



	MIN.	TYP.	MAX.	Unit
Break	88	88	1,000,000	μs
MAB		8		μs
Frame Width		44		μs
Start/Data/Stop bits		4		μs
MTBF	0	NS	1,000,000	μs
MTBP	0	NS	1,000,000	μs

Remark NS: not specified

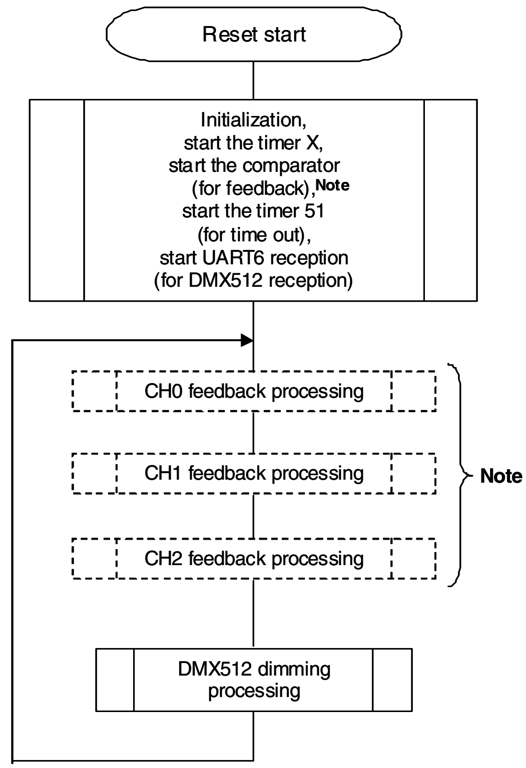
The meanings of addresses and data freely are defined by users. For example, while the DMX512 protocol is used to control stage lighting, one lamp has several addresses and data can be defined as the brightness, position, and so on.

The first byte after the start code (SC) is automatically taken as the data value for address 1, the next data value is for address 2, and so on. The slave counts the data and uses that which belongs to its address to start dimming processing.

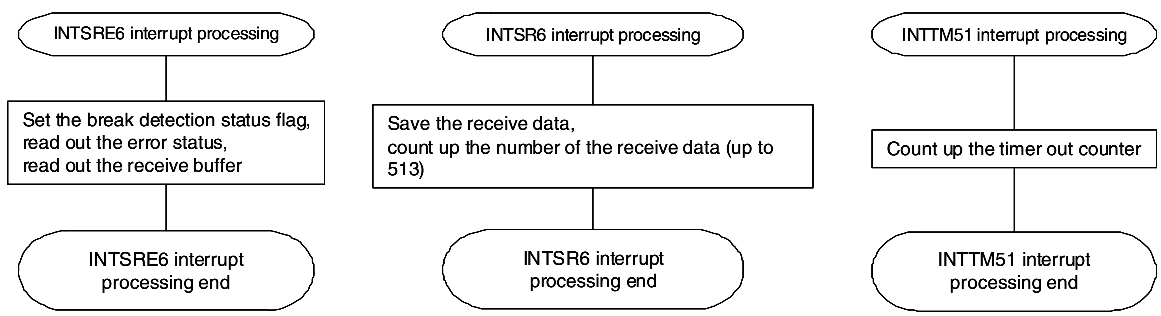
Figure 2-18 shows the flowchart of the dimming control by the DMX512 protocol communication interface. In this example, the 3 LED channels are controlled using independent address.

Figure 2-18. Flowchart of Dimming Control by DMX512 Protocol Communication Interface (1/2)

(Main processing)



(Interrupt processing: serial interface UART6 (no error during reception, error during reception), 8-bit timer 51)



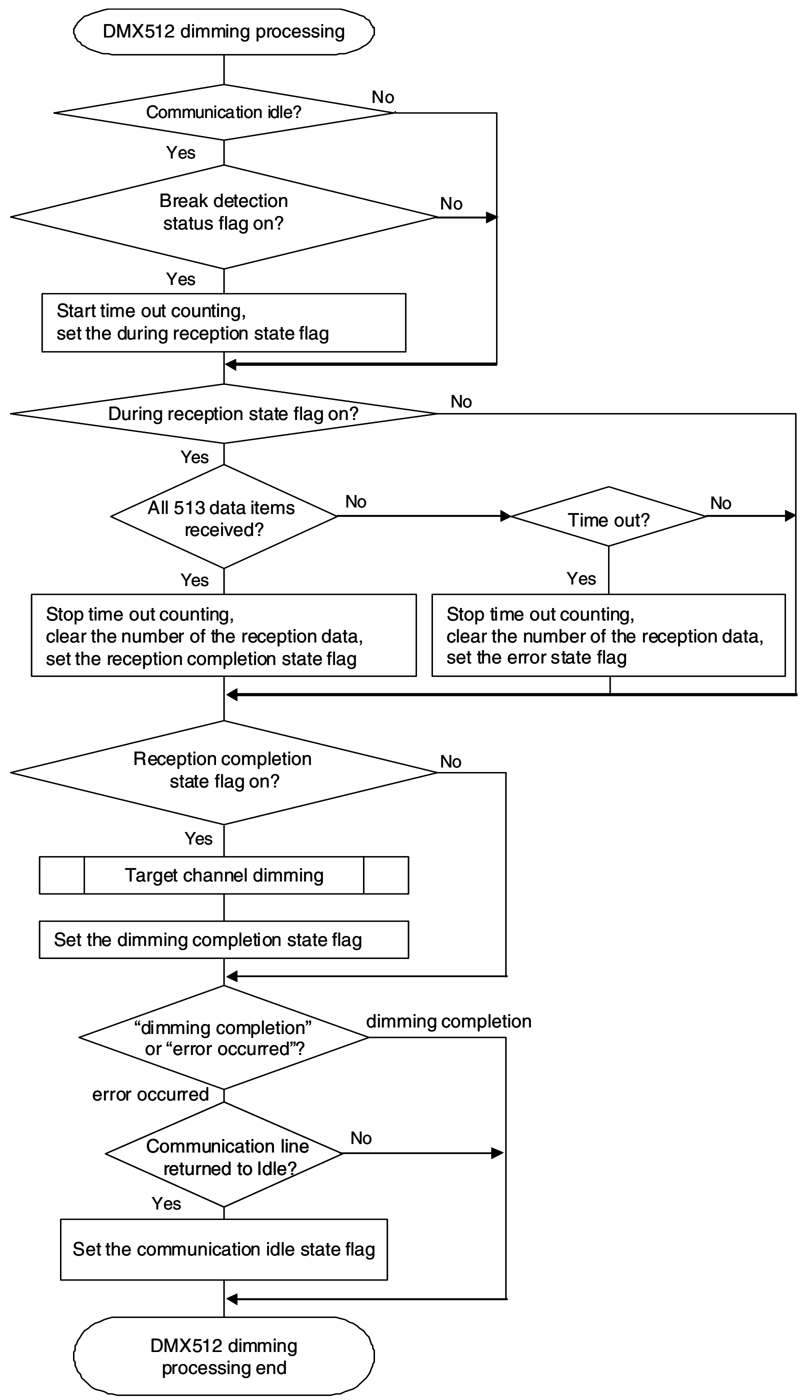
Note Using the comparator feedback processing only.
For the comparator feedback processing, see **2.2.1 Internal comparator feedback**.
For the A/D converter feedback processing, see **2.2.2 Internal A/D converter feedback**.

Caution Dimming processing controlled by DMX512 interface starts when the serial interface UART6 receives an error interrupt.

Remark The break detection status flag is used to show that the break time of the DMX512 signal has been detected.

Figure 2-18. Example Flowchart of Dimming Control by DMX512 Protocol Communication Interface (2/2)

(DMX 512 dimming processing)



Caution Dimming processing controlled by DMX512 interface starts when the serial interface UART6 receives an error interrupt.

Remark The status flag is used to show that the communication status has been detected during reception.

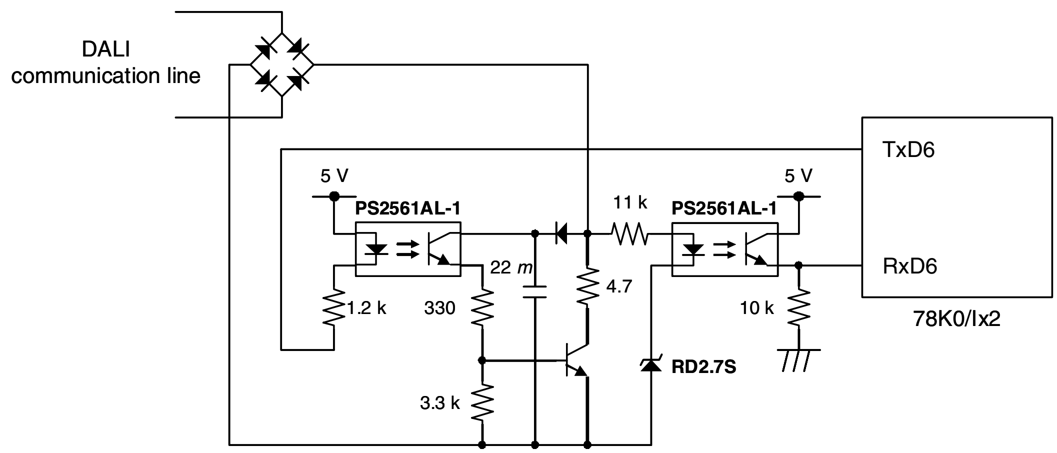
2.4.3 DALI protocol communication control interface

The serial interface UART6 of the 78K0/Ix2 microcontroller supports a special mode for performing transmission and reception as a DALI slave.

DALI stands for Digital Addressable Lighting Interface and is a royalty-free, non-proprietary, two-way, open, interoperable digital protocol. It is a standard in the United States and Europe. This protocol is used to dim multi ballasts or LEDs in a system. One system contains a maximum of 64 individual addressable slaves. The DALI protocol communicates at a rate of 1,200 Hz±10 %. The master dims and brightens slaves in 256 steps. Each step of brightness can be stored as a scene.

Figure 2-19 shows the example of the DALI slave circuit by using the 78K0/Ix2 microcontroller.

Figure 2-19. Example of DALI Slave Circuit by Using 78K0/Ix2 Microcontroller



Remarks 1. PS2561AL-1 is a photocoupler made by NEC Electronics.
2. RD2.7S is a Zener diode made by NEC Electronics.

The definitions of forward and backward message frames in the DALI communication protocol are as follows:

A forward message frame that consists of 19 bits is sent from the master:
- 1 start bit
- 1 address byte: 1 individual or group address bit, 6 address bits, 1 selection bit
- 1 data byte: 8 data bits
- 2 stop bits

A backward message frame that consists of 11 bits is sent from the slave:
- 1 start bit
- 1 data byte: 8 data bits
- 2 stop bits

Figure 2-20. Example of DALI Receiving Timing Chart by Using 78K0/Ix2 Microcontroller

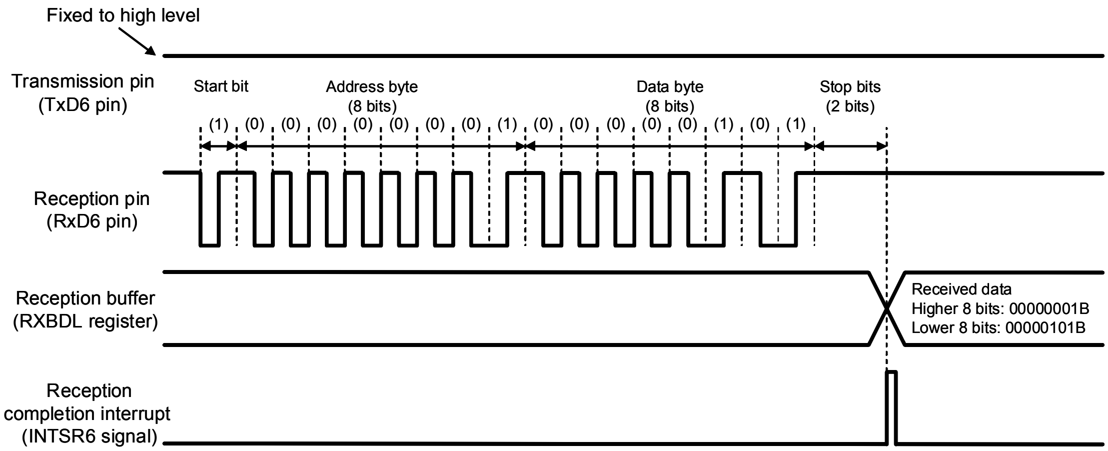
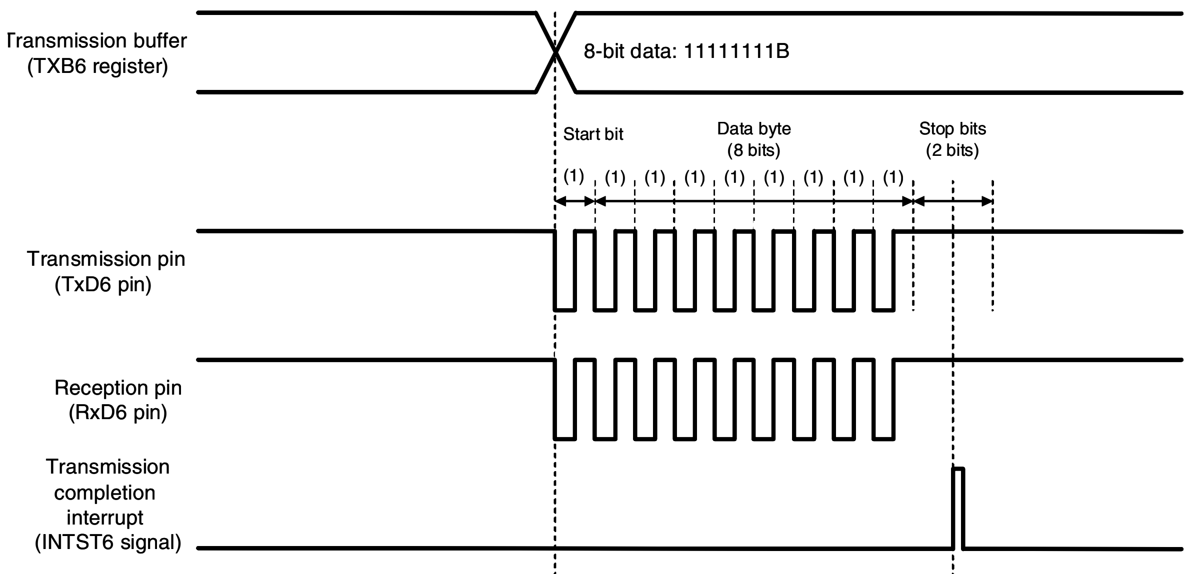


Figure 2-20. Example of DALI Transmitting Timing Chart by Using 78K0/Ix2 Microcontroller

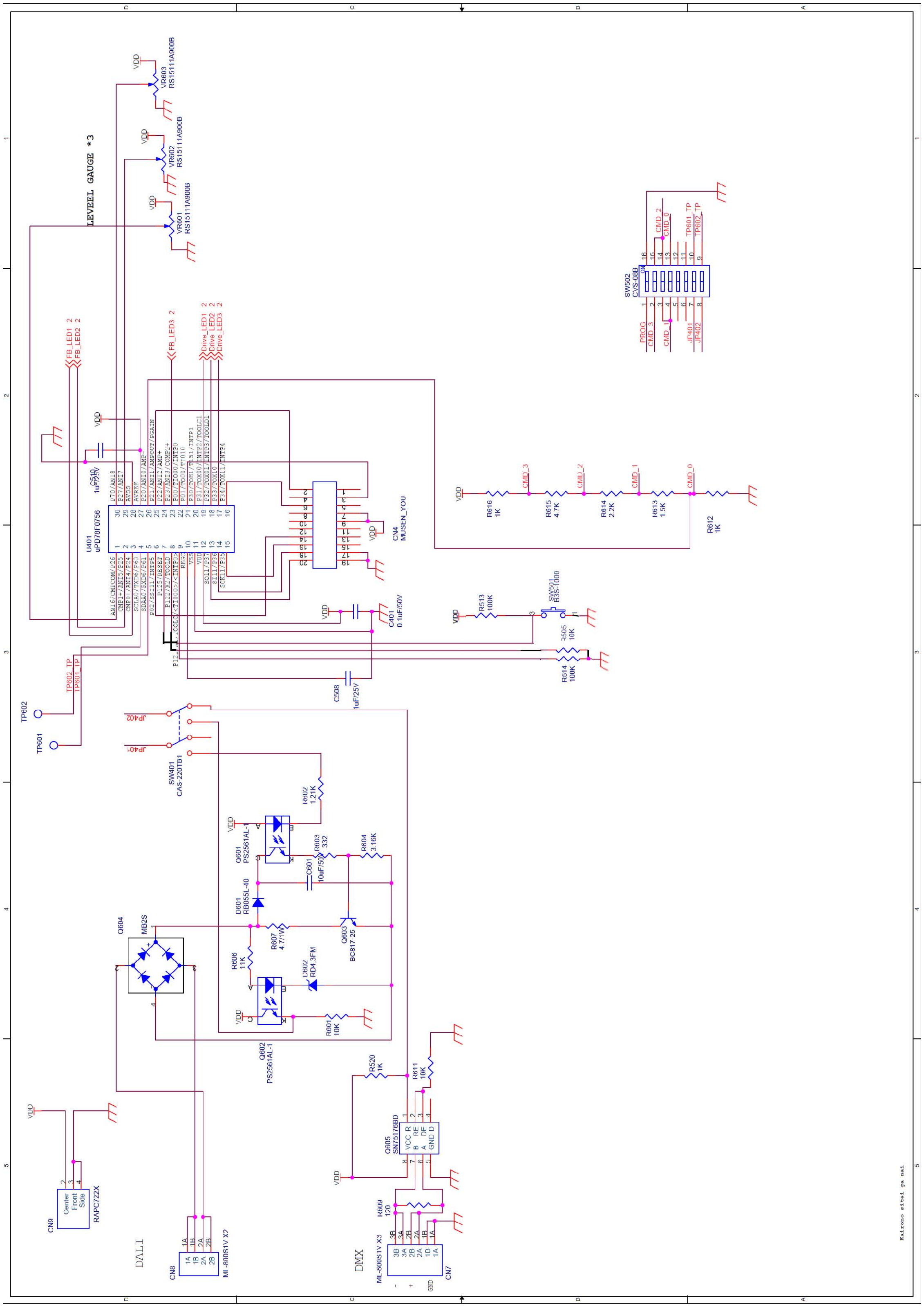


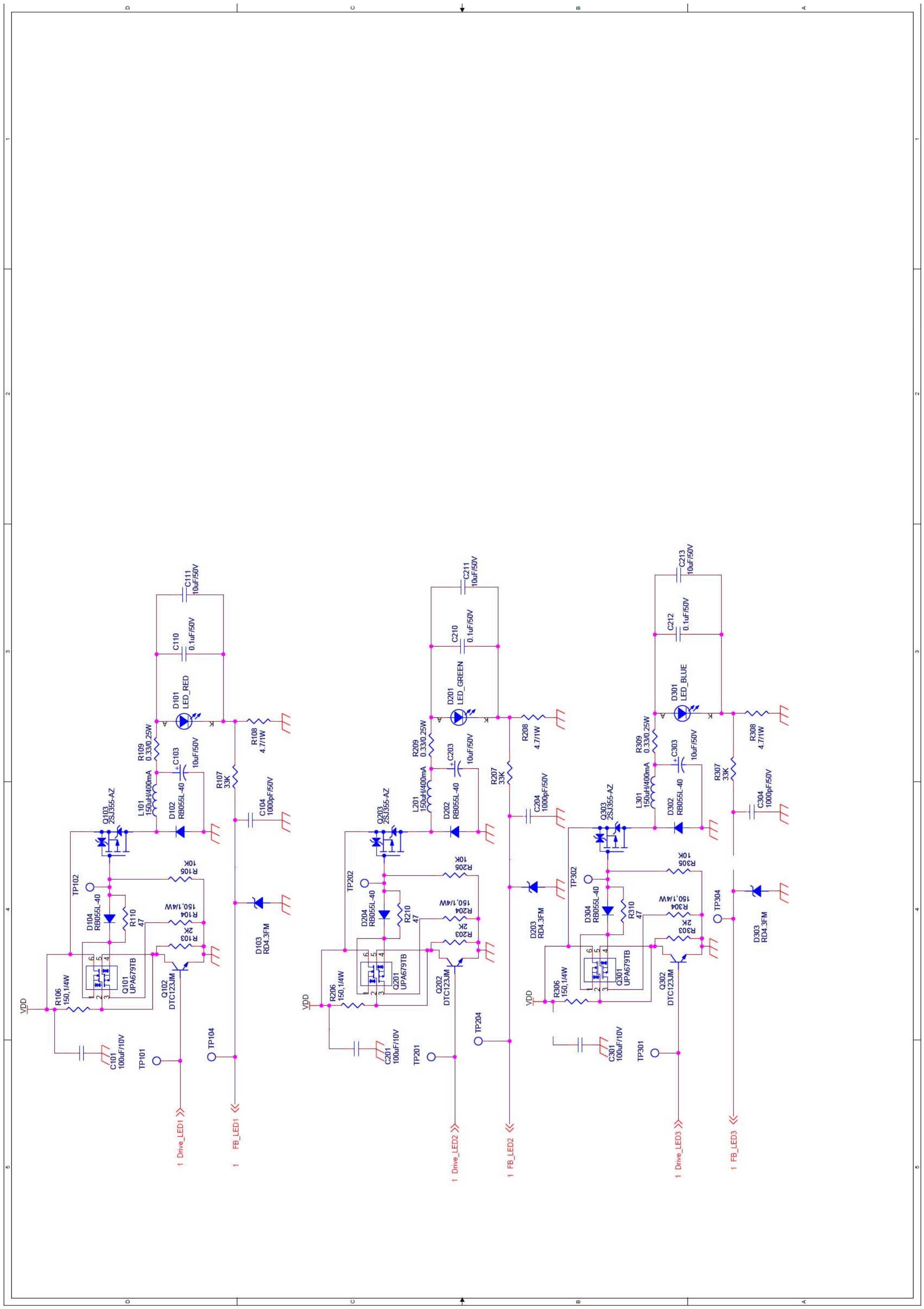
For details about the DALI interface control by using 78K0/Ix2 microcontroller, see the following document.

- **Controlling Fluorescent Lamp Ballasts by Using 78K0/Ix2 Application Note (Document No.: U19665)**

APPENDIX A REFERENCE CIRCUIT DIAGRAM (EZ-0005)

Caution Note that the evaluation board and its schematic are designed for evaluating high brightness control using the 78K0/Ix2 microcontroller and are not intended for use in the final product.




D101
LED_RED
D201
LED_GREEN
D301
LED_BLUE
C111
10uF/50V
C110
0.1uF/50V
C211
10uF/50V
C210
0.1uF/50V
C213
10uF/50V
C212
0.1uF/50V
R109
0.33/0.25W
R209
0.33/0.25W
R309
0.33/0.25W
C103
10uF/50V
C203
10uF/50V
C303
10uF/50V
L101
150uH/400mA
L201
150uH/400mA
L301
150uH/400mA
D102
RB055L-40
D202
RB055L-40
D302
RB055L-40
Q103
2SJ355-AZ
Q203
2SJ355-AZ
Q303
2SJ355-AZ
R108
4.7/1W
R208
4.7/1W
R308
4.7/1W
R107
33K
R207
33K
R307
33K
C104
1000pF/50V
C204
1000pF/50V
C304
1000pF/50V
R105
10K
R205
10K
R305
10K
R104
150,1/4W
R204
150,1/4W
R304
150,1/4W
R103
2K
R203
2K
R303
2K
D104
RB055L-40
D204
RB055L-40
D304
RB055L-40
R110
47
R210
47
R310
47
Q101
UPA679TB
Q201
UPA679TB
Q301
UPA679TB
Q102
DTC123JM
Q202
DTC123JM
Q302
DTC123JM
R106
150,1/4W
R206
150,1/4W
R306
150,1/4W
C101
100uF/10V
C201
100uF/10V
C301
100uF/10V
D103
RD4.3FM
D203
RD4.3FM
D303
RD4.3FM
VDD
TP101
TP102
TP104
TP201
TP202
TP204
TP301
TP302
TP304
1 Drive_LED1
1 FB_LED1
1 Drive_LED2
1 FB_LED2
1 Drive_LED3
1 FB_LED3

APPENDIX B REFERENCE PARTS TABLE (EZ-0005)

Table B-1. Reference Parts Table (EX-0005) (1/2)

Item No.	Maker	Part No.	Spec
C101	MURATA	GRM31CR60J107M	100 µF/10 V
C103	TAIYO YUDEN	UMK325BJ106KH-J	10 µF /50 V
C104	MURATA	GRM188B11H102KA01D	1000 pF/50 V
C110	MURATA	GRM188B31H104KA92D	0.1 µF/50 V
C111	TAIYO YUDEN	UMK325BJ106KH-J	10 µF/50 V
C201	MURATA	GRM31CR60J107M	100 µF/10 V
C203	TAIYO YUDEN	UMK325BJ106KH-J	10 µF/50 V
C204	MURATA	GRM188B11H102KA01D	1000 pF/50 V
C210	MURATA	GRM188B31H104KA92D	0.1 µF/50 V
C211	TAIYO YUDEN	UMK325BJ106KH-J	10 µF/50 V
C212	MURATA	GRM188B31H104KA92D	0.1 µF/50 V
C213	TAIYO YUDEN	UMK325BJ106KH-J	10 µF/50 V
C301	MURATA	GRM31CR60J107M	100 µF/10 V
C303	TAIYO YUDEN	UMK325BJ106KH-J	10 µF/50 V
C304	MURATA	GRM188B11H102KA01D	1000 pF/50 V
C401	MURATA	GRM188B31H104KA92D	0.1 µF/50 V
C508	MURATA	GRM188B31E105K	1 µF/25 V
C510	MURATA	GRM188B31E105K	1 µF/25 V
C601	TAIYO YUDEN	UMK325BJ106KH-J	10 µF/50 V
CN4	HONDA	FFC-20BMEP1	MUSEN_YOU
CN7	SATO_Parts	ML-800S1V-3P	ML-800S1V X3
CN8	SATO_Parts	ML-800S1V-2P	ML-800S1V X2
CN9	SwitchCraft	RAPC722	RAPC722X
D101	NICHIA	NS6R083	LED_RED
D102	ROHM	RB055LA-40	RB055L-40
D103	NEC Electronics	RD4.3FM	RD4.3FM
D104	ROHM	RB055LA-40	RB055L-40
D201	NICHIA	NS6G083	LED_GREEN
D202	ROHM	RB055LA-40	RB055L-40
D203	NEC Electronics	RD4.3FM	RD4.3FM
D204	ROHM	RB055LA-40	RB055L-40
D301	NICHIA	NS6B083	LED_BLUE
D302	ROHM	RB055LA-40	RB055L-40
D303	NEC Electronics	RD4.3FM	RD4.3FM
D304	ROHM	RB055LA-40	RB055L-40
D601	ROHM	RB055LA-40	RB055L-40
D602	NEC Electronics	RD4.3FM	RD4.3FM
L101	TDK	SLF7045T-151MR40-PF	150 µH/400 mA
L201	TDK	SLF7045T-151MR40-PF	150 µH/400 mA
L301	TDK	SLF7045T-151MR40-PF	150 µH/400 mA
Q101	NEC Electronics	µPA679TB	µPA679TB
Q102	ROHM	DTC123JM	DTC123JM
Q103	NEC Electronics	2SJ355	2SJ355-AZ
Q201	NEC Electronics	µPA679TB	µPA679TB
Q202	ROHM	DTC123JM	DTC123JM
Q203	NEC Electronics	2SJ355	2SJ355-AZ
Q301	NEC Electronics	µPA679TB	µPA679TB
Q302	ROHM	DTC123JM	DTC123JM
Q303	NEC Electronics	2SJ355	2SJ355-AZ

Table B-1. Reference Parts Table (EX-0005) (2/2)

Item No.	Maker	Part No.	Spec
Q601	NEC Electronics	PS2561AL-1	PS2561AL-1
Q602	NEC Electronics	PS2561AL-1	PS2561AL-1
Q603	Philipps	BC817-25	BC817-25
Q604	VISHAY	MB2S	MB2S
Q605	TI	SN75176BD	SN75176BD
R103	KOA	RK73B1JTTD202J	2 k
R104	KOA	RK73B2ATTD151J	150,1/4 W
R105	KOA	RK73B1JTTD103J	10 k
R106	KOA	RK73B2ATTD151J	150,1/4 W
R107	KOA	RK73B1JTTD333J	33 k
R108	KOA	RK73BW3ATTD4R7J	4.7/1 W
R109	KOA	SR732ETTDR33F	0.33/0.25 W
R110	KOA	RK73B1JTTD470J	47
R203	KOA	RK73B1JTTD202J	2 k
R204	KOA	RK73B2ATTD151J	150,1/4 W
R205	KOA	RK73B1JTTD103J	10 k
R206	KOA	RK73B2ATTD151J	150,1/4 W
R207	KOA	RK73B1JTTD333J	33 k
R208	KOA	RK73BW3ATTD4R7J	4.7/1 W
R209	KOA	SR732ETTDR33F	0.33/0.25 W
R210	KOA	RK73B1JTTD470J	47
R303	KOA	RK73B1JTTD202J	2 k
R304	KOA	RK73B2ATTD151J	150,1/4 W
R305	KOA	RK73B1JTTD103J	10 k
R306	KOA	RK73B2ATTD151J	150,1/4 W
R307	KOA	RK73B1JTTD333J	33 k
R308	KOA	RK73BW3ATTD4R7J	4.7/1 W
R309	KOA	SR732ETTDR33F	0.33/0.25 W
R310	KOA	RK73B1JTTD470J	47
R505	KOA	RK73B1ETTD103J	10 k
R513	KOA	RK73B1ETTD104J	100 k
R514	KOA	RK73B1ETTD104J	100 k
R520	KOA	RK73B1ETTD102J	1 k
R601	KOA	RK73B1ETTD103J	10 k
R602	KOA	RK73H1JTTD1211F	1.21 k
R603	KOA	RK73H1JTTD3320F	332
R604	KOA	RK73H1JTTD3161F	3.16 k
R606	KOA	RK73B2ATTD113J	11 k
R607	KOA	RK73BW3ATTD4R7J	4.7/1 W
R609	KOA	RK73B1ETTD121J	120
R611	KOA	RK73B1ETTD103J	10 k
R612	KOA	RK73B1ETTD102J	1 k
R613	KOA	RK73B1ETTD152J	1.5 k
R614	KOA	RK73B1ETTD222J	2.2 k
R615	KOA	RK73B1ETTD472J	4.7 k
R616	KOA	RK73B1ETTD102J	1 k
SW401	COPAL	CAS-220TB1	CAS-220TB1
SW501	COPAL	B3S-1000	B3S-1000
SW502	COPAL	CVS-08B	CVS-08B
U401	NEC Electronics	μPD78F0756	μPD78F0756
VR601	ALPS	RS15111A900B	RS15111A900B
VR602	ALPS	RS15111A900B	RS15111A900B
VR603	ALPS	RS15111A900B	RS15111A900B

APPENDIX C EXAMPLE INTERNAL REFERENCE VOLTAGES AND PWM OUTPUT DUTY PARAMETERS (FOR INTERNAL COMPARATOR FEEDBACK)

Table C-1. Example Internal Reference Voltages and PWM Output Duty Parameters (For Internal Comparator Feedback)

I_{LED} required(mA)	Vref required	Channel 0(RED)		Channel 1(GREEN)		Channel 2(BLUE)	
		DUTY_max0[28] TX0CR1 value for CH0(RED)	DUTY_min0[28] TX0CR1 value for CH0(RED)	DUTY_max1[28] TX0CR2 value for CH1(GREEN)	DUTY_min1[28] TX0CR2 value for CH1(GREEN)	DUTY_max2[28] TX1CR1 value for CH2(BLUE)	DUTY_min2[28] TX1CR1 value for CH2(BLUE)
300	1.4	129	121	2	80	188	170
287	1.35	125	117	68	85	176	167
277	1.3	123	115	72	89	172	163
266	1.25	119	111	78	91	168	160
255	1.2	115	107	80	95	164	156
245	1.15	113	105	84	99	162	153
234	1.1	109	101	88	102	156	148
223	1.05	105	97	90	106	152	144
213	1	101	95	96	110	148	140
202	0.95	97	90	104	115	146	136
191	0.9	95	86	108	119	140	133
181	0.85	91	85	112	123	135	128
170	0.8	87	81	116	128	132	124
160	0.75	83	77	118	132	128	122
149	0.7	79	73	122	138	124	118
138	0.65	77	70	130	143	120	114
128	0.6	73	67	132	147	116	110
117	0.55	71	63	138	152	112	106
106	0.5	67	60	142	157	108	100
96	0.45	65	57	146	161	104	96
85	0.4	63	55	154	167	100	92
74	0.35	61	51	158	174	98	89
64	0.3	57	48	164	178	92	83
53	0.25	55	45	168	182	88	80
43	0.2	53	35	174	196	82	74
32	0.15	47	31	180	202	76	68
21	0.1	35	7	190	238	66	36
11	0.05	23	1	216	250	40	6

Caution The above parameters are not guaranteed because they were calculated using experimented results.

APPENDIX D EXAMPLE A/D CONVERTER EXPECTED VALUES AND PWM OUTPUT DUTY PARAMETERS (FOR INTERNAL A/D CONVERTER FEEDBACK)

Table D-1. Example A/D Converter Expected Values and PWM Output Duty Parameters (For Internal A/D Converter Feedback)

I_{LED} required(mA)	Vref required	Adref[28] Target ADC value	DUTYref0[28] TX0CR1 value for CH0(RED)	DUTYref1[28] TX0CR2 value for CH1(GREEN)	DUTYref2[28] TX1CR1 value for CH2(BLUE)
300	1.4	287	123	1	171
287	1.35	276	119	84	168
277	1.3	266	116	88	164
266	1.25	256	112	90	161
255	1.2	246	109	94	157
245	1.15	236	106	98	154
234	1.1	225	100	101	149
223	1.05	215	98	105	145
213	1	205	94	109	141
202	0.95	195	91	114	138
191	0.9	184	87	118	134
181	0.85	174	84	122	130
170	0.8	164	80	127	126
160	0.75	154	78	131	123
149	0.7	143	74	137	119
138	0.65	133	71	142	115
128	0.6	123	68	146	111
117	0.55	113	64	151	107
106	0.5	102	61	156	101
96	0.45	92	59	160	98
85	0.4	82	56	166	94
74	0.35	72	53	170	90
64	0.3	61	49	176	85
53	0.25	51	46	181	81
43	0.2	41	43	186	76
32	0.15	31	40	192	71
21	0.1	20	22	224	39
11	0.05	10	10	245	17

Caution The above parameters are not guaranteed because they were calculated using experimented results.

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