

FUJITSU Electronic Devices
User's Manual

F²MC-16LX STARTER KIT



USER'S MANUAL

Revision History

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Contents

Preface.....	1
1 Setting Up of Starter Kit	2
1.1 Setting Up of Personal Computer	8
1.1.1 Installing of USB driver	9
1.1.2 Installing of integrated development environment "SOFTUNE" (limited-function version)	10
1.1.3 Installing of demonstration version (trial version) of ACCEMIC MDE	16
1.1.4 Setting up of evaluation board and connecting of board to the personal computer.....	21
1.1.5 Starting and setting up of SOFTUNE	23
1.1.6 Starting and setting up of ACCEMIC MDE	26
1.1.7 Terminating of ACCEMIC MDE.....	37
1.1.8 Terminating of SOFTUNE	37
1.1.9 Board operation without ACCEMIC MDE	38
2 "Let's try to turn on the LED!"	40
2.1 What is an LED?	40
2.2 How can the LED emit light?	41
2.3 How to turn on an LED by microcomputer	42
2.4 How to create and execute a program to turn on the LED	44
2.4.1 Outline of program to be created	45
2.4.2 Creating and executing of program	45
2.5 How to create and execute a program to make the LED blinking	46
2.5.1 Outline of the program to be created	46
2.5.2 Creating and executing of program	47
3 "Let's try to control the LED by switch operation!"	49
3.1 How the microcomputer detects switch operation	49
3.2 How to create and execute a program to control LEDs by switch operation	51
3.2.1 Outline of program to be created	51
3.2.2 Creating and executing of program	52
4 "Let's try to sound a buzzer!"	54
4.1 Devices used for buzzer	54

4.1.1	Crystalline characteristics of piezoelectric device	55
4.1.2	Piezoelectric characteristics	55
4.1.3	Principle of piezoelectric device	56
4.2	Microcomputer and piezoelectric buzzer	56
4.2.1	Self-excited and separately excited vibrations	57
4.2.2	Pulse wave generated by the microcomputer	57
4.3	How to sound the buzzer by PPG	57
4.3.1	Setting of L-level and H-level duration	58
4.3.2	PPG count clock	58
4.4	How to create and execute a program to sound the buzzer	58
4.4.1	Outline of the program to be created	59
4.4.2	Creating and executing of program	60
4.4.3	Changing the tone of a buzzer sound	62
5	“Let's try to control the LED by interrupt.”	63
5.1	What is an interrupt?	63
5.2	How to detect a switch operation by interrupts	64
5.3	How to create and execute a program to control the LED by switch Input operation	65
5.3.1	Outline of the program to be created	65
5.3.2	Creating and executing of program	67
6	“Let's blink the LED by using a timer interrupt.”	69
6.1	What is a timer?	69
6.2	How to create and execute a program to control the LED blinking by using a timer interrupt	70
6.2.1	Outline of the program to be created	70
6.2.2	Creation and execution of the program	72
7	“Let's use the A/D converter.”	74
7.1	Analog and Digital	74
7.1.1	Outline of A/D converter	75
7.1.2	Scheme of volume tab	76
7.2	How to create and execute a program to display potential	76
7.2.1	Outline of program to be created	76
7.2.2	Creation and execution of the program	80
8	“Let's use the temperature sensor.”	82
8.1	What is a temperature sensor?	82
8.2	How to detect temperatures by using "temperature sensor"	83

8.3	How to create and execute a program to display temperature	85
8.3.1	Outline of the program to be created	85
8.3.2	Creation and execution of the program.....	88
A	Appendix (Program Creation Procedure).....	90
A.1	Program Creation Procedure	90
A.2	Program Building Procedure.....	94
A.3	Program Execution Method	96
B	Appendix (Method To Write/Read Values in Registers)	97
B.1	About the Method To Write/Read Values in Registers.....	97
C	Appendix (Method To Change the Include Path).....	98
C.1	About the Method To Change the Include Path	98

Preface

Thank you for your purchase of this Starter Kit.

The Starter Kit is intended for first-time users of microcomputers. The Starter Kit is designed in such a way that even beginners who have neither any actual experience with microcomputers nor any knowledge about what microcomputers do and how they are used can easily learn about microcomputers.

The Starter Kit includes a flash microcomputer and application development tools in order to enable a user with some knowledge of C language to modify sample programs and make the microcomputer actually perform various operations. This User's Manual gives detailed descriptions of how to control LED operations and buzzer sounds using the microcomputer. Even users with no knowledge about programming languages will be able to comfortably learn in an enjoyable way about microcomputers provided they have an introductory reference book on the C language handy.

This User's Manual has been established incorporating various recommendations of employees who had only been engaged in microcomputer-related work for one to three years and had had only little prior knowledge of microcomputers to begin with. Therefore, this User's Manual has been written specifically for questions that beginners of microcomputers usually have.

The Starter Kit can be effectively used as a tool for training about electronic circuits or as introductory education for embedded-software developers in classes at universities, technical colleges, and industrial high schools, as well as in new-employee education programs at corporations.

1 Setting Up of Starter Kit

Before setting up the Starter Kit, make sure that all the components and equipment listed in Table 1.1 are ready for use.

You should install the software on your personal computer before connecting the evaluation board to the personal computer.

The Starter Kit software is available in two versions: A CD-ROM version and a download version (the download version is not delivered on CD-ROM).

Table 1.1 List of components and necessary equipment

No.	Item	Qty	Specification	Remarks
1	Board	1	Evaluation board equipped with Fujitsu F2MC-16LX Series MB90F387 Microcomputer	See Figure 1.1.
2	USB cable	1	USB	Accessory
3	Installation CD-ROM	(1)	CD-ROM for installing SOFTUNE, ACCEMIC MDE, and sample programs Related manuals are contained on the CD-ROM. •User's Manual: <code>jouet_bleu_start_kit_manual_E.pdf</code> •USB Driver Installation Manual: <code>USB_driver_installation_manual_E.pdf</code> •MB90385 Series Hardware Manual: <code>MB90385_HM_E.pdf</code> •MB90385 Series Data Sheet: <code>MB90385_DS_E.pdf</code> •Set of SOFTUNE-related manuals: SOFTUNE¥ MANUAL folder	CD-ROM version only The download version has the same contents.
4	Personal computer	1	Personal computer on which Windows XP/Me/2000/98 can operate normally USB2.0 port necessary About 200 megabytes of free space necessary on the hard disk	To be prepared by the user

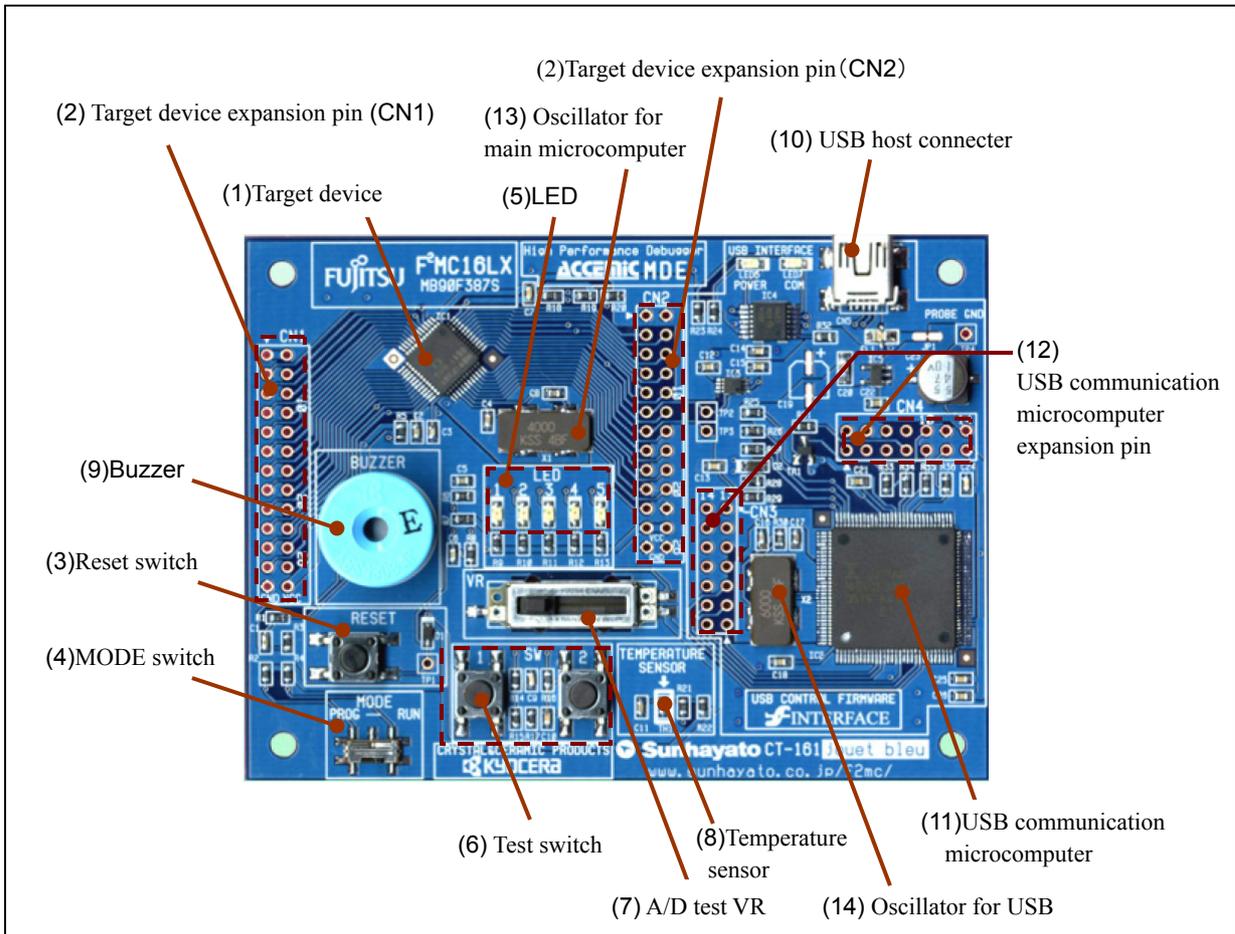


Figure 1.1 Board

Figure 1.2 is a circuit diagram for the evaluation board.

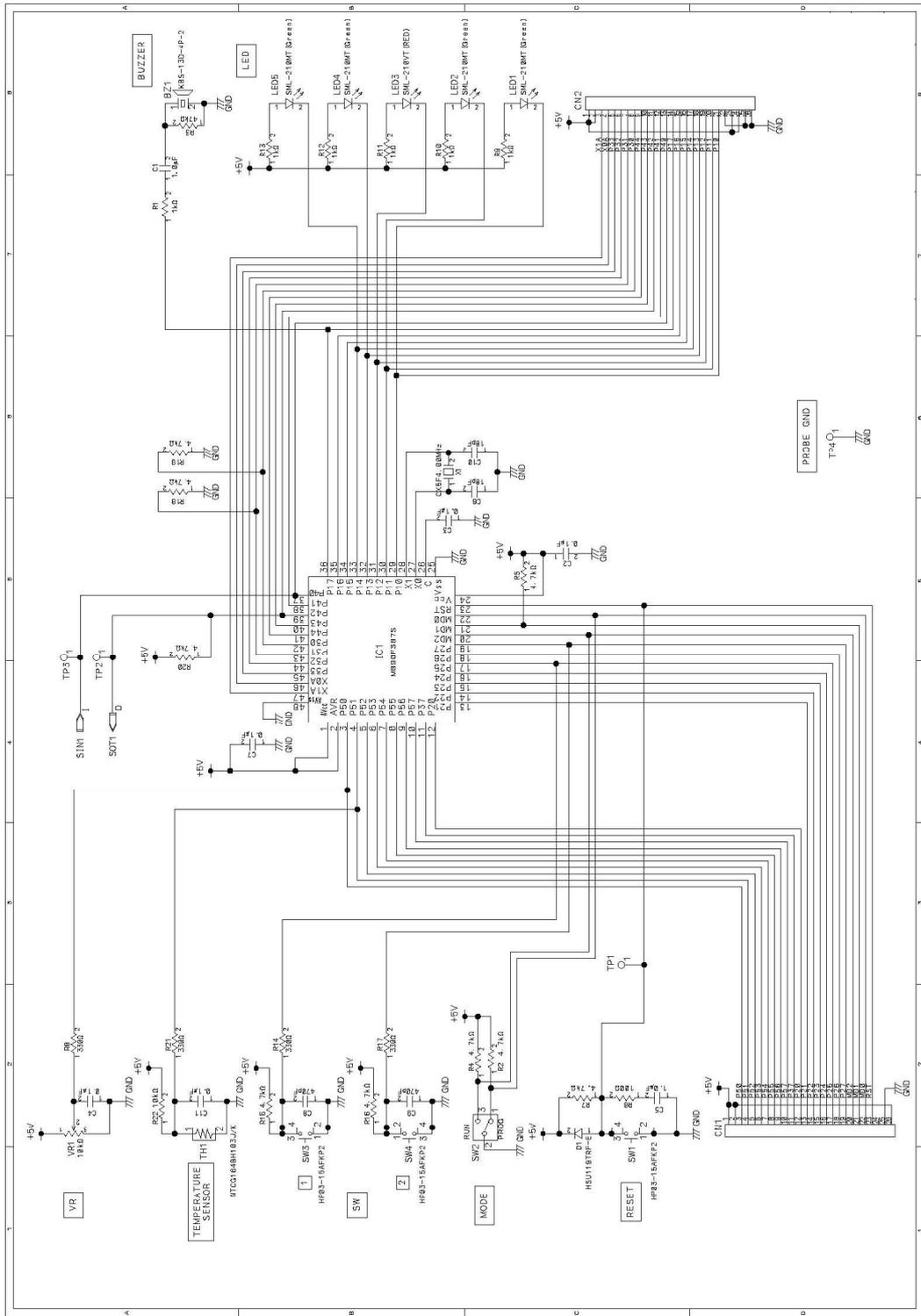


Figure 1.2 Evaluation board circuit diagram

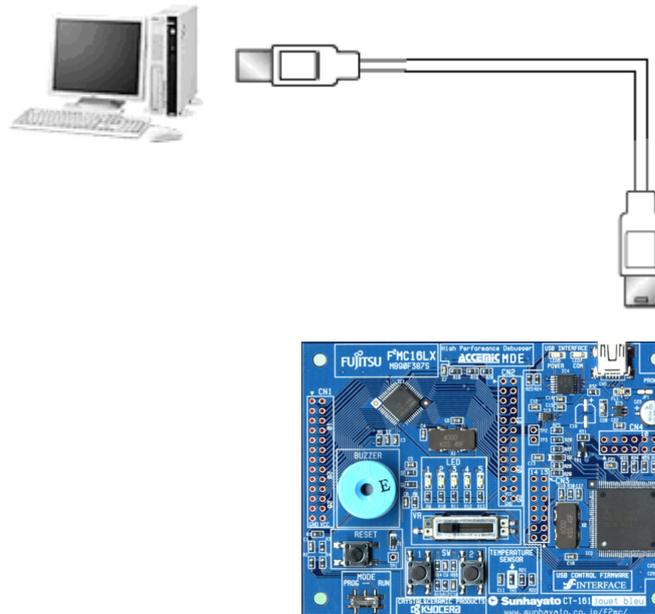
Table 1.2 lists the parts of the evaluation board.

No	Item	Specification	Function
(1)	Target device	MB90F387S	Main microcomputer (MB90F387S) on this board
(2)	Target device expansion pin	26PINX2	I/O expansion pin of the main microcomputer
(3)	Reset switch	A push switch	Pressing this switch resets the main microcomputer.
(4)	MODE switch	A slide switch	It switches the operation mode of the main microcomputer (MB90F387S).
(5)	LED lamp	5 LED lamps (1 red and 4 green lamps)	LED lamps that are connected to the general-purpose I/O pin
(6)	Test switch	2 push switches	Push switches for tests that are connected to the general-purpose I/O pin
(7)	A/D test VR	Slide VR	A slide VR that is connected to the A/D converter input
(8)	Temperature sensor	Thermistor	A temperature sensor that is connected to the A/D converter input
(9)	Buzzer	Buzzer	Kyocera's separate-excitation type piezo alarm with a case (KBS-13DB-4P-2) It is connected to the PPG timer output pin.
(10)	USB host connector	MIN-B	A USB pin to connect the evaluation board and the host PC
(11)	USB communication microcomputer	MB90F334	A USB communication microcomputer to connect the main microcomputer (MB90F387S) and the host PC It contains the USB communication firmware that has been developed by Interface Co., Ltd.
(12)	USB communication microcomputer expansion pin	2 14-pins	An expansion pin of the USB communication microcomputer
(13)	Oscillator for main microcomputer	CX-5FD (4MHz)	Kyocera's crystal oscillator (CX-5FD) It is an oscillator for the main microcomputer.
(14)	Oscillator for USB communication microcomputer	CX-5FD(6MHz)	Kyocera's crystal oscillator (CX-5FD) It is an oscillator for the USB communication microcomputer.

Table 1.2 Evaluation board parts

Figure 1.3 shows the system configuration.

Prepare a personal computer by yourself.



Connect the evaluation board to the personal computer using the accessory USB cable. (Use the USB bus power as the power supply.)

Microcontroller evaluation board

Figure 1.3 System configuration

Connect the board to the personal computer by using the accessory USB cable.

Supply power to the board by USB bus power system.

Be sure to connect the USB cable directly to the personal computer. Do not connect the USB cable via a USB hub.

Table 1.3 shows the assignment of functions to the pins of MB90F387 microcomputer.

Table 1.3 Function assignments to the pins of F²MC-16LX Series MB90F387 Microcomputer

Pin-No.	Function	Connection destination	Logic	Remarks
3	P50/AN0	VR	ANALOG	Division of power supply voltage: 0 to 100%
4	P51/AN1	TEMP.SENSOR	ANALOG	1/2VCC@25°C
17	P25/INT5	SW1	Negative logic	L level when the switch is pressed
19	P27/INT7	SW2	Negative logic	L level when the switch is pressed
20	MD2	MODE	--	--
21	MD1	PULL-UP	--	--
22	MD0	MODE	--	--
23	RST	RESET	Negative logic	On when the output is L level
29	P10/IN0	LED1	Negative logic	On when the output is L level
30	P11/IN1	LED2	Negative logic	On when the output is L level
31	P12/IN2	LED3	Negative logic	On when the output is L level
32	P13/IN3	LED4	Negative logic	On when the output is L level
33	P14/IN4	LED5	Negative logic	On when the output is L level
36	P17/PPG3	BUZZER	Rectangular wave	Initially at L level, C coupling, bias R
37	P40/SIN1	RS232C	--	--
39	P42/SOT1	RS232C	--	--
42	P30/SOT0	PULL-DOWN(50 kΩ)	--	--
43	P31/SCK0	PULL-DOWN(50 kΩ)	--	--

1.1 Setting Up of Personal Computer

This section describes how to install the software required to operate the Starter Kit on the personal computer. (Be sure to perform the software installation operation before connecting the board to the personal computer.)

Take the following steps to set up the personal computer:

- ① Installing the USB driver (See the separately provided "USB Driver Installation Manual.")
- ② Installing the integrated development environment "SOFTUNE" (limited-function version) (See Item 1.1.2.)
- ③ Installing the demonstration version of ACCEMIC MDE (See Item 1.1.3.)
- ④ Connecting the evaluation board to the personal computer (See Item 1.1.4.)
- ⑤ Starting and setting up SOFTUNE (See Item 1.1.5.)
- ⑥ Starting and setting up ACCEMIC MDS (See Item 1.1.6.)
- ⑦ Terminating ACCEMIC MDE (See Item 1.1.7.)
- ⑧ Terminating SOFTUNE (See Item 1.1.8.)

1.1.1 Installing of USB driver

Install the USB driver according to the content of the "USB Driver Installation Manual".

1.1.2 Installing of integrated development environment "SOFTUNE" (limited-function version)

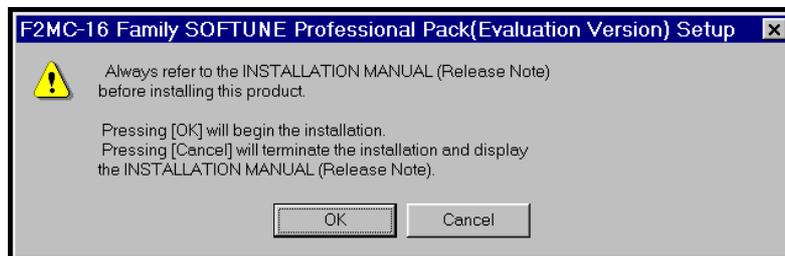
Install SOFTUNE (limited-function version).

The limited-function version of SOFTUNE is subject to the limitation on the program size that can be debugged to 32 kilobytes. The limited-function version cannot be used to create a program over 32 kB.

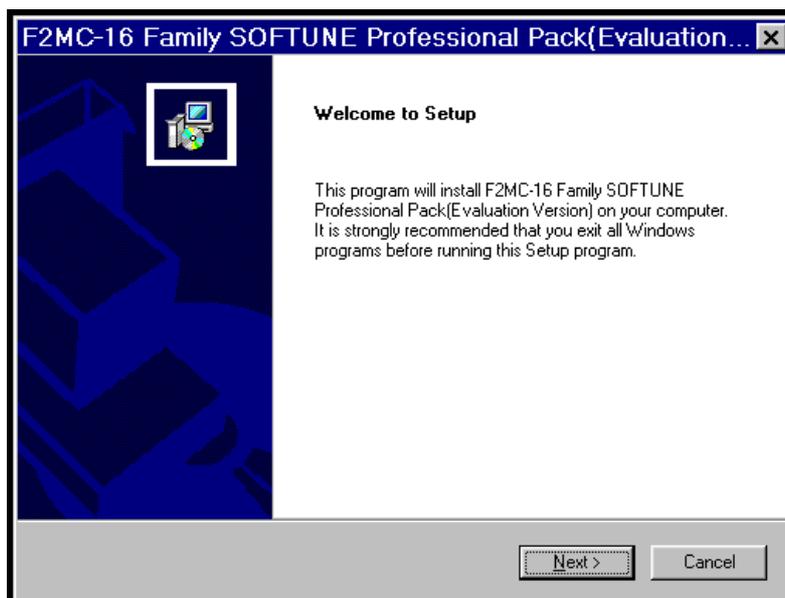
- ① Insert the CD-ROM into the CD-ROM drive. When using the download version, download the software for F²MC-16LX Starter Kit (Jouet Bleu), and open the folder where the files are decompressed.
- ② Double-click on the Setup.exe icon in the ¥¥jouet_bleu ¥SOFTUNE folder to start installation.



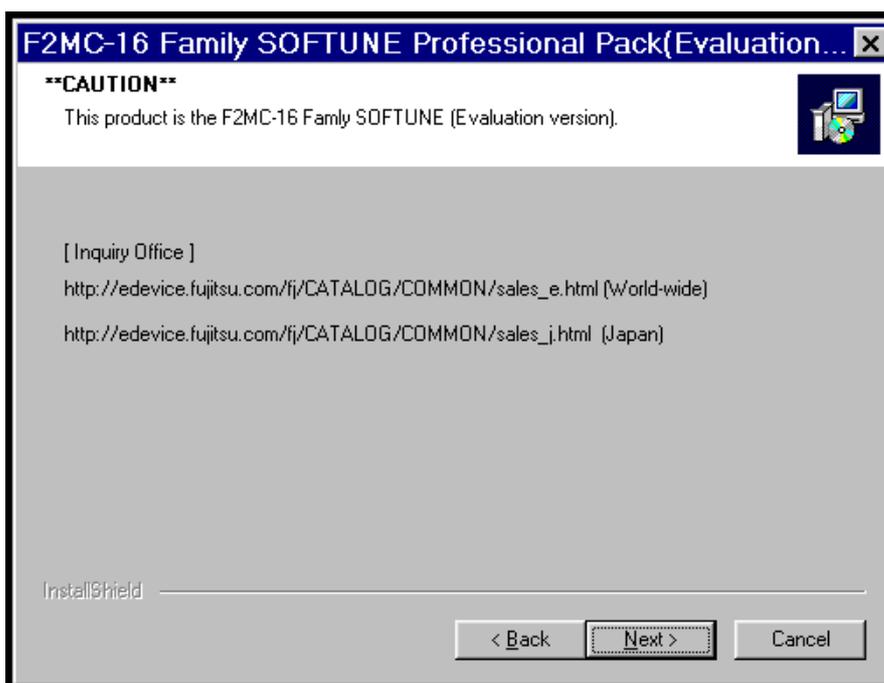
- ③ Follow the instructions on the screen to perform installation.



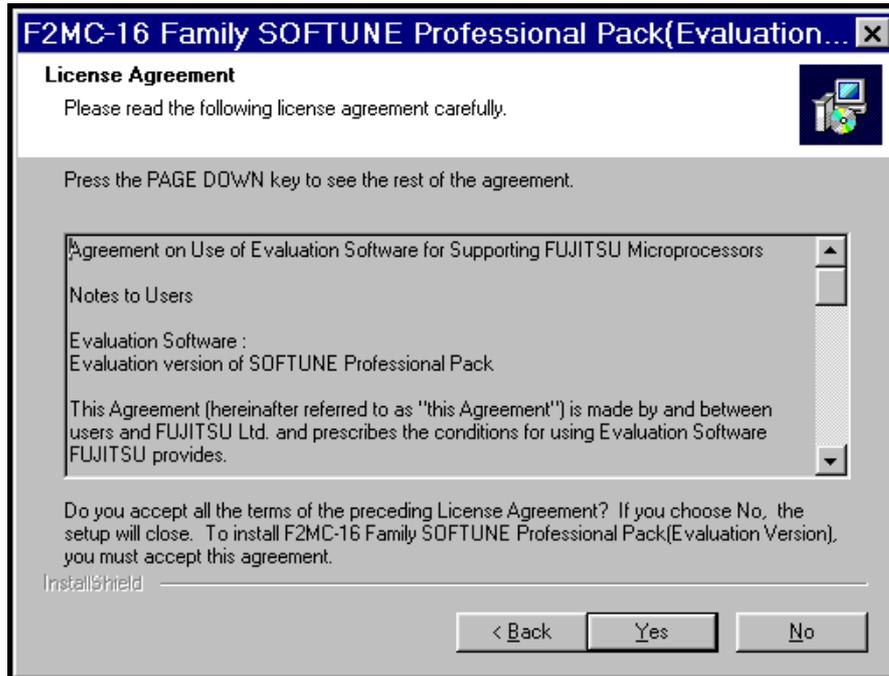
Click 'OK.'



Click 'Next >.'

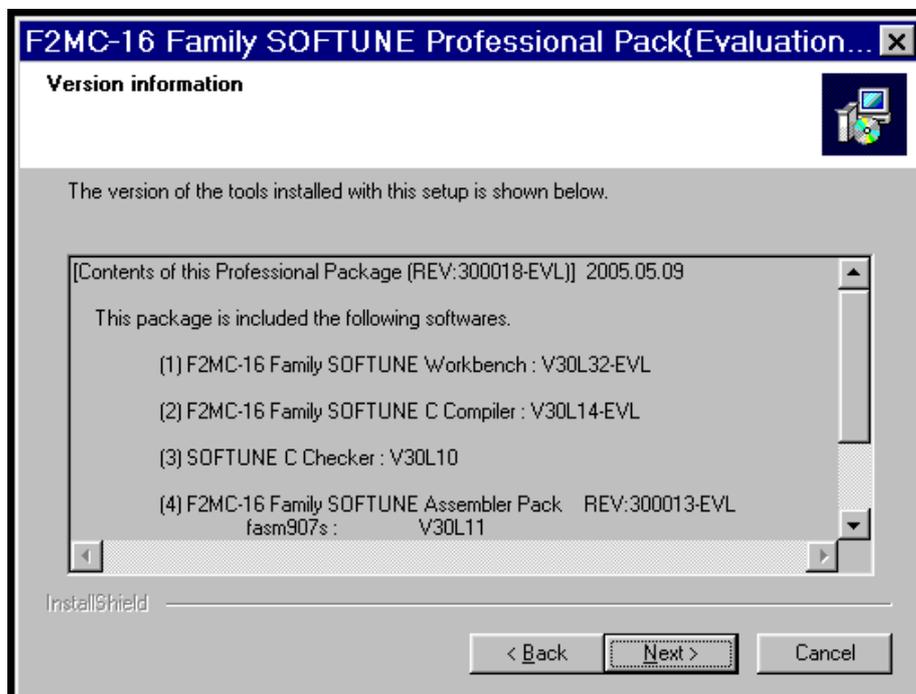


Click 'Next >.'

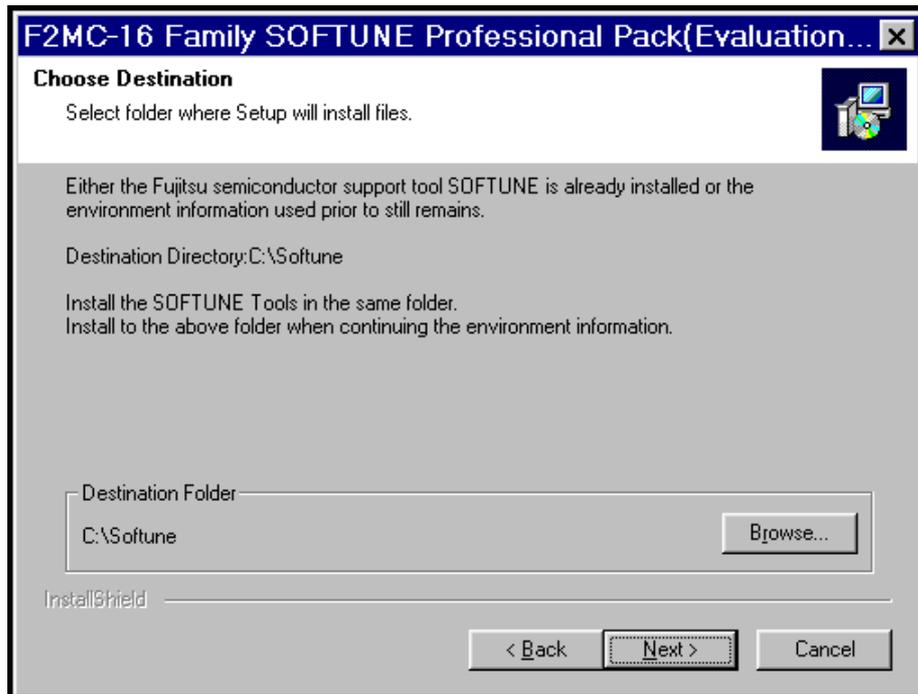


If you accept the agreement, click 'Yes.'

(If you refuse the agreement, you cannot install SOFTUNE.)

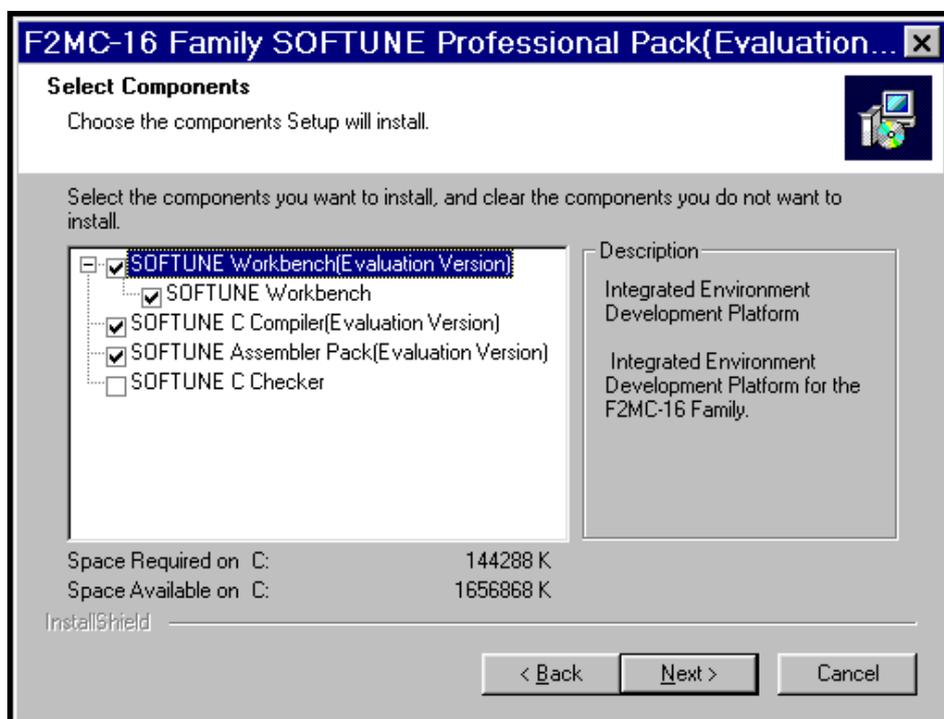


Click 'Next >.'

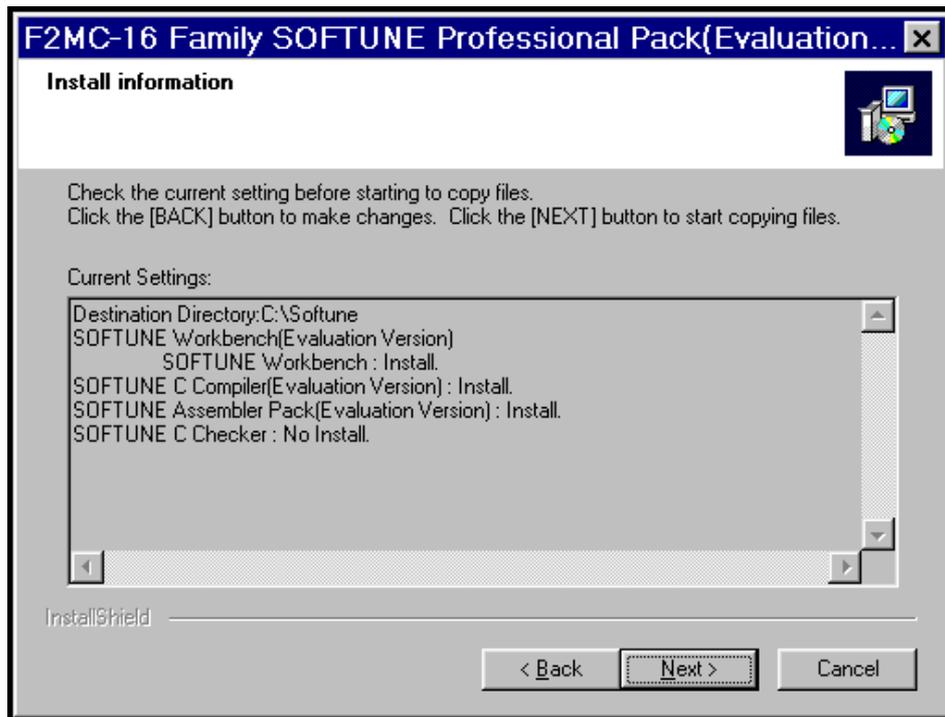


Click 'Next >.'

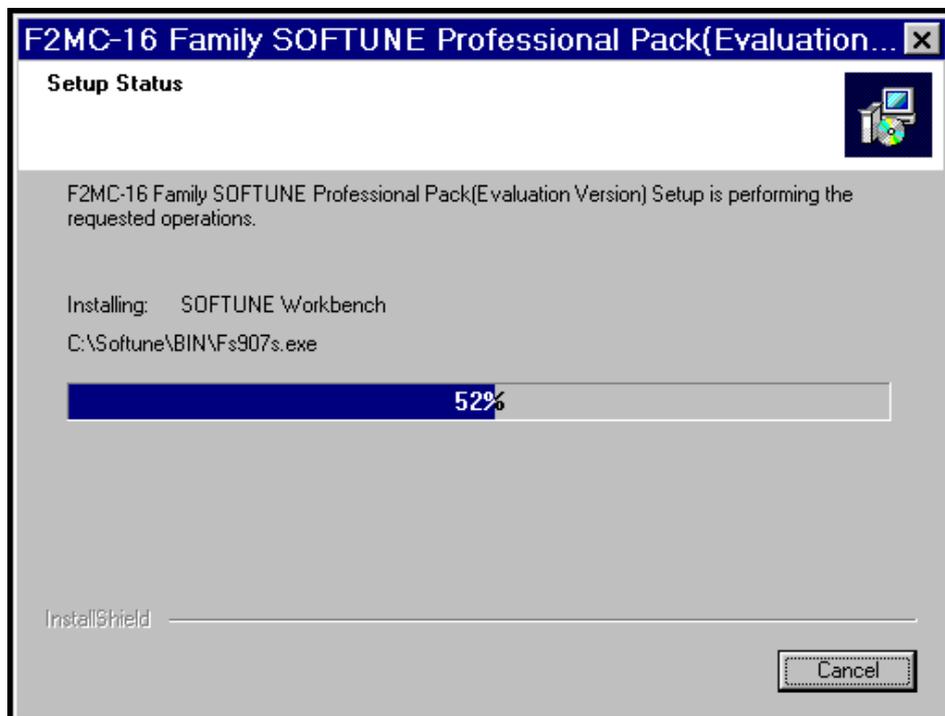
(Do not change the installation-destination folder here.)



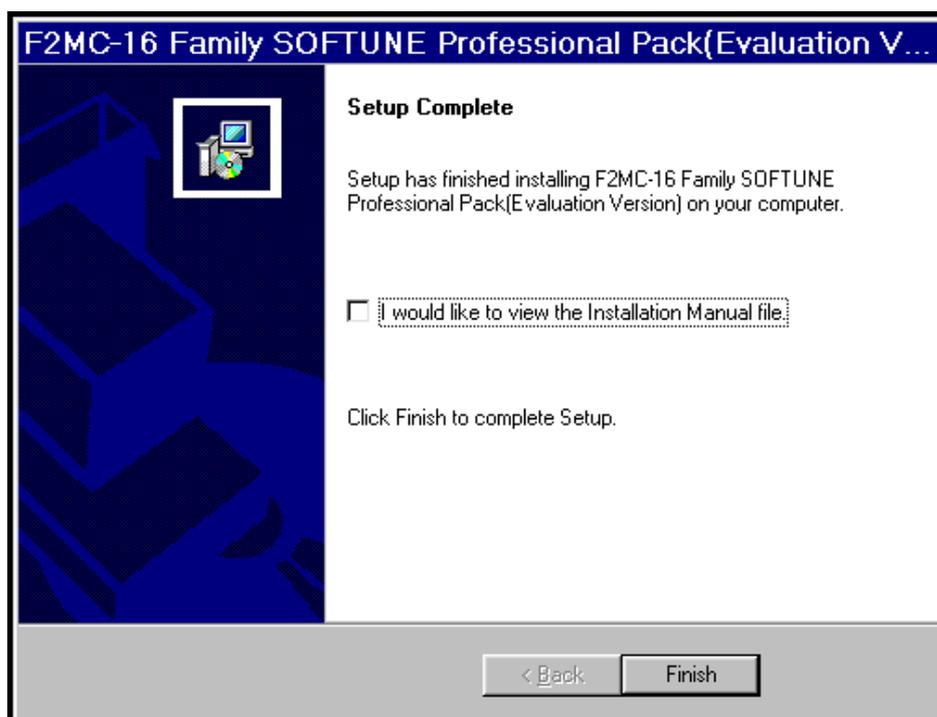
Click 'Next >.'



Click 'Next >.'



The installation is executed.



Click 'Finish.'

The installation of SOFTUNE (limited-function version) is completed.

Proceed to the installation of the demonstration version of ACCEMIC MDE.

1.1.3 Installing of demonstration version (trial version) of ACCEMIC MDE

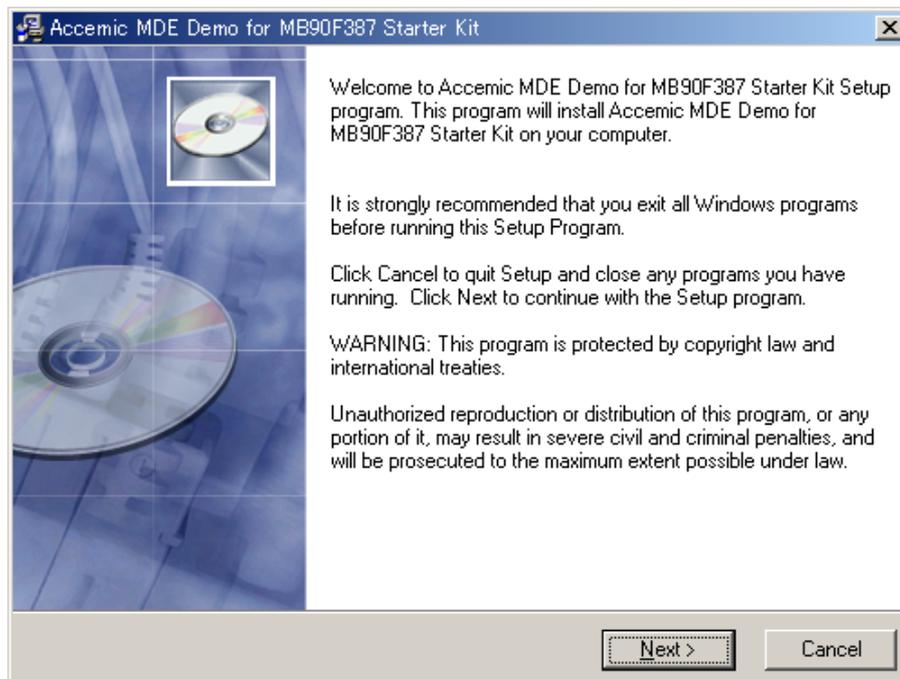
Install the demonstration version (trial version) of ACCEMIC MDE.

The trial version of ACCEMIC MDE is subject to a limitation on the size of the program that can be debugged to 12 kB. The trial version cannot be used to create a program over 12 kB.

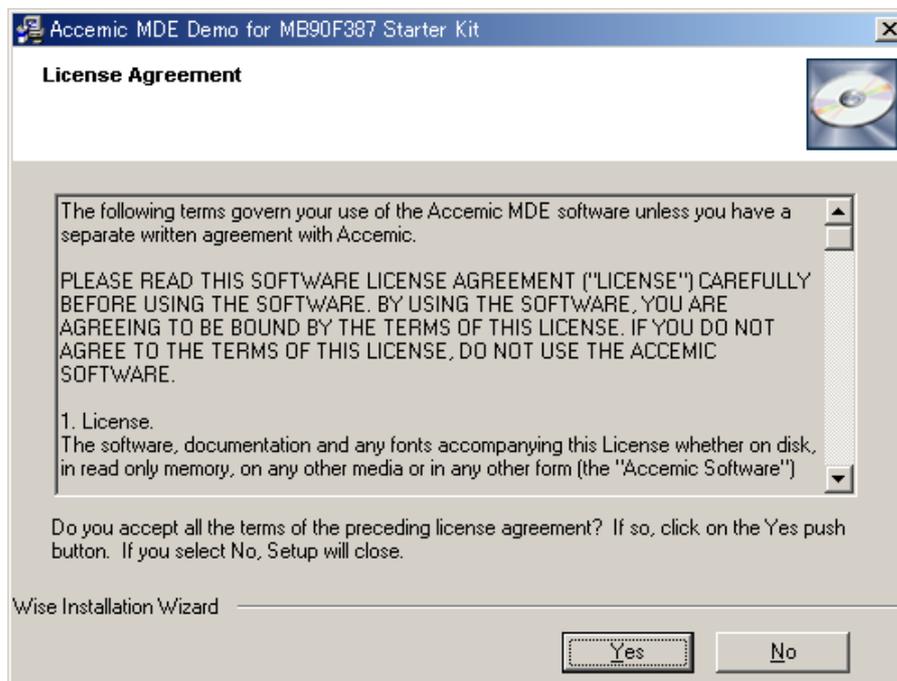
- ① Insert the CD-ROM into the CD-ROM drive. When using the download version, download the software for F²MC-16LX Starter Kit (jouet bleu), and open the folder where the files are decompressed.
- ② Double-click the MDE_16LX_DEMO_V22ST_STARTERKIT.exe icon in the ¥¥jouet_bleu¥¥MDE_16LX_DEMO_V22ST_STARTERKIT folder to start installation.



- ③ Follow the instructions on the screen to perform the installation.

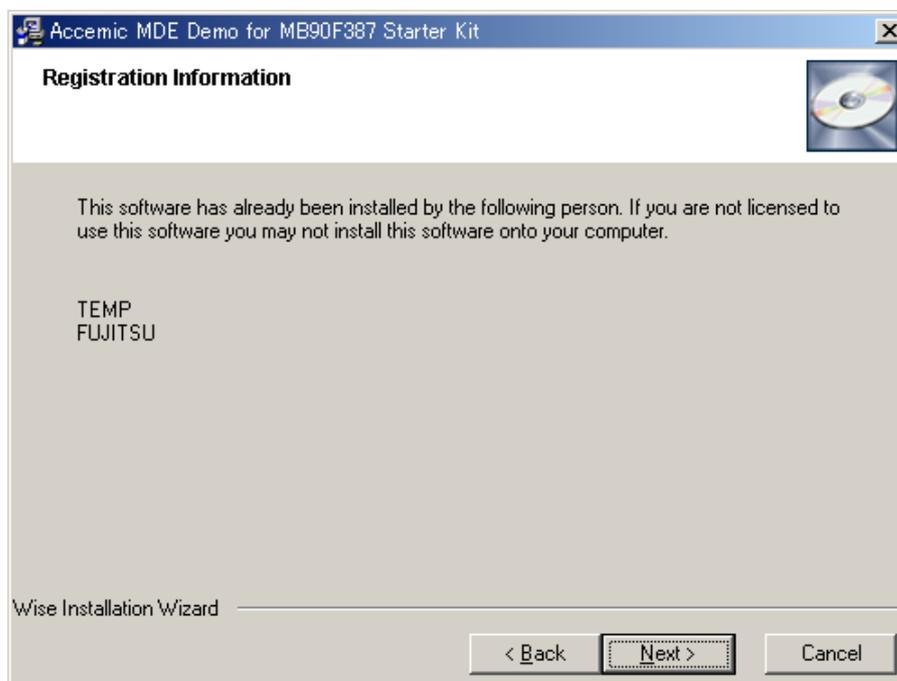


Click 'Next >'

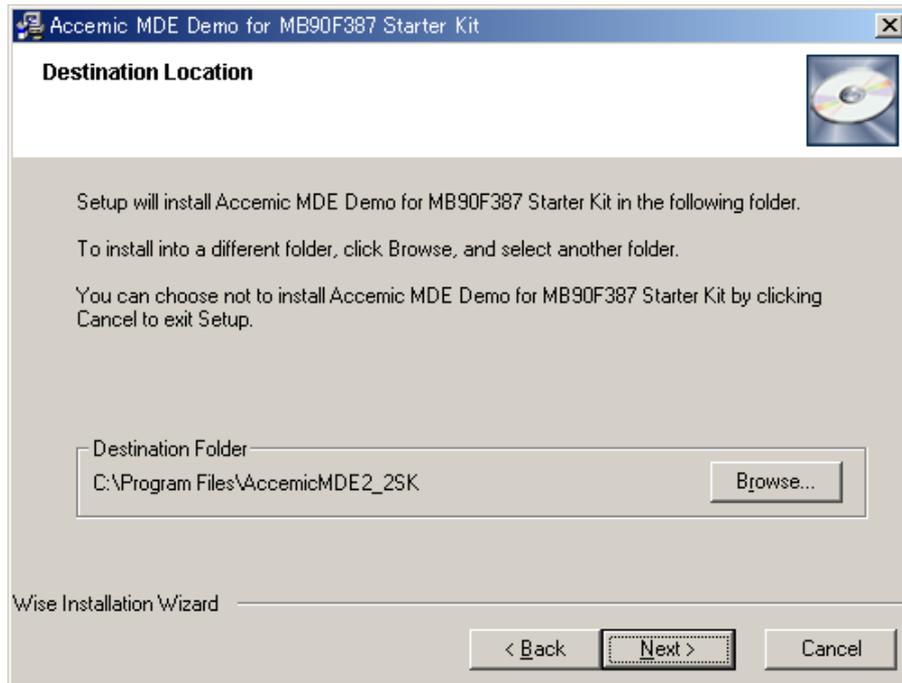


If you accept the agreement, click 'Yes.'

(If you refuse the agreement, you cannot install ACCEMIC MDE.)

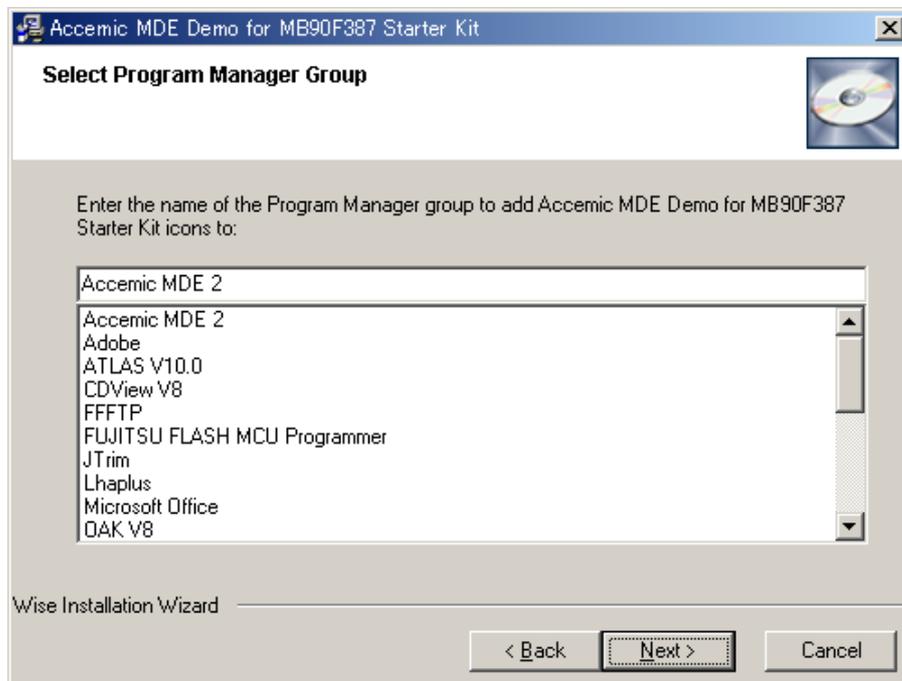


Click 'Next >.'

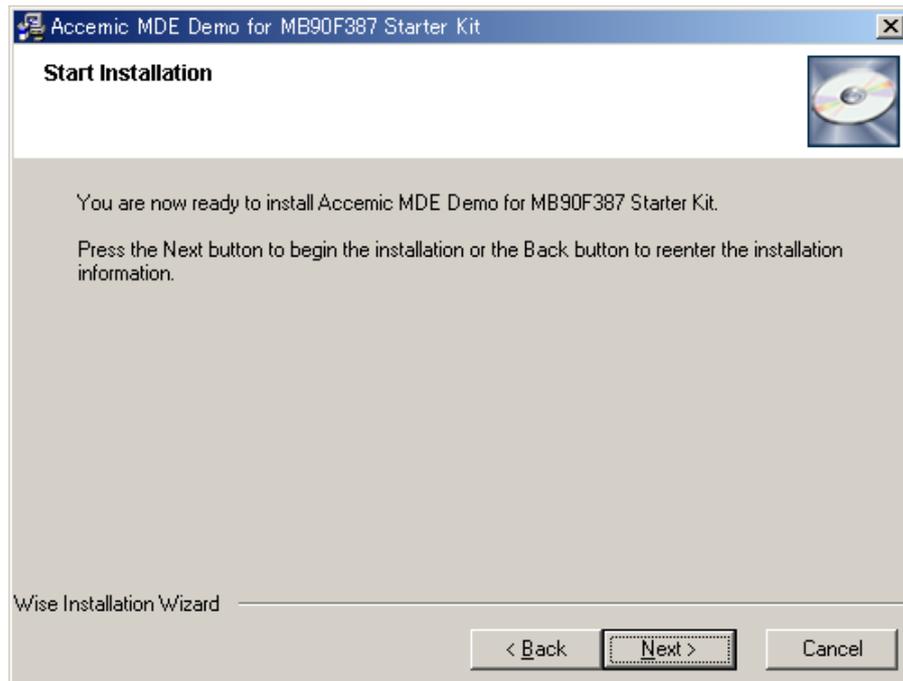


Click 'Next >.'

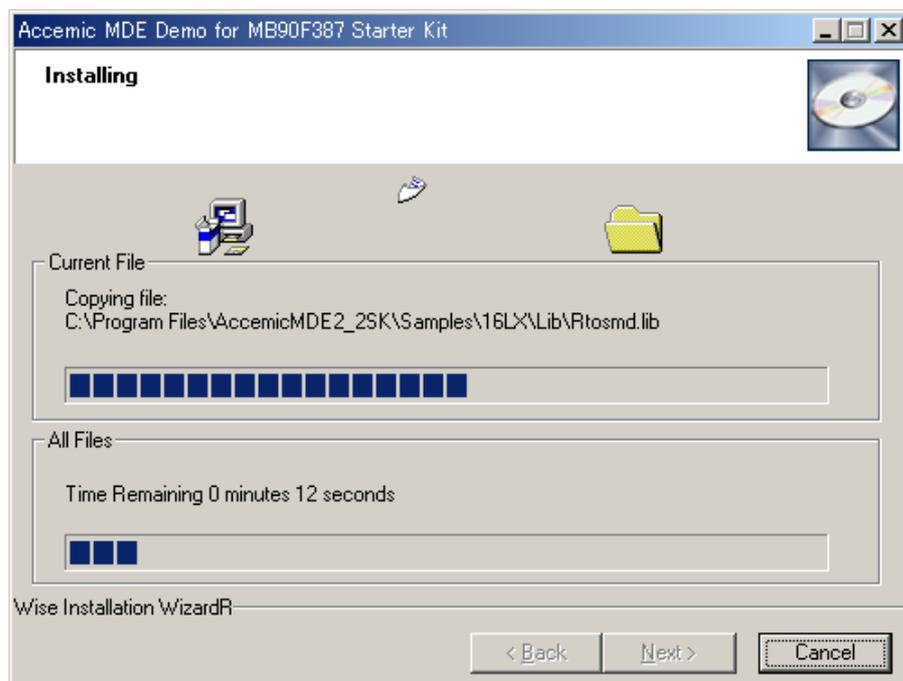
(Do not change the installation-destination folder here.)



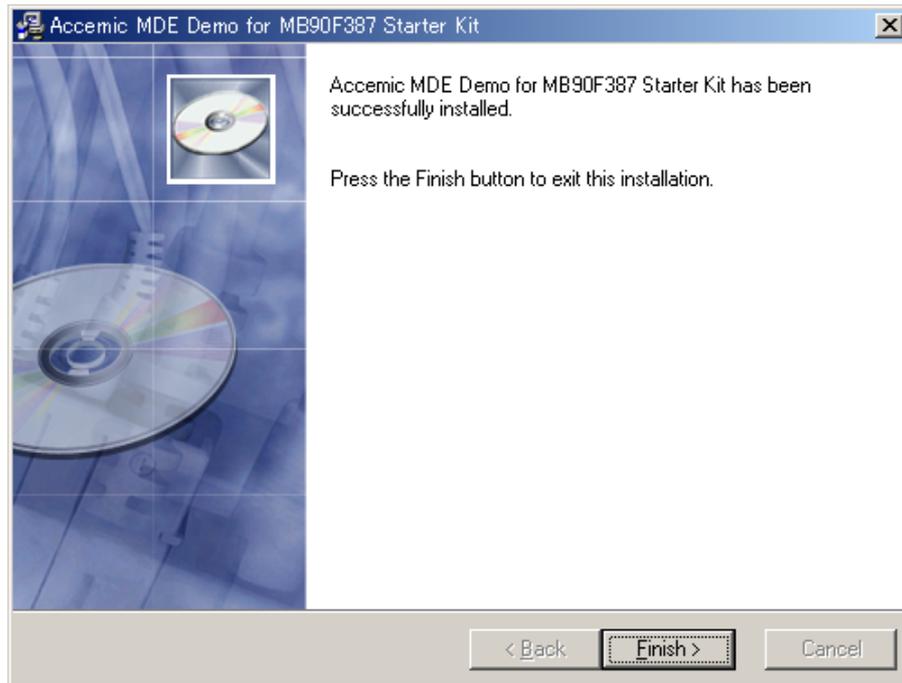
Click 'Next >.'



Click 'Next >.'



The installation is executed.



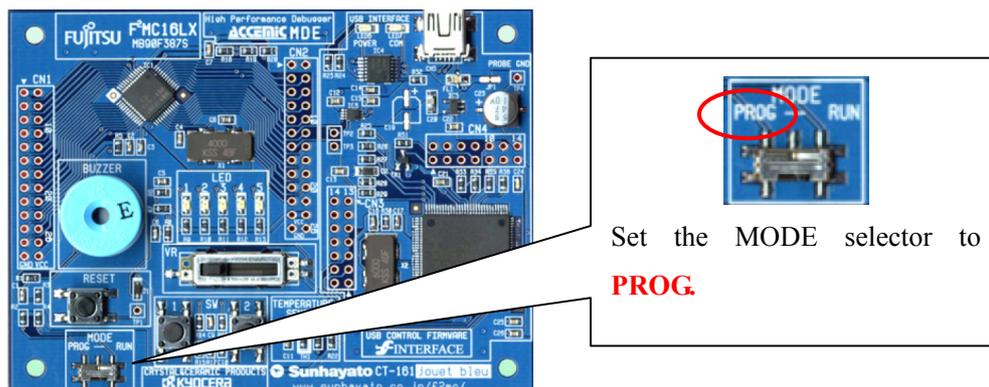
When the installation is completed, click 'Finish >.'

Installation of the demonstration version of ACCEMIC MDE is completed.

Proceed to the setup of the evaluation board and its connection to the personal computer.

- 1.1.4 Setting up of evaluation board and connecting of board to the personal computer
 After the installation of SOFTUNE and ACCEMIC MDE, perform switch setting on the evaluation board and connect the board to the personal computer.

On the evaluation board, set the MODE selector to **PROG**.



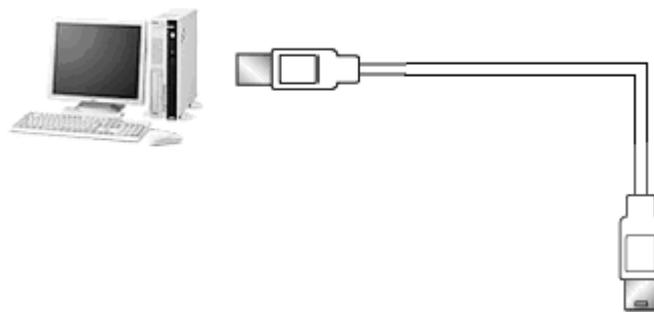
MODE selector	Operation mode
PROG	Flash memory serial write mode → Used to write a program to the microcomputer
RUN	Single chip mode → Used to actually run the program written to the microcomputer

Confirm that the MODE selector is set to **PROG**.

Next, perform the cable connection.

Connect the USB port of the evaluation board to a USB port of the personal computer using the accessory USB cable. Do not connect the USB cable via a USB hub, but connect it directly between the board and personal computer.

Connect the USB cable to a USB port of the personal computer.
For the location of USB port, refer to the manual for the personal computer.



After installing SOFTUNE and ACCEMIC MDE, connect the board and personal computer using the USB cable.



← USB port

The power of the evaluation board is supplied from the USB power supply (USB bus power).

Figure 1.4 Connection of the evaluation board and personal computer

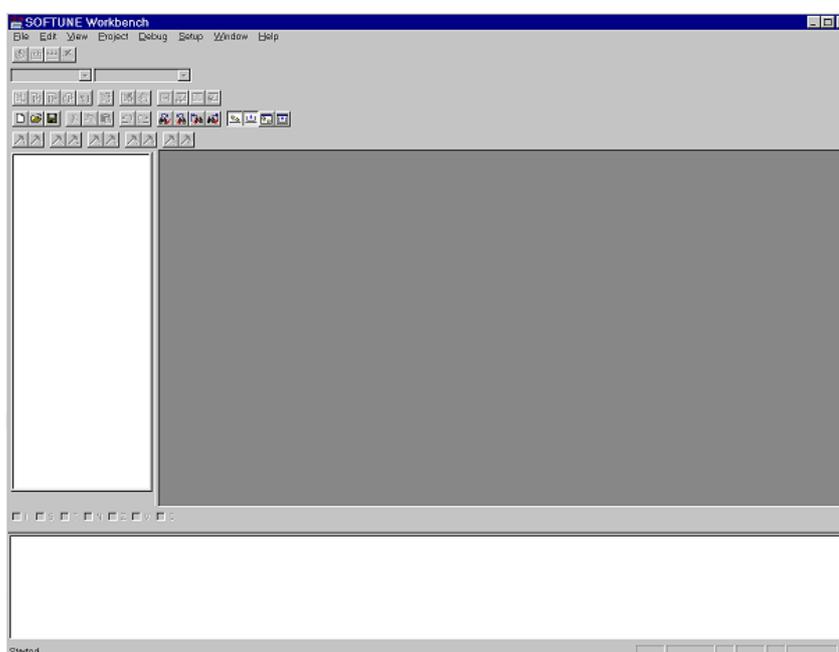
1.1.5 Starting and setting up of SOFTUNE

Preparation Before the operation described below, copy the sample programs to the hard disk of the personal computer.

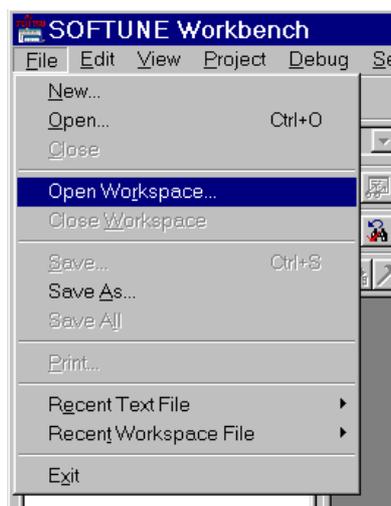
Uncompress the Fujitsu_starter_kit.zip file included in the CD-ROM or among the downloaded files in an arbitrary directory.

Start SOFTUNE (limited-function version).

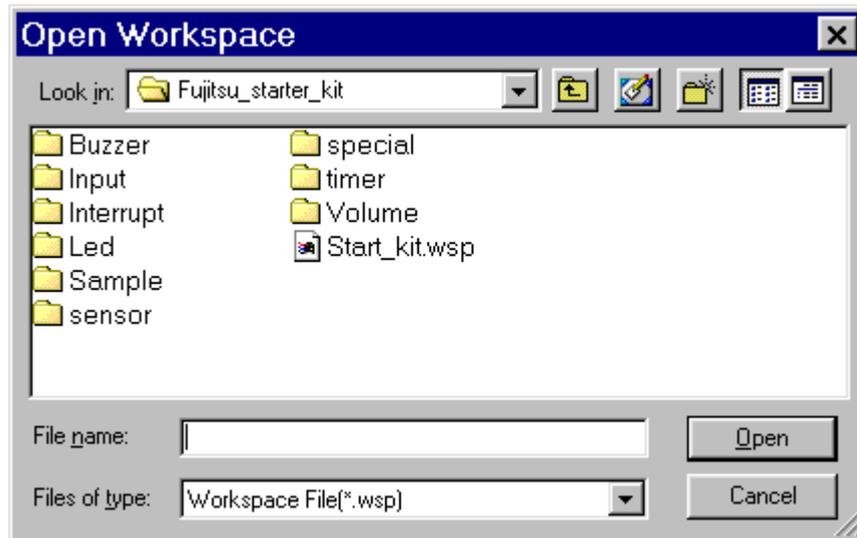
From the Start menu of Windows, select Programs (P) and Softune V3, in this order, and then click on FFMC-16 Family Softune Workbench (trial version) to start.



Open the workspace file for sample programs.



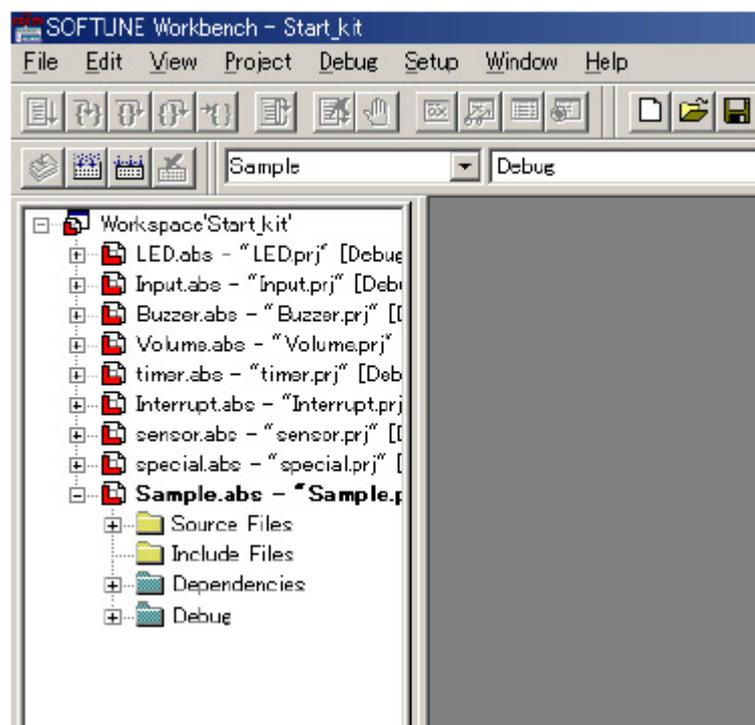
Select Open Workspace (R)... from the File (F) menu.



In this step, the workspace file to execute a sample program is opened. (No sample program is executed when the workspace file is opened.)

Open the Start_kit.wsp file located in the Fujitsu_starter_kit folder.

The project window displays the opened workspace.

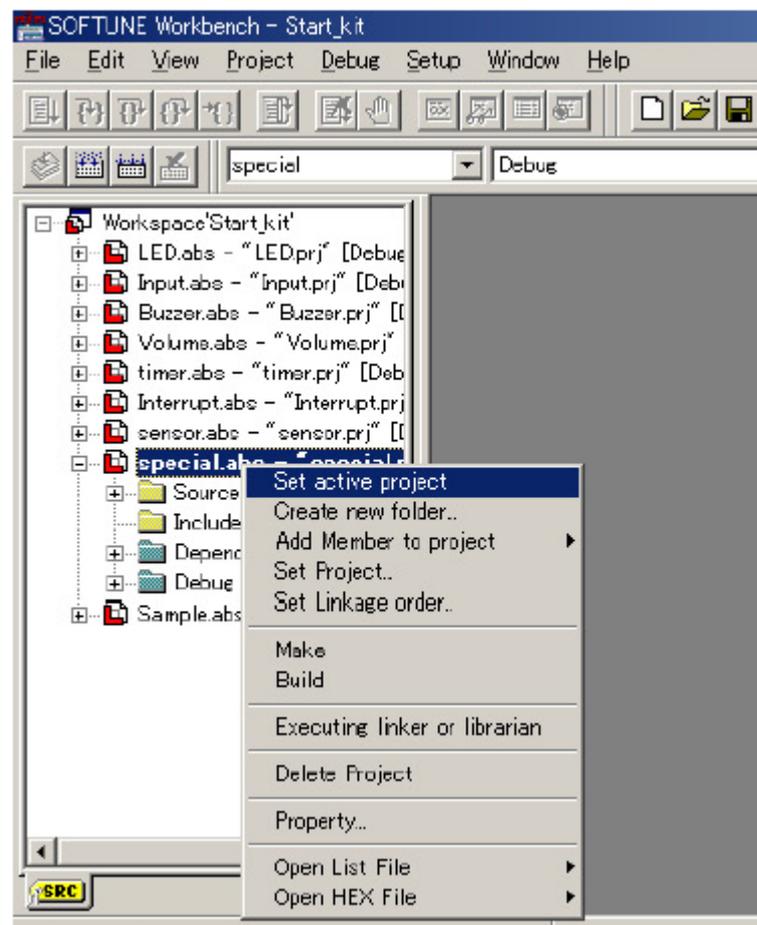


Make the settings for the active project.

Multiple projects can be stored in one workspace file.

The sample programs include already created projects, including LED.prj, Input.prj, and Buzzer.prj.

Since program debugging is performed in units of projects, you should specify the project to be debugged as an active project.



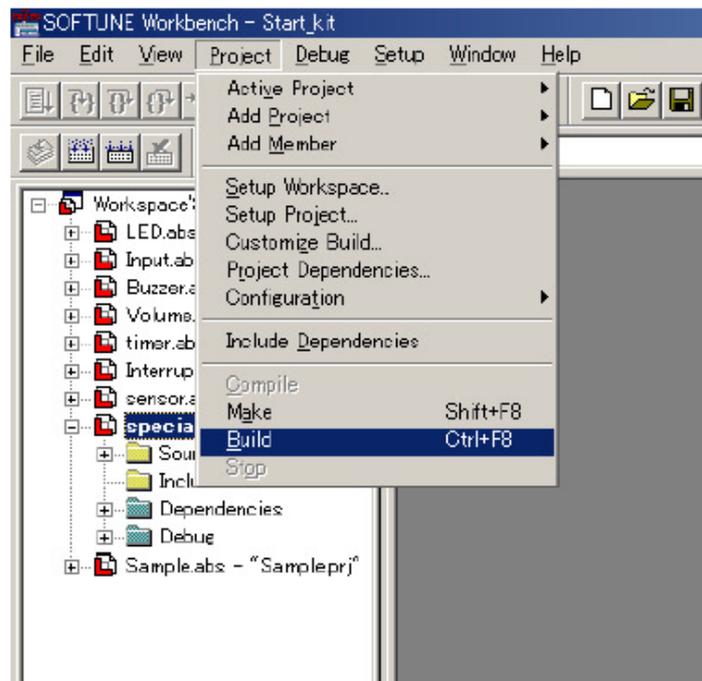
Select a project to be debugged and click the right mouse button.

A submenu appears. Select Set active project from the submenu. The project name in the list is displayed in **boldface**, and debugging of the project is enabled.

1.1.6 Starting and setting up of ACCEMIC MDE

Use the Start_kit.wsp workspace file opened in the previous step to start ACCEMIC MDE.

Confirm that the current active project of SOFTUNE is **special.prj**. Select Build (B) from the Project (P) menu to execute a build operation.



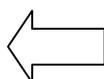
When the build operation is executed, the output screen of SOFTUNE displays the messages below.

```
Build operation started...
-----Configuration: special.prj - Debug-----
start905s.asm
monitor16LX.asm
_FFMC16.C
...
PPG_01_int.c
Linked...
*** I0312L: 0 warnings were output after S.C.F check.
D: ¥jouet_bleu¥fujitsu_starter_kit¥special¥Debug¥ABS¥pecial.abs
No error was found.
```

Confirm that **no error was found**.

If an **error** is detected as shown below in the build operation, perform the software installation again from the initial step as described in Item 1.1.2. When reinstalling the software, **be sure not to change the installation directory that is displayed on the screen.**

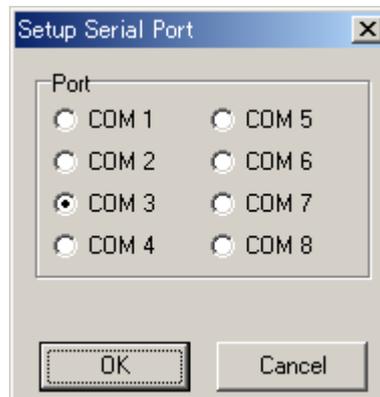
```
Build operation started...
----- Configuration: special.prj - Debug-----
start905s.asm
monitor16LX.asm
_FFMC16.C
*** D:\jouet_bleu\Fujitsu_start_kit\special\_ffmc16.c(9) E4038P: #include: File "_ffmc16.h" is
not found.
...
main.c
*** D:\jouet_bleu\Fujitsu_start_kit\special\main.c(17) E4038P: #include: File "_ffmc16.h" is not
found.
monitor16LX.asm
Error was found.
```



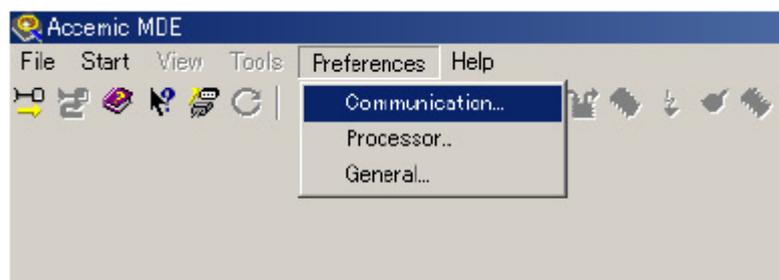
Example of **error detection**

Subsequently, ACCEMIC MDE starts automatically.

Input the COM port number that is confirmed after the USB driver is installed.



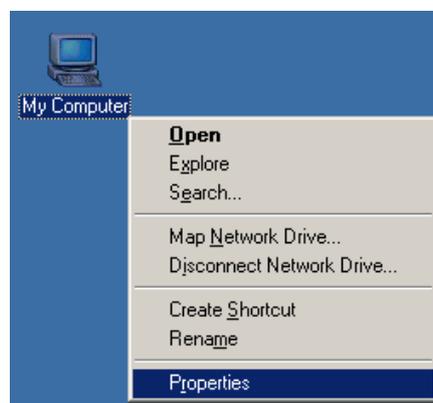
If you need to correct settings in the 'Select Processor dialog box' because you made an incorrect "Type" setting or for other reasons, select 'Communication...' from the Preferences menu to display the 'Select Processor dialog box.'



If the COM port number is unknown, use the following procedure to check the COM port number to which the board is connected.

[Procedure for checking the COM port number]

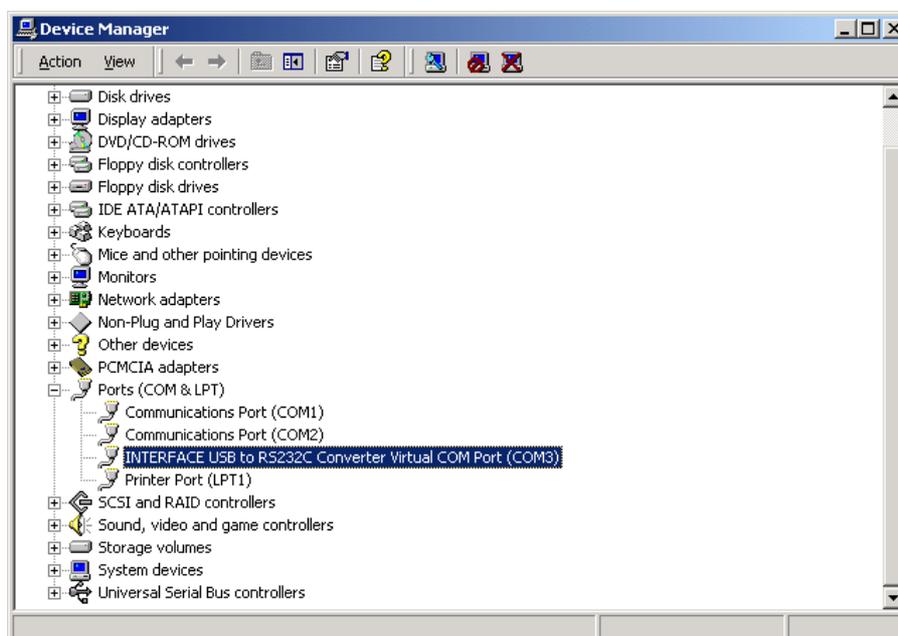
First, click the right side of a mouse on the "My Computer", and click on "Property(R)."



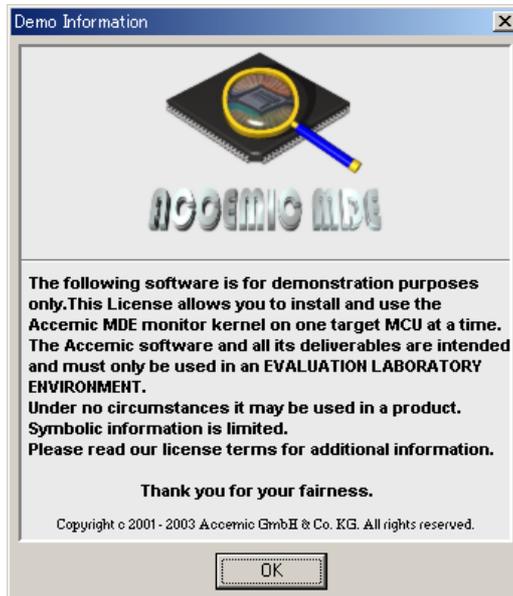
When the Property window of the system appears, click "Hardware," and then click "Device manager (D)."



When the Device manager window appears, check the indication of "INTERFACE USB to RS232C Converter Virtual COM Port(COMx)" under the "Port (COM and LPT." The "(COMx)" part indicates the COM port number.



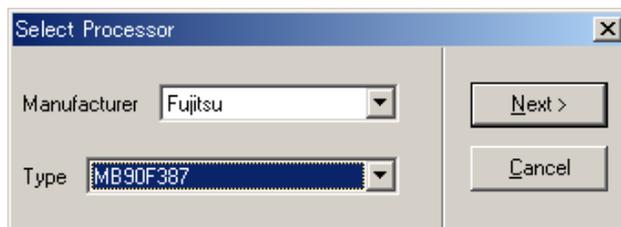
[Note] If the assigned COM port number is 5 or higher, ACCEMIC MDE cannot be used. Change the PC settings so that 4 or lower number is assigned to the port.



Click 'OK.' (With this trial version, the OK input will take effect 10 seconds later.)

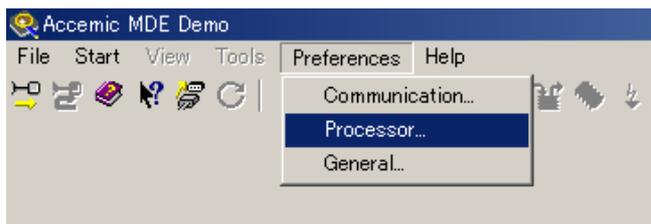
Make the settings of the target microcomputer.

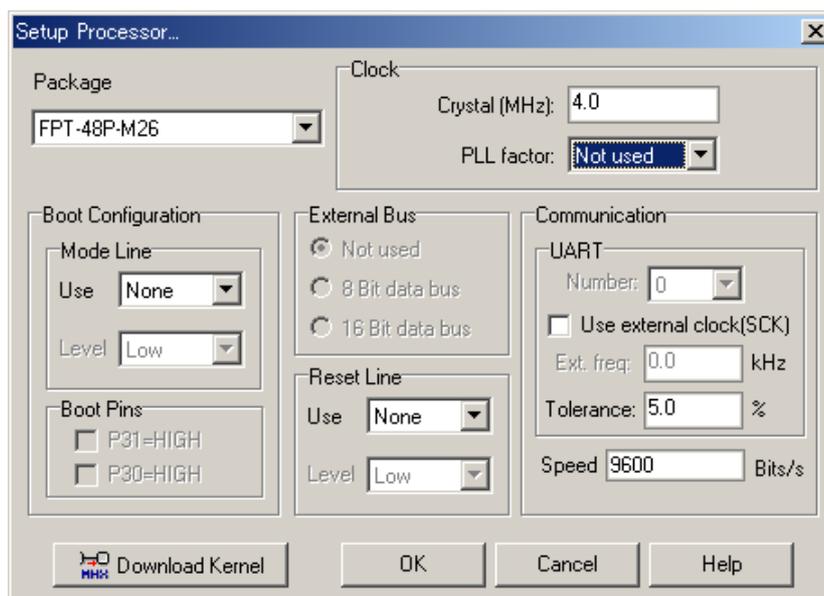
When you use ACCEMIC MDE for the first time, you should download the monitor debugger kernel. (You need not make these settings again unless you change the target microcomputer.)



Here, select **Fujitsu** for "Manufacturer" and **MB90F387** for "Type," and then click 'Next >.'

If you need to correct settings in the 'Select Processor dialog box' because you made an incorrect "Type" setting or for other reasons, select 'Processor...' from the Preferences menu to display the 'Select Processor dialog box.'





When the target microcomputer is the MB90F387, select **FPT-48P-M26** for "Package" and **Not used** for "PLL factor." Do not change other parameters from their defaults.

[Note] Use either "Not used" or "1" for the PLL setting. Note that the operations are not guaranteed if any other value is entered.

After the setup, press "Download Kernel."

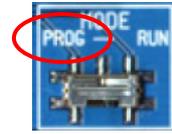
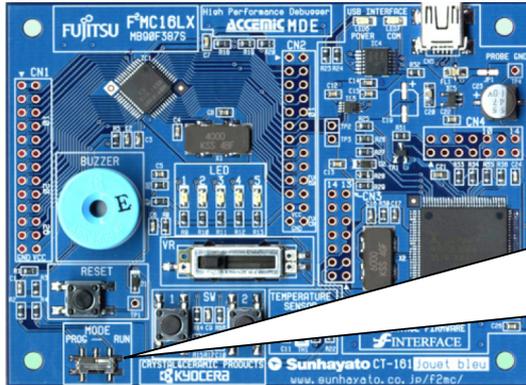
When ACCEMIC MDE is used for the first time, it is required to download the monitor debugger kernel only once.

When the following information is displayed, reconfirm that the MODE selector is set to the "PROG" side, **press the RESET switch on the board, then press "OK."**

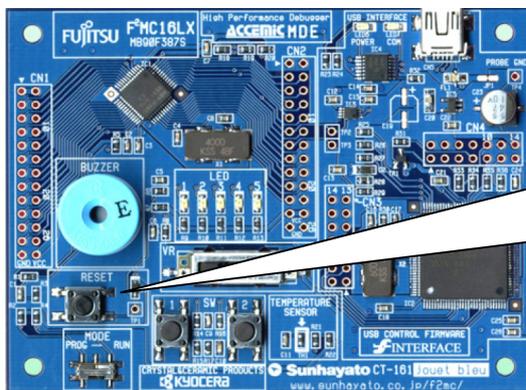


When you click OK after pressing the 'RESET' switch on the board, downloading starts.

If the above switch operation is not performed in correct order, ACCEMIC MDE will not start. If you fail to perform switch operation correctly, resume the operation from the step described in Item 1.1.6.



Reconfirm that the MODE selector is set to the "PROG" side.

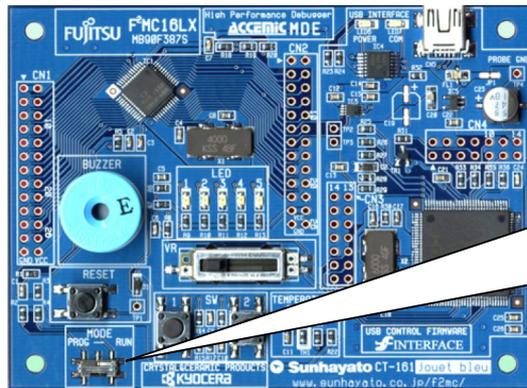


Press the 'RESET' switch.

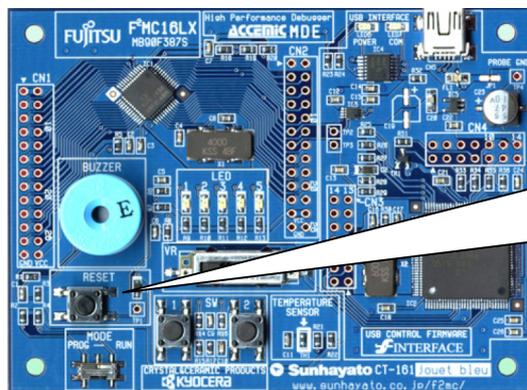
When downloading ends, the next information item appears. With the next Information dialog box displayed, **do not click OK immediately but perform necessary switch operations on the board.**



When this dialog box is displayed, do not click OK immediately, but perform switch operations on the board.



Set the MODE selector to **RUN**.

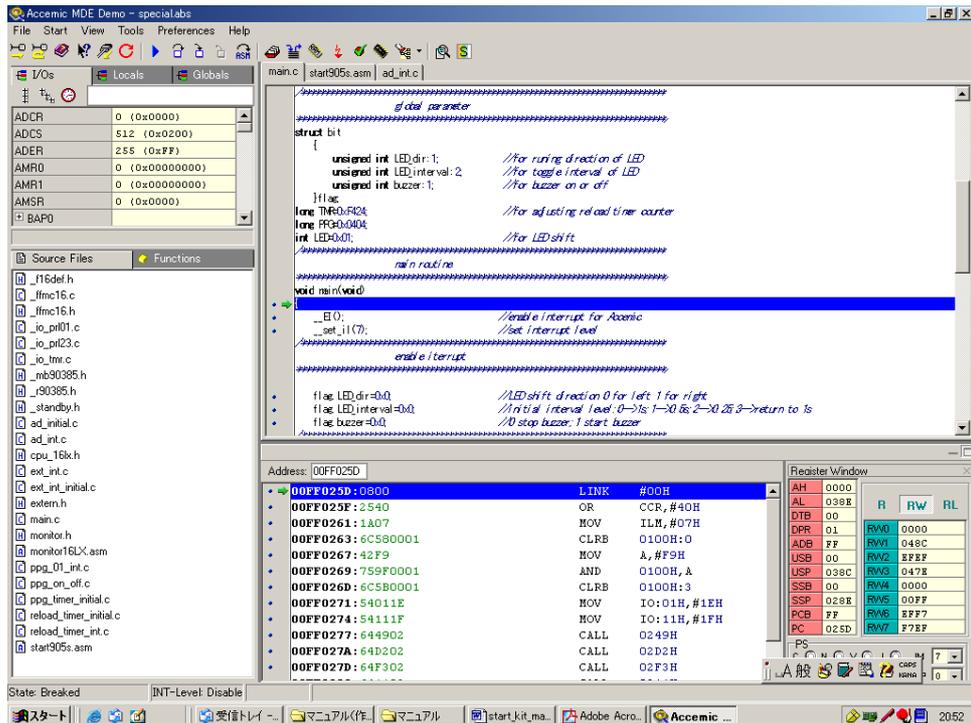


Press the 'RESET' switch.



Now, click 'OK.'

When you click 'OK' in the Information dialog box after pressing the 'RESET' switch on the board, ACCEMIC MDE starts.

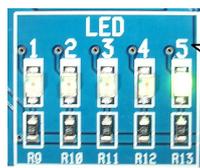
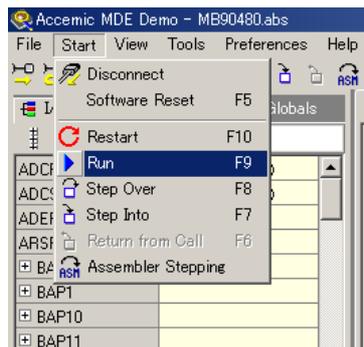


The ACCEMIC MDE window opens.

Execute the program of the sample project "special.prj."

Select "Run" under "Start."

The LEDs 1 to 5 on the board are shifted leftward respectively at one-second interval.

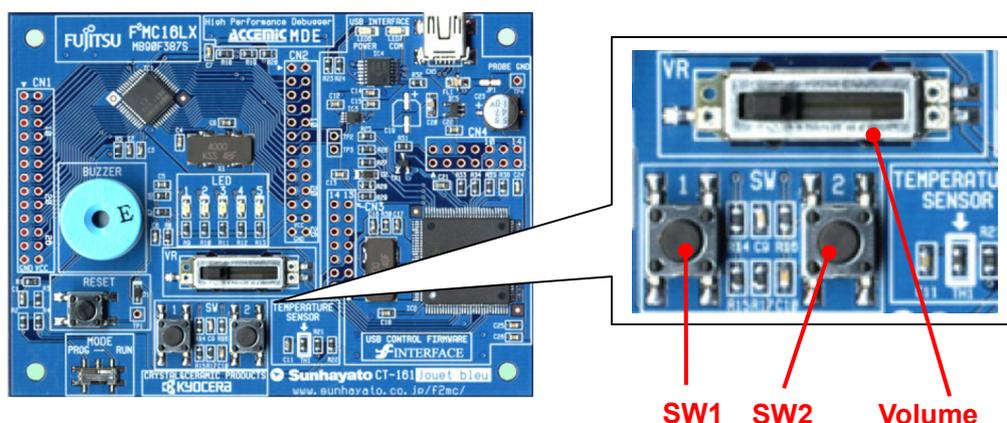


When the program is executed, the LEDs 1 to 5 on the evaluation board are shifted leftward respectively at one-second interval.

It also has the functions listed in **Table 1-4**.

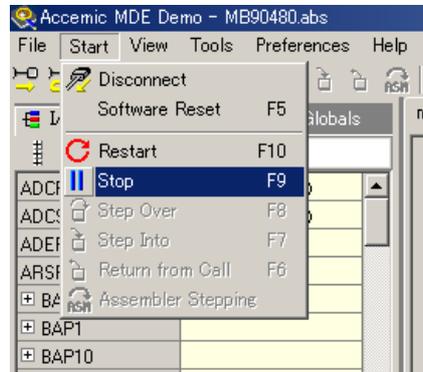
Table 1-4 Board operations at the special.prj execution

Switch control	Board operation
SW1 normal press	The LED shift direction is changed. Shift direction: Left shift→Right shift→Left shift→Right shift- - - -
SW2 normal press	The shift speed is changed. Shift speed: 1 second→0.5 seconds→0.25 seconds→0.125 seconds→1 seconds- - -
SW1 long press	It controls on and off of the buzzer.
Volume adjustment	It can adjust the volume of the buzzer while buzzer sounds.



Stop the program as follows:

Select Stop from the Start menu to stop the sample program.



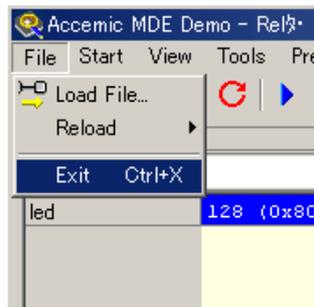
Reset the program as follows:

Select Restart from the Start menu. The program is reset.



1.1.7 Terminating of ACCEMIC MDE

To terminate ACCEMIC MDE, select 'Exit' from the File menu.

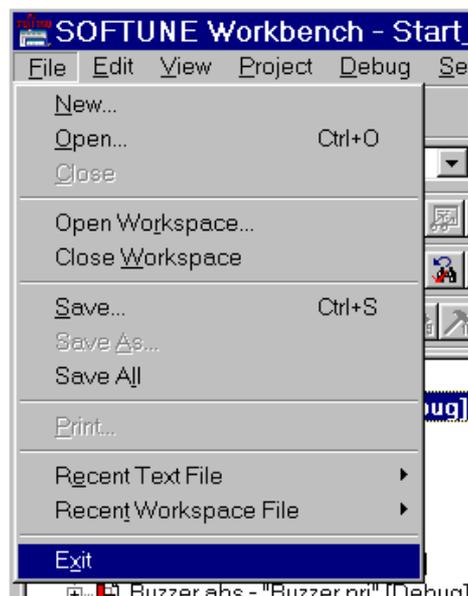


The ACCEMIC MDE window closes.

1.1.8 Terminating of SOFTUNE

After terminating ACCEMIC MDE, terminate SOFTUNE as follows:

Select 'Exit' from the File menu to terminate SOFTUNE.



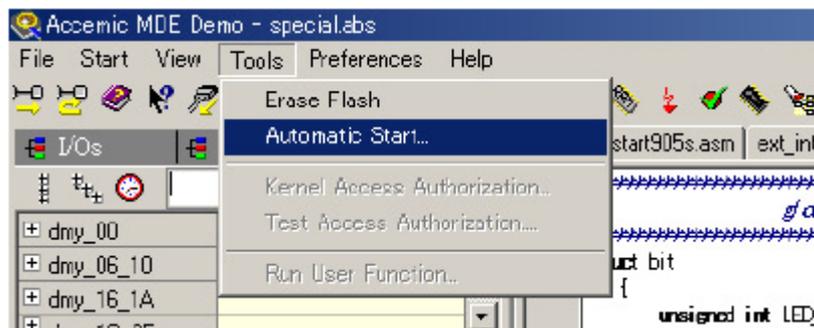
The SOFTUNE window closes.

Described above are the basic operation procedures using sample programs to start debugging.

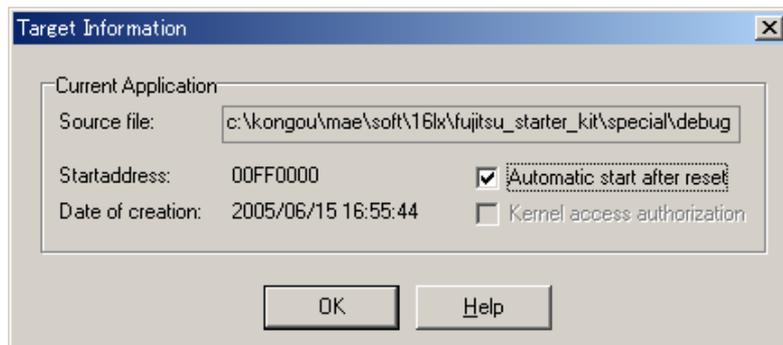
1.1.9 Board operation without ACCEMIC MDE

This Starter Kit can operate the generated program on the board without using ACCEMIC MDE. The procedure is described below.

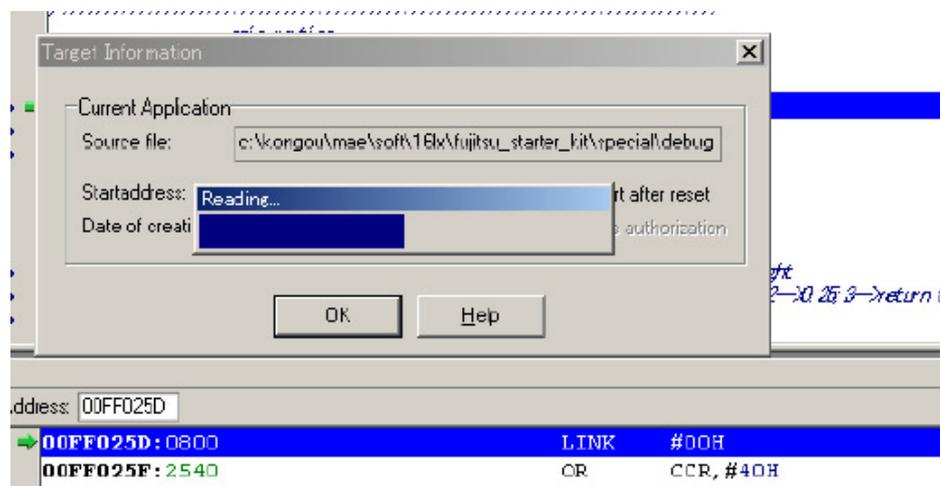
First, start the program to be operated on ACCEMIC MDE. The procedure for operation is described in Item 1.1.6. Confirm that the program runs on ACCEMIC MDE normally. Then, stop the program, and select "Automatic Start" under "Tools" in the menu. Then, the following window appears.



Then, put a checkmark on "Automatic start after reset," and press "OK."



It starts erasing the Flash memory and writing the program. It takes several tens of seconds to complete the writing. Wait for a while. When the program writing ends, the progress bar disappears.



After the writing ends, stop ACCEMIC MDE and SFTUNE. Then, press the "RESET" button on the board while the USB cable is connected. The same operations as confirmed on ACCEMIC MDE are available.

Described above are the basic operation procedures by using the sample programs to start debugging.

Next, let's try to control LED lighting!

2 “Let's try to turn on the LED!”

LEDs appear everywhere in our everyday lives -- for example, the LEDs indicating the power-on status of a laptop personal computer, digital camera, washing machine, air conditioner, or rice cooker, the LEDs display indicating train departure times at a railroad station, and in traffic signals using LEDs, which have now become widespread. This chapter explains how to control the port output of the microcomputer to turn on an LED on the board.

2.1 What is an LED?

A light-emitting diode (LED) is a semiconductor device that emits light when an electric current passes through it. The LED is represented by the symbol as shown in Figure 2.1. An LED has two electrodes: anode and cathode. When a voltage is applied across the LED so that the anode is at a positive potential with respect to the cathode, a current flows and the LED emits light. In the circuit shown in Figure 2.1, the LED goes on (emits light) when the switch (SW) is turned on and goes off when the switch is turned off. The brightness of the LED is controlled through the adjustment of flowing current by changing the resistance. As the current becomes larger, the emitted light becomes brighter. An LED can emit light in red, orange, yellow, green, or blue. Since the three primary colors (blue, green, and red) of light can be produced by combinations of the five colors, a full-color can be displayed by LEDs.

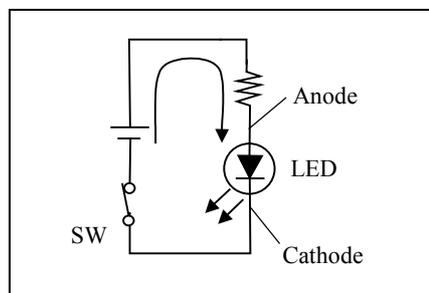


Figure 2.1 LED

Compared with an incandescent lamp, the LED has lower power consumption, longer operating life, and shorter response time. So, the LED is used in lighting equipment, backlight for liquid-crystal display monitor, traffic signals, tail lamps of cars, and displays. The board has red of LED3 and green of LEDs1, 2, 4, and 5 as shown in Figure 2.2.



Figure 2.2 LEDs mounted on the board

2.2 How can the LED emit light?

The LED has a pn-junction structure, which is the most fundamental structure of semiconductor devices. As shown in Figure 2.3, the pn-junction structure consists of a p-type semiconductor containing many electron holes and an n-type semiconductor containing many electrons that are joined to each other.

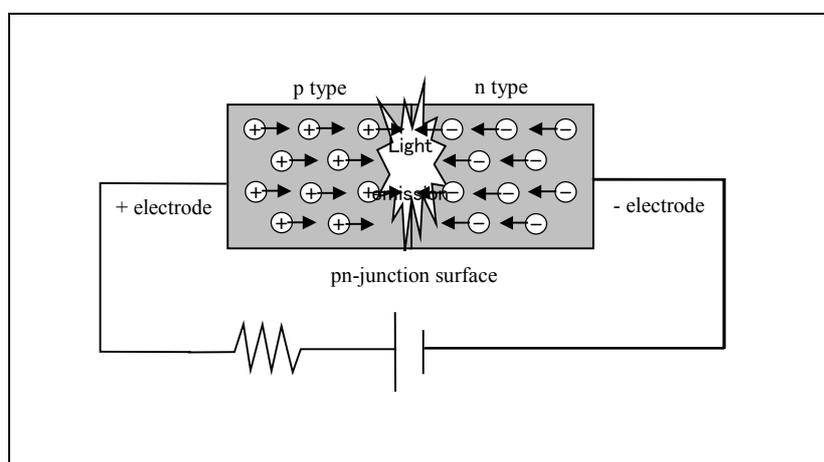


Figure 2.3 pn-junction structure

When a voltage is applied across the pn-junction structure so that the n-type semiconductor is at a negative potential with respect to the p-type semiconductor, electrons move from the n-type semiconductor to the p-type semiconductor, electron holes move in the reverse direction, and thereby a current flows. Then, some of electron holes and electrons collide with each other and are combined together. When an electron hole and an electron are combined together, they lose their energy partially, and the lost energy is emitted in the form of light. The color of emitted light depends on the material of the semiconductor. Table 2.1 shows examples of semiconductor materials and corresponding colors of emitted light.

Table 2.1 Examples of semiconductor materials and colors of emitted light

Semiconductor material	Color of emitted light
ZnCdSe	Blue
ZnTeSe	Green
AlGaAs	Red

2.3 How to turn on an LED by microcomputer

Figure 2.1 showed an example of circuit in which an LED is turned on and off by turning on and off a switch. This section explains how to control the switch using a microcomputer. Figure 2.4 shows the connection of LEDs to the microcomputer on the board. Figure 2.5 shows a conceptual diagram of the connection. In the case of (a) in Figure 2.5, the signal output from pin P10 is at the high level. Therefore, no current flows through the LED and the LED is off. In the case of (b) in Figure 2.5, the signal output from pin P10 is at the low level. Therefore, a current flows through the LED, and the LED goes on. The switch in the microcomputer can be operated by a program that controls the microcomputer.

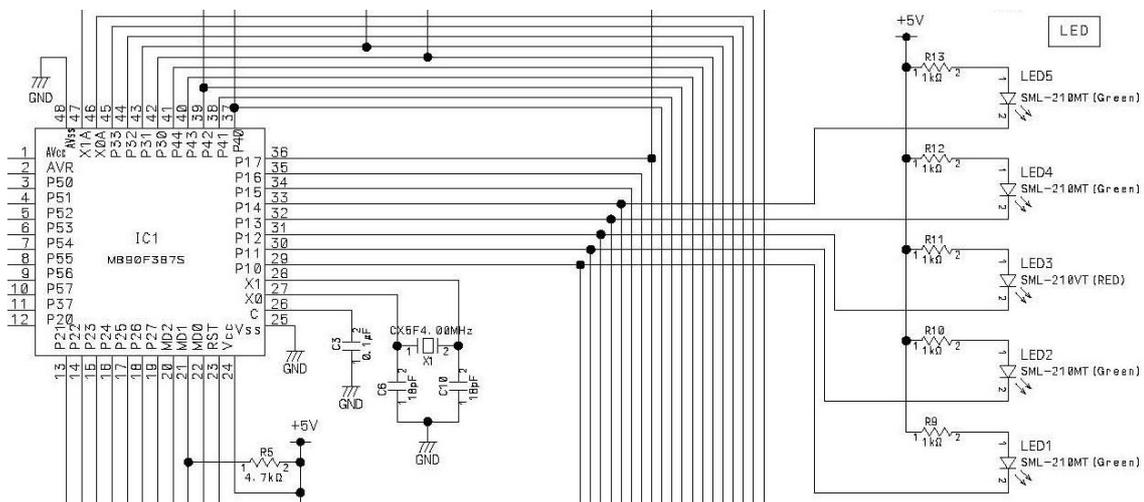


Figure 2.4 Actual circuit diagram

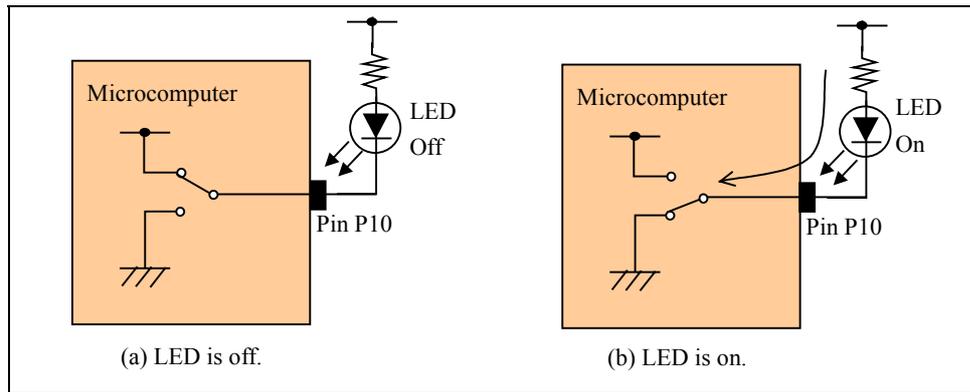


Figure 2.5 Example of circuit to turn on/off an LED (with a conceptual diagram of the internal circuit of microcomputer)

The output settings of pins P10 to P14 are controlled by using the internal registers of the microcomputer. The pins P10 to P14 are controlled by the PDR1 and DDR1 registers as shown in Figure 2.6. To use a port for output, write the value (0 [low] or 1 [high]) to be output to the PDR1 register bit corresponding to the pin, and 1 to the DDR1 register bit corresponding to the pin.

Registers are the memory areas to control microcomputer operation and retain microcomputer operation status. Writing data to, and reading data from registers enables you to control the CPU and peripheral functions of the microcomputer. Here, the term peripheral functions means the functions of the I-O ports, timers, and A/D converter incorporated in the microcomputer.

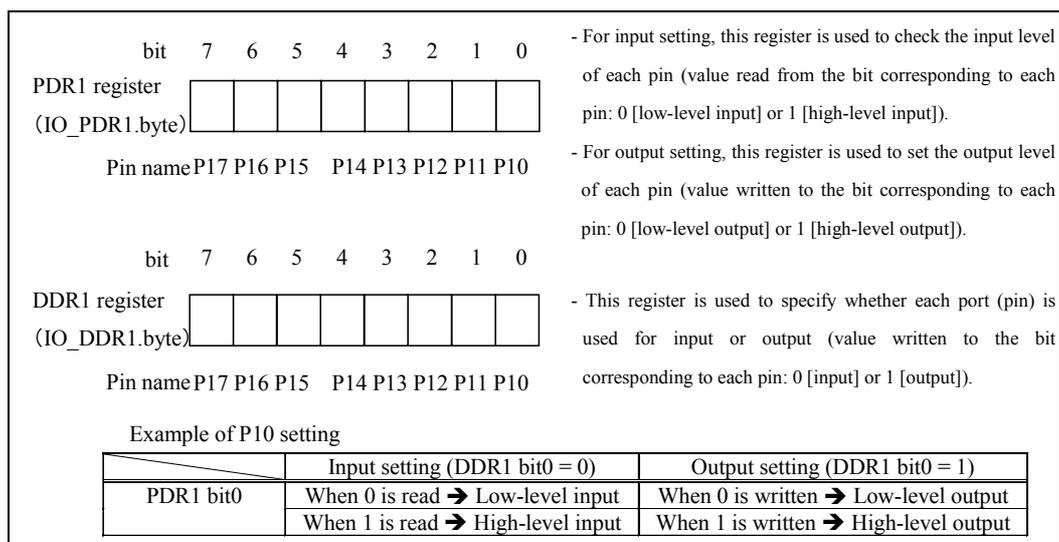


Figure 2.6 Explanation of registers to control the output from P10 to P14

The internal switch of microcomputer as shown in Figure 2.5 actually consists of a p-channel type transistor and an n-channel type transistor as shown in Figure 2.7. The pin outputs a low-level signal when the n-channel type transistor is in the on state; the pin outputs a high-level signal when the p-channel type transistor is in the on state. You can switch the output level of each port by setting the relevant value in the PDR1 register of the microcomputer. In the example shown in Figure 2.7, '0' is written to the bit 0 of PDR1 to set pin P10 for low-level output, and '1' is written to the bit 1 of PDR1 to set pin P11 for high-level output. With these settings, LED0 is turned on, and LED1 is turned off.

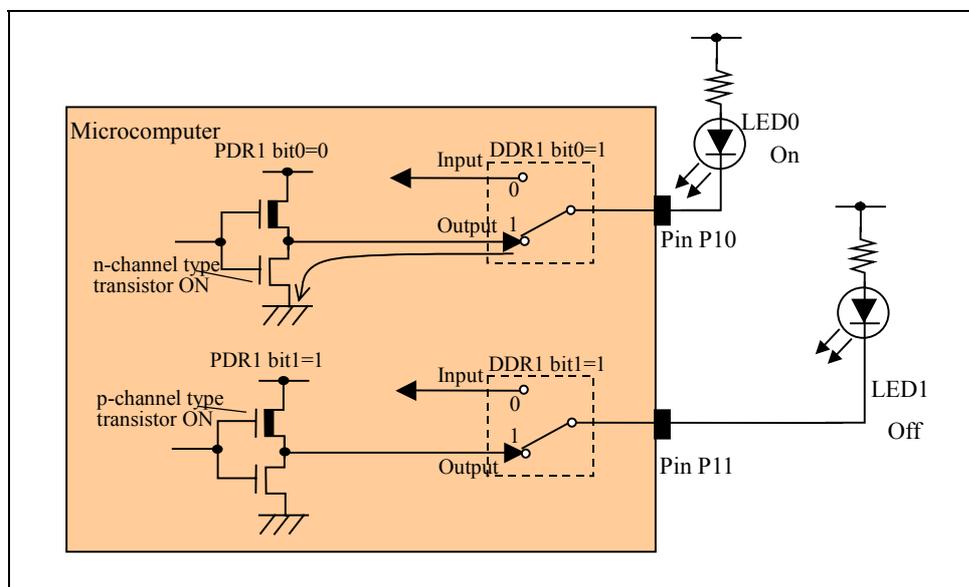


Figure 2.7 LED on/off control by rewriting the PDR1 register (with a conceptual diagram of the internal circuit of microcomputer)

On the board, the LEDs are connected to pins P10 to P14. Therefore, the five pins are set to the output mode for controlling the LEDs. When the microcomputer is reset, all bits of DDR are reset to 0 (initial value), which means the ports are set to the input mode. In this status, to use a pin as an output port, be sure to write '1' to the bit corresponding to the pin.

2.4 How to create and execute a program to turn on the LED

This section explain how to create a program that actually controls a microcomputer pin to turn on an LED.

2.4.1 Outline of program to be created

Here, you will create a program that outputs a low-level signal from pin P14 of the microcomputer to turn on LED5. Figure 2.8 shows the flow of the program. In the flow, a value is set in the PDR1 register first, and then output setting is made using the DDR1 register. For port output, be sure to set the output level in the PDR1 register before the output setting using the DDR1 register. The setting operation should be performed in this order because the initial value that is applied after the microcomputer is reset is not defined for the PDR1 register (to set the output level).

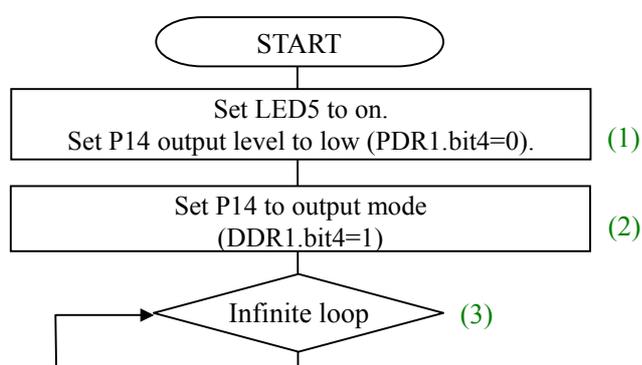


Figure 2.8 Flow of the program to turn on the LED

2.4.2 Creating and executing of program

Let us now create the actual program. According to the procedure described in Appendix A.1, open the source file "main.c" stored in "sample.prj", and input the program portion enclosed by dotted line in Figure 2.9. Use the files other than "main.c" without modification. After the input of the program, build the program according to the procedure described in Appendix A.2. If an error message is output, check that the content of the input program is exactly the same as the description shown in Figure 2.9. When the build operation ends successfully, ACCEMIC MDE starts automatically.

After the ACCEMIC MDE window appears, execute the program and check its operation. For how to execute the program, see Appendix B.1. While the program is executed, you can see that LED5 goes on on the board.

```

void main(void)
{
    IO_PDR1.byte=0xEF;
    IO_DDR1.byte=0x1F;
    while(1);
}

```

Program to be added

(1) LED5 on setting (P14=Low, P10 to P13=High)
 (2) P10 to P14 output setting
 (3) Infinite loop

Figure 2.9 Program to turn on the LED

Descriptions "IO_XXX.byte" and "IO_YYY.bit" included in the above program code are the convenient formats of description defined in the I-O header file. For further information, see Appendix B.1.

2.5 How to create and execute a program to make the LED blinking

This section explains how to create a program that makes the LED be blinking.

2.5.1 Outline of the program to be created

Here, you will create a program that switches the output from pin P14 of the microcomputer between the low and high levels repeatedly to make LED5 turn on and off repeatedly. While 0 and 1 are written alternately to the bit 4 of the PDR1 register, LED5 is blinking as shown below.

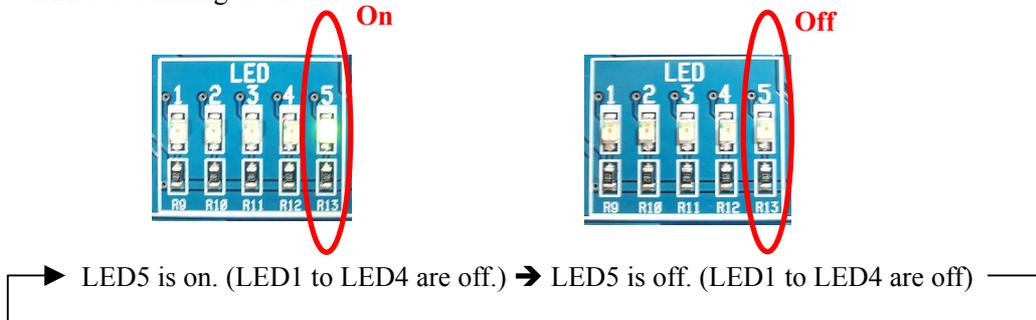


Figure 2.10 shows the flow of the program. The only difference of this program from the LED lighting program shown in Figure 2.8 is that this program has additional steps of LED off and LED on/off time count processing. The LED on/off time count processing is described by the for-statement as shown below to enable you to visually confirm the on/off operation of the LED. You can vary the on/off time by changing the currently set value (30000).

```

- On/off time count    for(i=0;i<30000;i++);

```

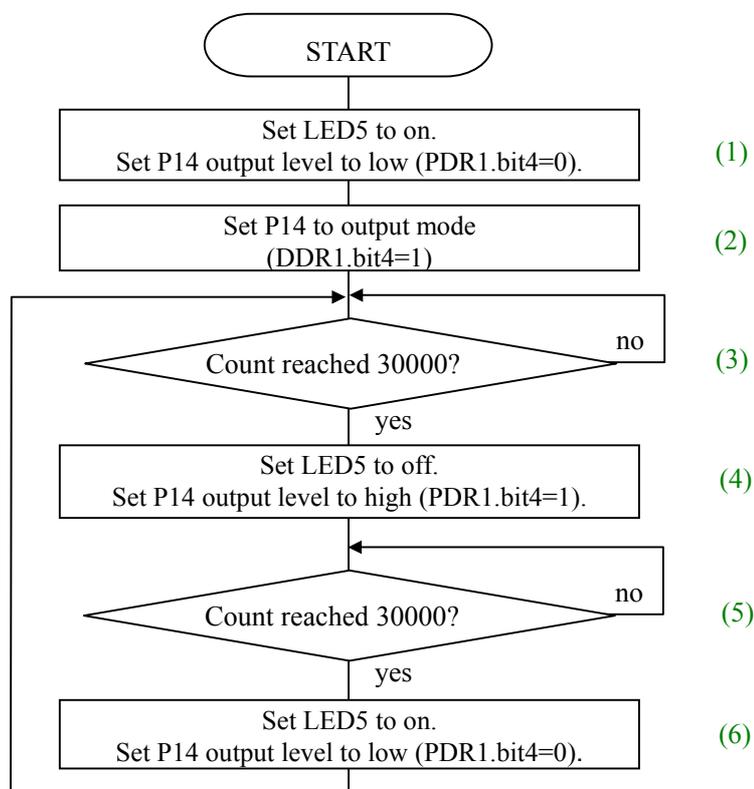


Figure 2.10 Flow of the program to make LED5 blinking

2.5.2 Creating and executing of program

Let us now create the actual program. According to the procedure described in Appendix A.1, open the source file "main.c" stored in "sample.prj", and input the program portion (after "while (1)") enclosed by dotted line in Figure 2.11 to the LED lighting program created in Section 2.4.2. Use the files other than "main.c" without modification. After the input of the program, build the program according to the procedure described in Appendix A.2. If an error message is output, check that the content of the input program is exactly the same as the description shown in Figure 2.11. When the build operation ends successfully, ACCEMIC MDE starts automatically.

After the ACCEMIC MDE window appears, execute the program and check its operation. For how to execute the program, see Appendix A.3. While the program is executed, you can see that LED5 goes on on the board.

```

void main(void)
{
    IO_PDR1.byte=0xEF;           ← (1) LED5 on setting (P14=Low, P10 to P13 =High)
    IO_DDR1.byte=0x1F;         ← (2) P10 to P14 output setting

    while(1)
    {
        int i;
        for(i=0;i<30000;i++);   ← (3) LED5 on time count
        IO_PDR1.byte=0xFF;     ← (4) LED5 off setting (P10 to P14 =High)
        for(i=0;i<30000;i++);   ← (5) LED5 off time count
        IO_PDR1.byte=0xEF;     ← (6) LED5 on setting (P14=Low, P10 to P13=High)
    }
}

```

Program to be added

Figure 2.11 Program to make LED5 blinking

3 “Let's try to control the LED by switch operation!”

This chapter explains how to control LEDs by operating the push switches on the board and how to create a program that controls LEDs based on switch operations.

3.1 How the microcomputer detects switch operation

The board of the Starter Kit has two switches (SWs) as shown in Figure 3.1. The switches are connected to pins P25 and P27 of the microcomputer. The following explains how the microcomputer detects your operation of these switches.

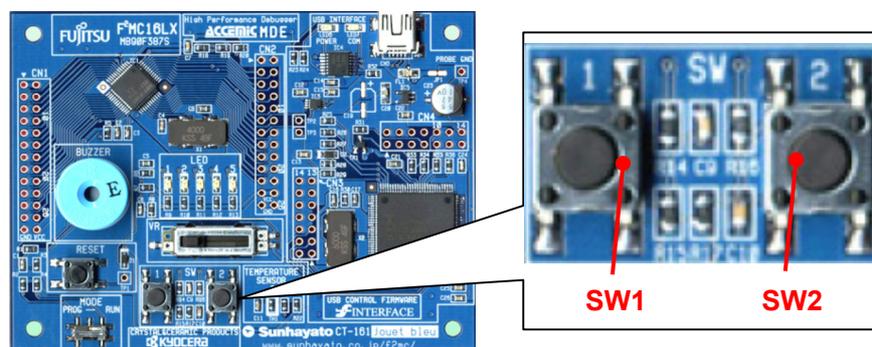


Figure 3.1 Switches on the Starter Kit board

Figure 3.2 shows a conceptual diagram of the connection of SW1 on the board. On the board, SW1 is connected to pin P25, which is a general I-O port of the microcomputer. While SW1 is released (off state), the voltage applied to pin P25 of the microcomputer is V_{cc} (5 V), which is the high-level input. When SW1 is pressed (on state), the input to pin P25 becomes the low level because the voltage at pin P25 becomes GND. Thus, the input status at pin P25 of the microcomputer changes depending on the state of SW1. The same mechanism applies to SW2, except that SW2 is connected to pin P27, which is a general I-O port of the microcomputer. Therefore, the input status at pin P27 changes when SW2 is operated.

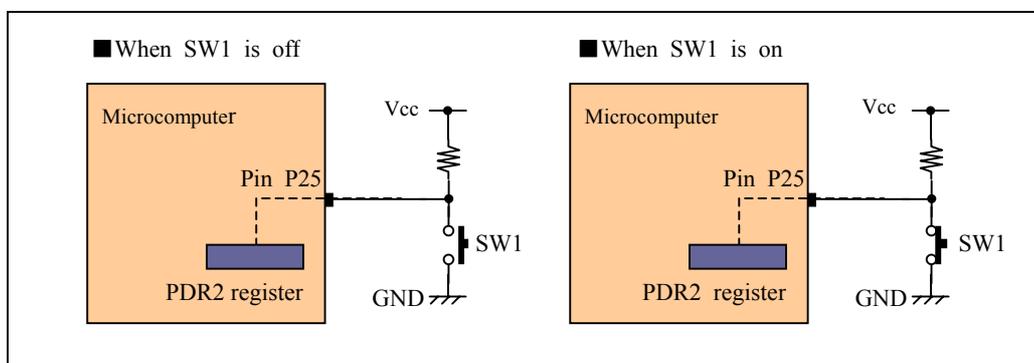


Figure 3.2 Connection of SW1 to microcomputer pin (conceptual diagram)

The change of pin status can be detected by a program running on the microcomputer. The microcomputer of the Starter Kit can determine the status of pins P25 and P27 from the corresponding values in an I-O port register (PDR2). Register values can be read using instructions of a microcomputer program. In other words, the microcomputer can determine the operation state of a switch by reading the corresponding value from PDR2 by the program. Let us explain some specifications of PDR2. PDR2 is the 8-bit register that indicates the status of port 2 pins (P20 to P27). Figure 3.3 shows the association of the pins at port 2 with the bits of PDR2. When a pin is at the high level, the corresponding bit is 1; when the pin is at the low level, the bit is 0. Therefore, the status of pin P25, or the operation state of SW1, can be known when the value of the bit 5 of PDR2 is read. Similarly, the operation state of SW2 can be known when the bit 7 of PDR2 is read.

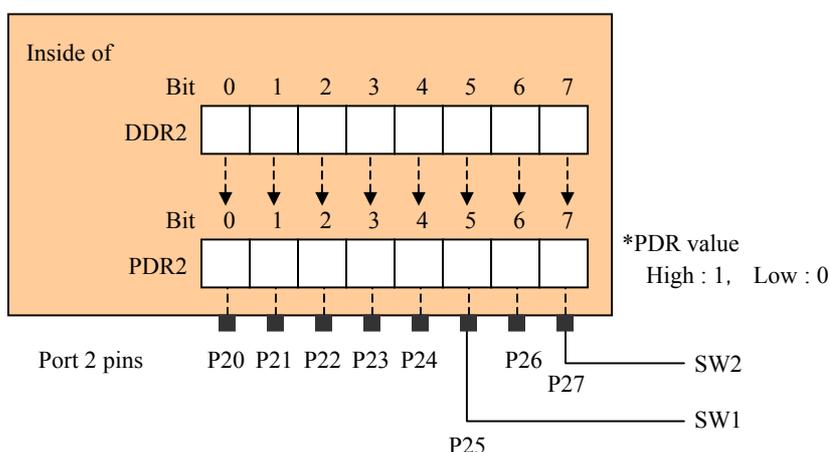


Figure 3.3 Outline of PDR2 and DDR2 registers (conceptual diagram)

When using port 2 pins, you must specify whether they are used for input or they are used for output. DDR2 is the 8-bit register to switch the signal direction (between input and output) of each pin at port 2. The association of the bits of DDR2 with the pins at port 2 is as shown in Figure 3.3. To use a pin for output, 1 should be written to the corresponding bit of DDR2; to use the pin for input, 0 should be written to the corresponding bit of DDR2. Here, P25 and P27 are used as input pins to input signals from SW1 and SW2. Therefore, 0 should be written to the bits 5 and 7 of DDR2.

The above explanation can be summarized into the following processes to detect the switch state by a microcomputer program:

- (1) Write '0' to DDR2 bits 5 and 7, and set port 2 pins P25 and P27 to input mode.
- (2) Read the values of PDR2 bits 5 and 7.

- When the read value is '0,' the switch can be determined to be in the on state.
- When the read value is '1,' the switch can be determined to be in the off state.

3.2 How to create and execute a program to control LEDs by switch operation

This section explains how to create a program to detect the switch operation state. The program also controls LED operation to enable you to visually know that the switch operation state is detected. The program applies the method of turning on the LED described in the previous chapter.

3.2.1 Outline of program to be created

The operation of the program to be created is as described below. Figure 3.4 is the flow of the program that performs the operation.

- (1) When SW1 is pressed, LED1 is turned on.
- (2) While SW1 is in the on state, LED1 is kept lighting.
- (3) When SW1 is released (set to off), LED1 is turned off.
- (4) Similarly, LED2 is turned on and off according to the SW2 state.

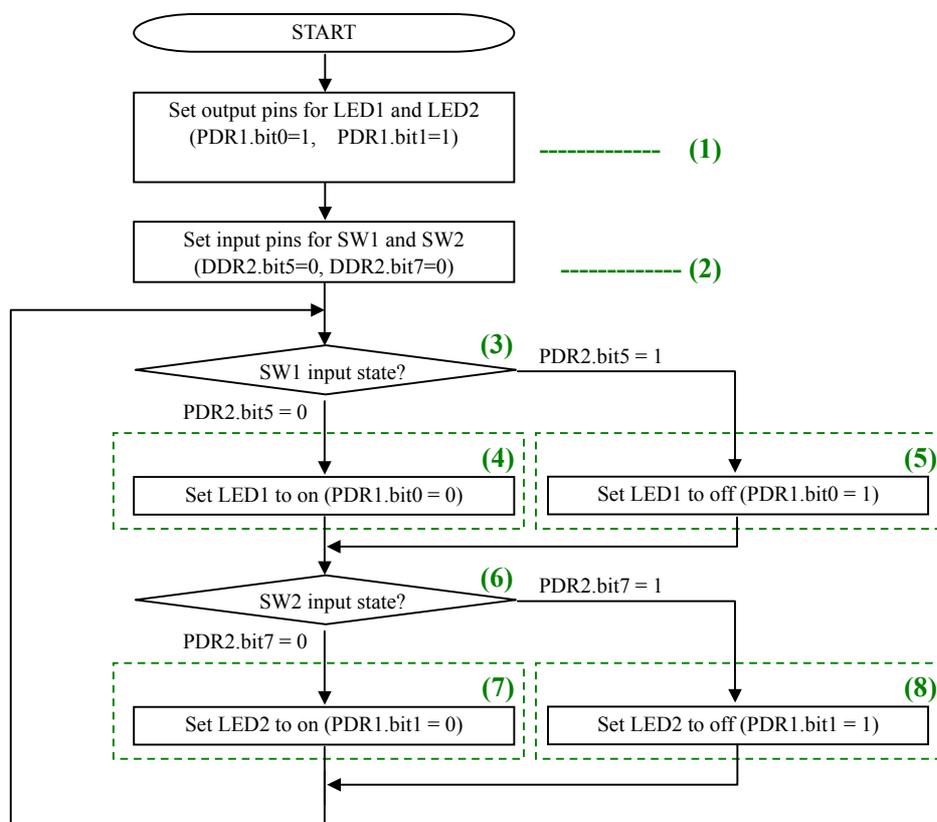


Figure 3.4 Flow of program

This program first sets the output pins for the LEDs, and then sets the input pins for the switches. The necessity of these settings was explained in the previous section. The program subsequently reads the value of the bit 5 of PDR2 to detect the state of SW1. The program turns on or off LED1 according to the read value. To turn on and off LED1, the program writes 0 or 1, respectively, to the bit 0 of PDR1. Also for SW2, the program performs the similar processing and controls LED2.

3.2.2 Creating and executing of program

Let us now create the actual program. According to the procedure described in Appendix A.1, open the source file "main.c" stored in "sample.prj", and input the program portion enclosed by dotted line in Figure 3.5. Use the files other than "main.c" without modification. After the input of the program, build the program according to the procedure described in Appendix A.2. If an error message is output, check that the content of the input program is exactly the same as the description shown in Figure 3.5. When the build operation ends successfully, ACCEMIC MDE starts automatically. After the ACCEMIC MDE window appears, execute the program and check its operation. For how to execute the program, see Appendix A.3. After executing the program, press SW1 or SW2. If LED1 or LED2 goes on, the program operation is correct.

```

void main(void)
{
    __set_irq(7);
    __EI();

    IO_PDR1.byte = 0x00;
    IO_DDR1.byte = 0x1F;

    IO_DDR2.byte = 0x00;

    while(1)
    {
        if(IO_PDR2.bit.P25==1){
            IO_PDR1.bit.P10 = 1;
        }
        else{
            IO_PDR1.bit.P10 = 0;
        }

        if(IO_PDR2.bit.P25==1){
            IO_PDR1.bit.P10 = 1;
        }
        else{
            IO_PDR1.bit.P10 = 0;
        }
    }
}

```

← (1) Port 1(LED control) output setting
 ← (2) Port 2 (SW input) input setting
 ← (3) SW1 input state ?
 ← (4) LED1 on
 ← (5) LED1 off
 ← (6) SW2 input state ?
 ← (7) LED2 on
 ← (8) LED2 off

Program code added

Figure 3.5 Sample program code (main routine)

Descriptions "IO_XXX.byte" and "IO_YYY.bit" included in the above program code are the convenient formats of description defined in the I-O header file. For further information, see Appendix B.1.

4 “Let’s try to sound a buzzer!”

Our daily life is full of sounds. Many of them are not natural sounds but artificial sounds that give us signals, draw our attention to something, and give us information. The loud sound of the alarm clock wakes us up every morning. The cooking timer buzzer sounds to let us know when to stop boiling eggs for our favorite softness of yolk. We are surrounded and given much information by artificial sounds varied in loudness and tone, including those of microwave ovens, level crossing alarms, and automobile horns.

Microcomputers are often used to produce these artificial sounds. A microcomputer can be used to control the timing, tone, and pitch of a sound. This chapter explains how to control a buzzer sound simply by using microcomputer functions.

4.1 Devices used for buzzer

Before explaining the mechanism of a buzzer, this section describes the piezoelectric device that is used for a buzzer.

A piezoelectric device is a circuit element that uses a piezoelectric effect. The piezoelectric device incorporates a substance characterized by the piezoelectric effect (which causes a voltage when an impact or pressure is applied) or the inverse piezoelectric effect (which causes a crystalline distortion when a voltage is applied).

A quartz oscillator is a familiar example of piezoelectric device that uses the piezoelectric characteristics. The buzzer to be controlled by the microcomputer of the Starter Kit incorporates this piezoelectric device. Piezoelectric devices are also used for piezoelectric loudspeakers, crystal earphones, vibration sensors, and microphones.

4.1.1 Crystalline characteristics of piezoelectric device

A piezoelectric device uses a substance that has a polarization characteristic.

Some crystals have an electrical deflection as an inherent characteristic. This characteristic is called "polarization," and the crystal having this characteristic is called a "polarized crystal." More specifically, the polarized crystal contains polarized molecules as shown in Figure 4.1.

In the figure, the direction of polarization is represented by the green arrow indicating the direction from the positive (+) pole to the negative (-) pole.

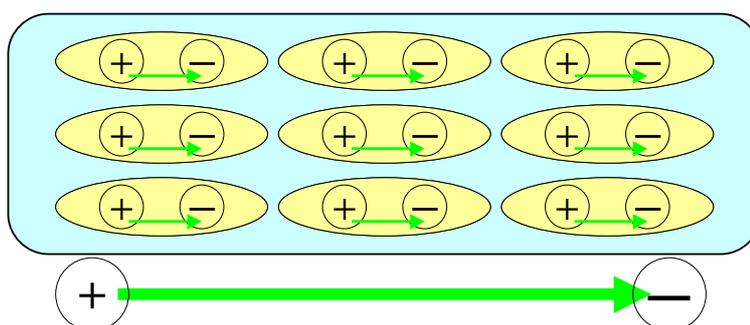


Figure 4.1 Polarization of molecules and crystal

4.1.2 Piezoelectric characteristics

As shown in Figure 4.2, a crystal sometimes has a characteristic that expands the crystal when a voltage is applied in the direction of polarization (direction of green arrow). This characteristic is called the piezoelectric effect. When a piezoelectric crystal is given a voltage in the reverse direction of polarization (reverse direction of green arrow), the crystal contracts.

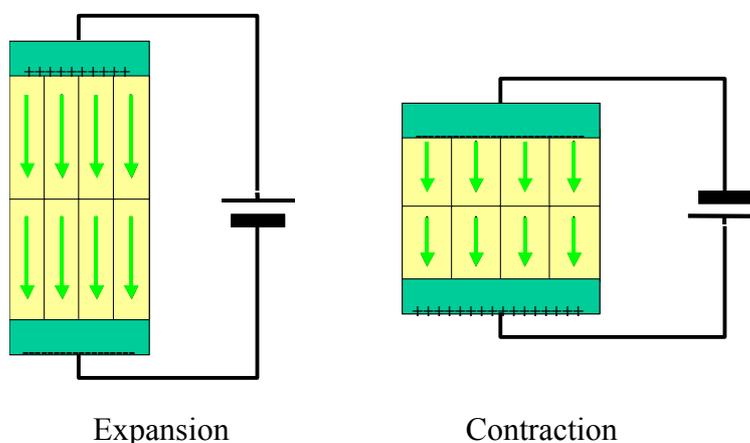


Figure 4.2 Piezoelectric crystal

4.1.3 Principle of piezoelectric device

When an AC voltage is applied across a piezoelectric crystal, the crystal contracts or expands alternately each time the direction of current is reversed as shown in Figure 4.3. The cycle of contraction and expansion changes when the frequency of AC voltage is varied. This characteristic can be used to vibrate the crystal at various frequencies. If the vibrational energy of the crystal is large, the crystal can generate an aerial vibration, which makes a sound. Piezoelectric buzzers use this principle.

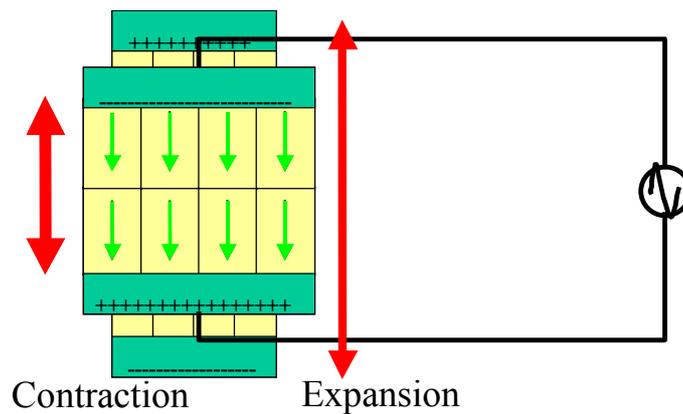


Figure 4.3 Principle of piezoelectric device

4.2 Microcomputer and piezoelectric buzzer

A piezoelectric buzzer uses a piezoelectric device as described above. To produce a sound from the piezoelectric buzzer, you should apply a changing voltage, e.g., AC or pulse voltage, to the buzzer. Here, let's sound a piezoelectric buzzer by using a pulse wave (pulse voltage) output from the microcomputer.

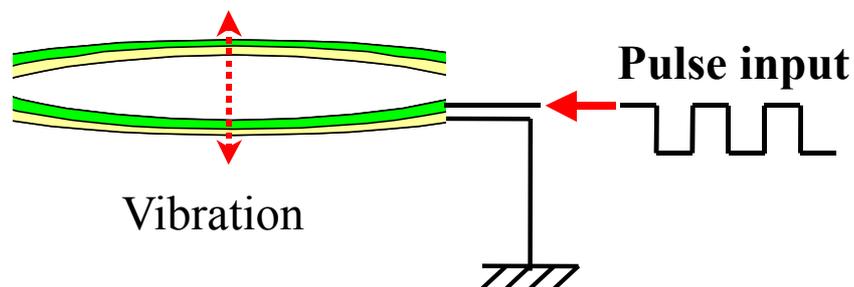


Figure 4.4 Buzzer using a piezoelectric device

4.2.1 Self-excited and separately excited vibrations

Buzzers are classified into two types. One type, called a self-excited buzzer, generates only one sound by the self-resonance of the crystal when a voltage is applied. The other type, called a separately excited buzzer, generates different kinds of sound according to the frequency of applied voltage. The self-excited buzzer can generate only one kind of buzzer sound based on the self-resonant frequency of the crystal. The separately excited buzzer can generate the buzzer sound that varies depending on the frequency of applied voltage. Therefore, the separately excited buzzer enables to vary the sound in a wide range of frequencies.

The board of the Starter Kit has a built-in buzzer, the KBS-13BB-4P-2 made by Kyocera Corporation. Since this buzzer is of separately excited type, it can be used to produce various tone colors of sound in principle.

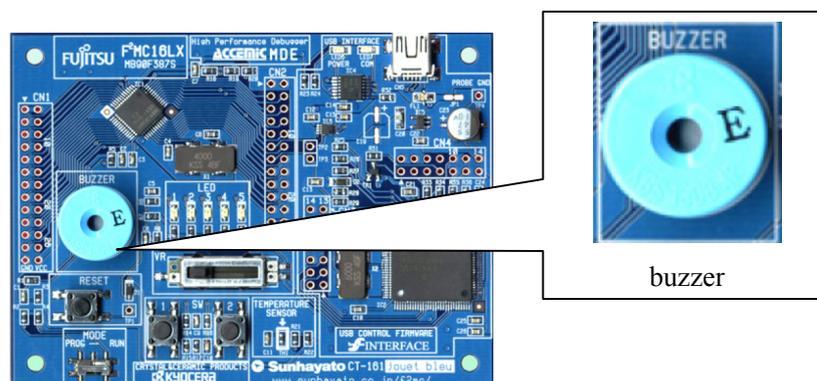


Figure 4.5 buzzer

4.2.2 Pulse wave generated by the microcomputer

The microcomputer can output a pulse wave in several ways. The basic method to output a pulse wave is to use a built-in timer and the setting of H-level and L-level widths. The microcomputer has different built-in timers that can be used for different purposes. Here, use the programmable pulse generator (PPG) timer, which is convenient for pulse output, to output a simple pulse wave for sounding the buzzer.

4.3 How to sound the buzzer by PPG

The programmable pulse generator (PPG) enables you to obtain the output of various widths of pulse from the microcomputer through programming. You can basically output a pulse wave from the microcomputer when you make the following settings on the PPG timer:

- Setting of L-level and H-level duration
- Setting of PPG count clock

The following sections sequentially explain how to use the PPG timer:

4.3.1 Setting of L-level and H-level duration

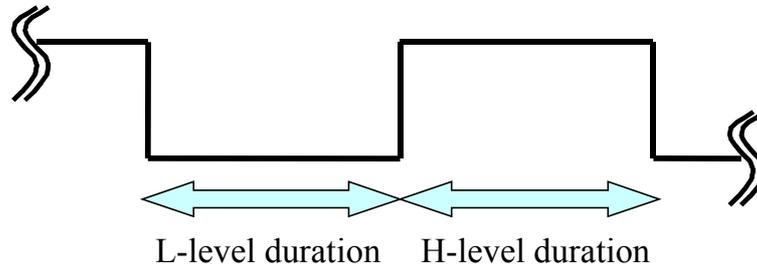


Figure 4.6 Cycle of pulse and L-level and H-level duration

To output a pulse wave based on the PPG timer, you should set the duration of L-level and H-level signals as the counts by the PPG timer. For example, when you specify 300 as the count of L-level duration and 500 as the count of H-level duration, the PPG outputs the L-level signal while the PPG timer counts 300 and the H-level signal while the PPG timer counts 500 alternately from the PPG output pin. The counting by the PPG timer is called "PPG counting."

4.3.2 PPG count clock

To output a pulse wave based on the PPG timer, you should also set the speed of PPG counting. The PPG count per second (that is, the frequency of PPG counting) is called the "PPG count clock."

The PPG count clock is set on the basis of the CPU clock (internal operating frequency) of the microcomputer. In details, the PPG count clock is set to the divide-by-1, divide-by-2, divide-by-4, divide-by-8, or divide-by-16 (whole, one half, one quarter,...) frequency of the CPU clock.

When the PPG count clock is set, the cycle of pulse set in Item 4.3.1 is determined.

4.4 How to create and execute a program to sound the buzzer

Here, let's create a program to actually control the operation of the PPG timer in the microcomputer and sound the buzzer.

4.4.1 Outline of the program to be created

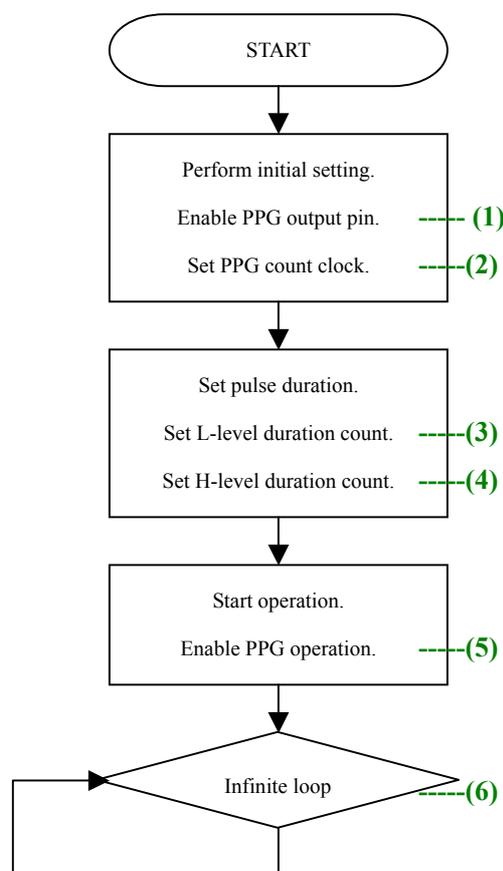


Figure 4.7 Flow of program to sound the buzzer

The following describes the detailed method of PPG setting:

Let's try to make the settings of L-level duration, H-level duration, and PPG count clock as described in Items 4.3.1 and 4.3.2. To make these settings, write values to the registers dedicated to PPG setting in the microcomputer. Writing a value to a register is a programmed operation in by which the value is set in the register according to an instruction.

Here, try to make settings for the output of a 4 kHz pulse wave as an example. To make the setting easier, specify an equal count for L-level and H-level duration, and specify the PPG count clock same as the internal CPU operating frequency. The CPU operating frequency is 2 MHz. Therefore, the counts of L-level and H-level duration should be 250 as shown in Table 4.1.

In addition to the above pulse information, you should make settings to enable PPG pin output and PPG operation. Table 4.1 shows all the necessary register settings.

Table 4.1 Register settings

Setting item	Register for setting (bit)	Value to be set (meaning of setting)
	Register name	
L-level duration	PRL (bits 0 to 7)	0xFA
	PPG reload register (L)	(Count: 250)
H-level duration	PRLH (bits 0 to 7)	0xFA
	PPG reload register (R)	(Count: 250)
PPG count clock	PPG (bits 0 to 7)	0x00
	PPG count clock selection register	(Same as internal operating frequency)
Enabling PPG pin output	PPGC (bit 13)	0 (disabling)
	PPG operation mode control register	1 (enabling)
Enabling PPG operation	PPGC (bit 15)	0 (disabling)
	PPG operation mode control register	1 (enabling)

4.4.2 Creating and executing of program

Let us now create the actual program. According to the procedure described in Appendix A.1, open the source file "main.c" stored in "sample.prj", and input the program portion enclosed by dotted line in the figure below. Use the files other than "main.c" without modification. After the input of the program, build the program according to the procedure described in Appendix A.2. If an error message is output, check that the content of the input program is exactly the same as the description shown in the figure below. When the build operation ends successfully, ACCEMIC MDE starts automatically.

After the ACCEMIC MDE window appears, execute the program and check its operation. For how to execute the program, see Appendix A.3.

The PPG count clock is set to 2 MHz, equal to the CPU operating frequency. The pulse duration count is set to 0xFA (250) for both L and H levels. Therefore, the total count of a cycle is 500, and the pulse wave at 4 kHz will be output. The pulse frequency is calculated as follows:

$$2 \text{ MHz} \div 500 \text{ (count)} = 4 \text{ kHz}$$

Table 4.2 Correspondence of counts and pulse frequencies (with operating frequency at 2 MHz)

Count per cycle (L-level duration + H-level duration)	Pulse frequency
125	16 kHz
250	8 kHz
500	4 kHz
1000	2 kHz

After the PPG pulse output is started by the program and the buzzer starts sounding, the buzzer sound cannot be stopped even when the stop button on the ACCEMIC screen is clicked. This is because the PPG timer continues operation and pulse output is not stopped even when the CPU stops. To stop the buzzer, press the stop button and then reset the microcomputer.

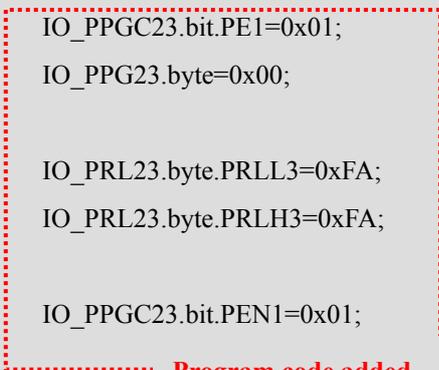
```

void main(void){
    __set_il(7);
    __EI();
    IO_PPGC23.bit.PE1=0x01;
    IO_PPG23.byte=0x00;

    IO_PRL23.byte.PRL3=0xFA;
    IO_PRL23.byte.PRLH3=0xFA;

    IO_PPGC23.bit.PEN1=0x01;
    while(1);
}

```


Program code added

- ← (1) Enabling PPG pin output
- ← (2) PPG count clock setting
- ← (3) PPG timer count for L-level
- ← (4) PPG timer count for H-level
- ← (5) Enabling PPG
- ← (6) Infinite loop

Figure 4.8 Program to sound the buzzer

Descriptions "IO_XXX.byte" and "IO_YYY.bit" included in the above program code are the convenient formats of description defined in the I-O header file. For further information, see Appendix B.1.

4.4.3 Changing the tone of a buzzer sound

Try to vary the setting of pulse duration to check how the buzzer sound changes. Our audible frequencies are said to range from 20 Hz to 20 kHz. Try to confirm the range of audible frequencies by changing the buzzer sound. Also, the buzzer sound will change when the PPG count clock is varied. Try to find the reason for the change.

5 “Let's try to control the LED by interrupt.”

A method to detect the switch operation state was described in Chapter 3. There are also other methods to detect switch operation than the one described in Chapter 3. One of the other methods is to use an external interrupt input. This chapter explains how to detect switch operation by using an external interrupt input.

5.1 What is an interrupt?

Let's begin with a brief explanation of interrupts. The word "interrupt" is popularly used in daily life, and the meaning of the word is similar when the word is used in the world of microcomputers. Imagine that you are studying at home on the day before an examination day. You need to focus on study but are disturbed by a telephone call from a friend or an unexpected visitor. The telephone call and visitor are interrupts. The microcomputer terminology names the events like the telephone call and visitor as "interrupt factors" and the handling of such events as "interrupt processing." Of course, the interrupts in the world of microcomputers are not telephone calls and visitors but the on/off operation of a switch, reception of communication data, generation of a timer event, and other various events typical for microcomputers.

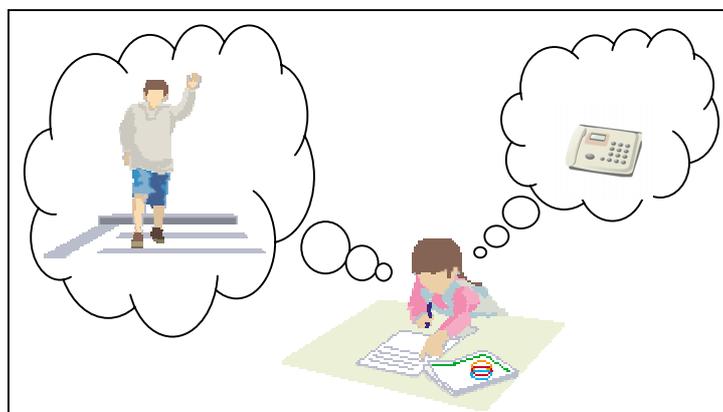


Figure 5.1 Cases of interrupt

In the field of microcomputer and embedded system, using interrupts in programs is generally regarded as an efficient programming method. In the real world, you cannot predict when you will receive telephone calls and visitors. You cannot focus on study if you have to often look at the telephone or get the door to check to see if there is a visitor. Therefore, you usually keep concentrating on study and interrupt it only when you receive a telephone call or visitor actually; this is more efficient.

The microcomputer is provided with a mechanism that notifies the microcomputer program of a switch on/off operation, communication data reception, timer event, or the like

(corresponding to the telephone call or visitor in the real world) when the event occurs. This mechanism is the interrupt. A program can be efficient when it uses interrupts. The sample program described in Chapter 3 uses a procedure for checking the on/off state of the switches cyclically. However, an interrupt is used in the program, the microcomputer can be notified of a switch on/off operation by the interrupt when the operation occurs. Therefore, the processing to cyclically check the on/off state of the switches can be eliminated, and the efficiency of the program can be increased thereby. This chapter explains how to detect switch operation by using an interrupt and how to create the program for the operation.

5.2 How to detect a switch operation by interrupts

As described in Chapter 3, the board of the Starter Kit has two switches that are connected to pins P25 and P27 of the microcomputer. Pins P25 and P27 connecting the switches were used as input ports in the program example described in Chapter 3. These pins can be used also as external interrupt input pins (INT5 and INT7). The following describes how to detect switch operation (pressing of a switch) by using an external interrupt input.

Figure 5.2 shows an outline of SW1 connection circuit on the board of the Starter Kit. SW1 is connected to pin INT5 of the microcomputer as shown in Figure 5.2. While SW1 is released (in the off state), the voltage at pin INT5 of the microcomputer is Vcc (5 V), and the signal input to pin INT7 is at the high level. When SW1 is pressed (in the on state), the voltage at pin INT5 becomes the GND level, and the signal input to pin IN5 changes from the high level to the low level. When SW1 is released subsequently, the signal input to pin INT5 changes from the low level to the high level. When the external interrupt function of pin INT5 of the microcomputer is used, an interrupt can be generated when the pin status is changed. In short, this mechanism enables the microcomputer to be informed of switch operation by the interrupt. SW2 can be handled in a similar way to handle SW1. Because SW2 is connected to pin INT7 of the microcomputer, an external interrupt is generated at pin INT7 when SW2 is operated.

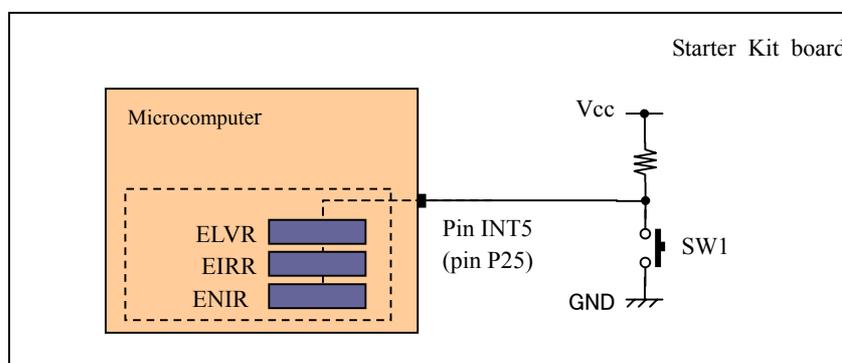


Figure 5.2 Connection of SW1 to microcomputer pin (conceptual diagram)

Explained next is the procedure for using pin INT5 as an external interrupt pin. To use pin INT5 for the input of external interrupt, you should set the I-O direction of the pin to input by using the port 2 register "DDR2." Handling of DDR2 was described in Chapter 3. Write '0' to the bit 5 of DDR2. You should also set necessary values in external interrupt registers "EIRR," "ENIR," and "ELVR" for using pin INT5 as the external interrupt input pin. EIRR is an 8-bit register that indicates external interrupt factors. ENIR is an 8-bit register that enables and disables external interrupts. ELVR is a 16-bit register that specifies the conditions for external interrupt detection.

Assume the processing to detect the SW1 operation from the off state to the on state by using an interrupt. When SW1 is pressed, the signal input to pin INT5 changes from the high level to the low level (as described before). When values are set in external interrupt registers in steps (1) to (4) below, the external interrupt function enables the microcomputer to detect the change (falling edge) of the signal input to pin INT5 from the high level to the low level. In this way, the on operation of SW1 can be detected as the generation of an interrupt.

- (1) Write '0' to the bit 5 of both EIRR and ENIR (to disable the external interrupt via INT5)
- (2) Write '1' to the bits 10 and 11 of ELVR (to generate an external interrupt when a falling edge is detected)
- (3) Write '0' to the bit 13 of both EIRR and ENIR (to clear the INT5 interrupt factor)
- (4) Write '1' to the bit 5 of both EIRR and ENIR (to enable the external interrupt via INT5)

5.3 How to create and execute a program to control the LED by switch Input operation

This section explains how to create a program to detect switch operation by an external interrupt. The program is also designed to operate an LED to enable you to visually see the detection of switch operation. The program incorporates the method to turn on an LED explained in Chapter 2.

5.3.1 Outline of the program to be created

Let's create a program to better understand the operation of interrupt processing. This program will be very similar in contents to the LED control program created in Chapter 2, except that this program will have an additional portion to process the interrupt generated by switch operation. The main operation by the program is as described

below. Figure 5.3 shows the flow of the program.

- (1) When the program starts, LED1 starts blinking.
- (2) When SW1 is pressed, LED3 goes on.
- (3) Each time SW1 is pressed, LED3 goes off and on alternately.

The main processing by the program begins with the setting of LED output and switch input pins. This setting was described in Chapter 3. Next, the program makes the settings related to the external interrupt and enables the external interrupt. Then, the program makes LED1 be blinking. Blinking of LED1 continues until the stop or reset button is pressed on the ACCEMIC screen. When SW1 is pressed after the external interrupt is enabled, an INT5 interrupt is generated, and an interrupt routine is called. The interrupt routine clears the interrupt factor and switches LED3 between on and off states. In summary, this program makes LED1 blinking processing usually as the main processing, and switches LED3 between the on and off states only when the interrupt is generated by switch operation.

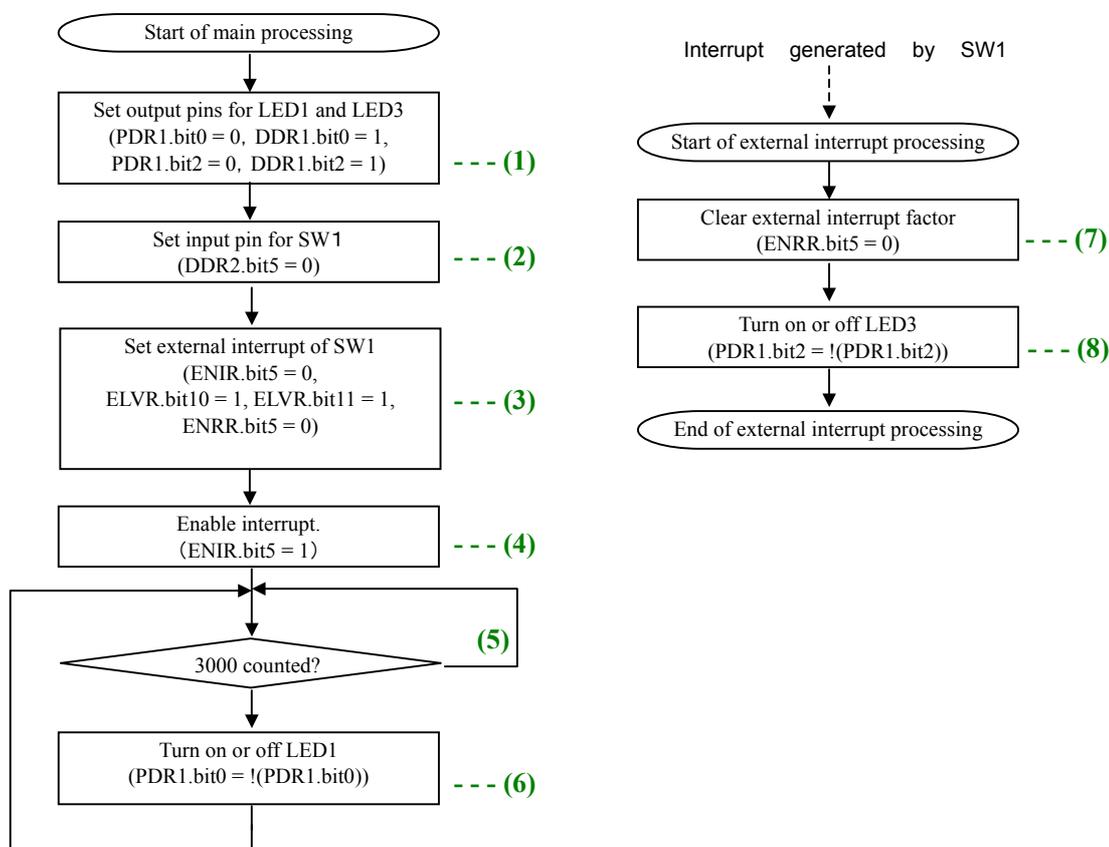


Figure 5.3 Flow of the program

5.3.2 Creating and executing of program

Let us now create the actual program. According to the procedure described in Appendix A.1, open the source file "main.c" stored in "sample.prj", and input the program portions enclosed by dotted line in Figure 5.4 and Figure 5.5. Use the files other than "main.c" without modification. After the input of the program, build the program according to the procedure described in Appendix A.2. If an error message is output, check that the content of the input program is correct. When the build operation ends successfully, ACCEMIC MDE starts automatically.

After the ACCEMIC MDE window appears, execute the program and check its operation. For how to execute the program, see Appendix A.3. After the program starts normally, check LED1. LED1 is blinking when the program is operating normally. Also, press SW1 to check for normal interrupt operation. The interrupt operation is normal if LED3 goes on and off alternately each time SW1 is pressed.

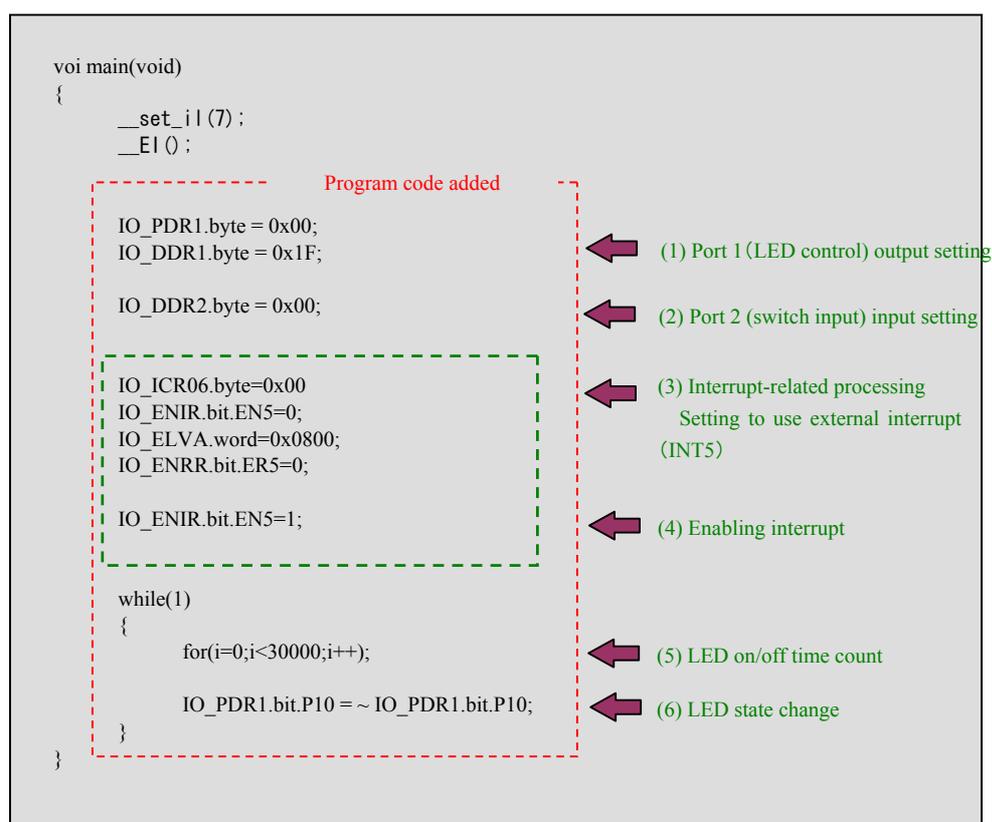


Figure 5.4 Sample program code (main routine)

```

__interrupt void ext_int(void)
{
    IO_EIRR.bit.ER4=0x0;
    IO_PDR1.bit.P12=~IO_PDR1.bit.P12;
}

```

Program code added

(7) Interrupt factor clearance

(8) LED on/off switching

Figure 5.5 Sample program code (interrupt routine)

The `ext_int` function is called when the external interrupt (INT5) is generated. If you program the above operation without using this sample project, you should register the interrupt routine in the vector table so that the `ext_int` function will be called when the external interrupt (INT5) is generated. You need not perform the registration when you use this sample project in which the interrupt routine has already been registered.

Descriptions "IO_XXX.byte" and "IO_YYY.bit" included in the above program code are the convenient formats of description defined in the I-O header file. For further information, see Appendix B.1.

6 “Let's blink the LED by using a timer interrupt.”

The procedure for controlling the LED blinking is described in Item 2.5 in Chapter2. There are some other methods to control the LED blinking other than the method described in Chapter 2. One of them is the method using a "timer interrupt." This chapter describes the method to control the LED blinking by using a 16-bit reload timer.

6.1 What is a timer?

Let's begin with a brief explanation of the "timer." The word "timer" is often heard in daily life, such as a recording timer of VCR, a start timer or sleep timer of the audio system, a kitchen timer for cooking, or the timer function of an alarm clock. The function of the timer contained in the microcomputer is the same as those timers. Let's take the alarm clock timer as an example to explain the timer function. Most of the people set the alarm clock timer for a certain time and wake up at the sound of the alarm every morning. What would happen if there was no alarm timer function? People would be bothered about the time to wake up once the dawn breaks and could not keep relaxing and sleeping. People can re-realize that the timer function of the alarm clock allows us to sleep tight until the time to get up.

The microcomputer has the timer interrupt function that performs as an alarm timer function. In this case, the timer interrupt is used for the LED-on time count and the LED-off time count. Because the LED blinking control described in Item 2.5 in Chapter2 counts the LED-on time and LED-off time by executing the CPU instruction, the CPU is always required to perform the processing for controlling the LED blinking. Figure 6-1 **LED blinking processing without using the timer interrupt** shows the LED blinking processing without using the timer interrupt. This figure shows that the CPU must always control the LED and there is no time for other processing.

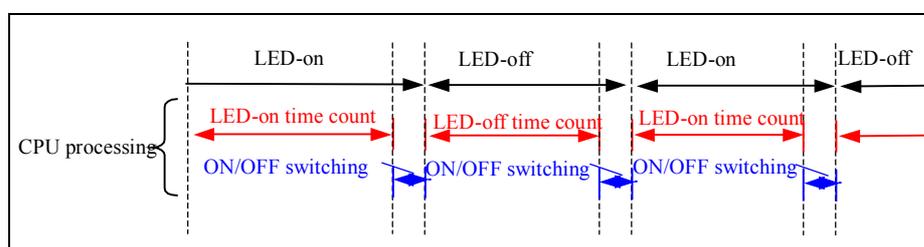


Figure 6-1 LED blinking processing without using the timer interrupt

When a timer is used, the timer can take the processing of counting the LED-on and -off time that is described in Figure 6-1 so that the CPU does not have to count the LED-on and -off time. The CPU can perform processing other than the LED blinking control accordingly.

Figure 6-2 shows the LED blinking processing with using the timer.

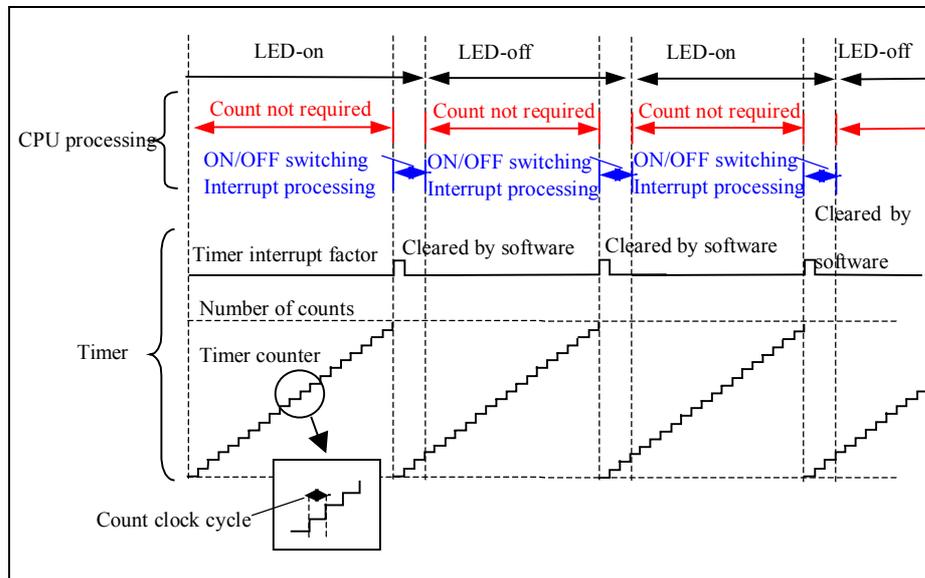


Figure 6-2 LED blinking processing with using the timer

To use the timer to count the LED-on and -off time, the count clock and the number of the counts need to be specified. The LED-on and -off time can be calculated by using the following expression. Using the timer, as just described, has the advantage of enabling the accurate time count.

$$\text{LED-on and -off time period} = \text{count clock cycle} \times \text{number of counts}$$

6.2 How to create and execute a program to control the LED blinking by using a timer interrupt

This section explains how to create a program to control the LED blinking by using a timer interrupt. The 16-bit reload timer is used for the timer of this program.

6.2.1 Outline of the program to be created

In Chapter 2, the LED blinking time is controlled by a WAIT of the loop processing. In this section, a program that uses the 16-bit reload timer interrupt to count the LED blinking time is created. The LED operation of this program is the same as that of the program created in Chapter 2. However, as the operation of the microcomputer, the 16-bit reload timer instead of the CPU is used for counting the LED-on and -off time. The CPU is not

required for counting the LED-on and -off time.

Figure 6-3 Flow of the program shows the flow of the program.

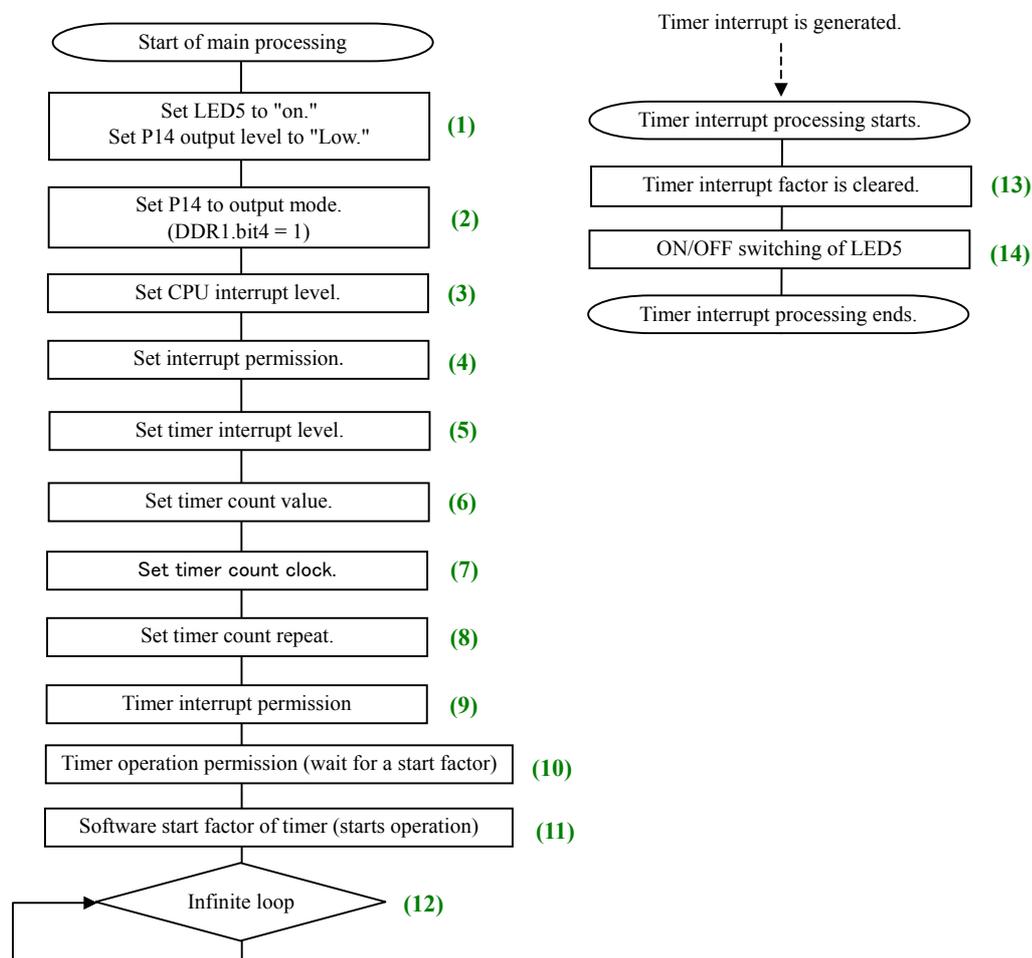


Figure 6-3 Flow of the program

The program created in this section goes into an infinite loop (No. 12 in the flow of the program) after a sequence of the processing. During this infinite loop processing, the CPU can execute any processing other than the LED processing. Table 6-1 **Register setting of 16-bit reload timer** shows the register of the 16-bit reload timer that is set in the program created in this section. Suppose the LED-on and -off time is one second. The value to be set for the counter of the 16-bit reload timer can be calculated by using the following expression accordingly.

$$\begin{aligned}
 \text{LED -on and -off time period} &= \text{Count clock cycle (16 } \mu\text{s)} \times \text{Number of counts (62500)} \\
 &= 1 \text{ s}
 \end{aligned}$$

Table 6-1 Register setting of 16-bit reload timer

Setting item	Register name	Setting value (meaning)
	Setting bit	
Timer count value	TMRLR register	0 × F424 (62500 counts)
	D0 to D15 (bit0 to bit15)	
Timer count clock	TMCSR0 register	10 (count clock cycle: 16 μs)*
	CSL0, CSL1(bit10, bit11)	
Timer count repeat	TMCSR0 register	0 (Timer stops at an interrupt generation.)
	RELD (bit4)	1 (Timer count is reset at an interrupt generation and the operation continues.)
Timer interrupt permission	TMCSR0 register	0 (Timer interrupt permitted)
	INTE (bit3)	1 (Timer interrupt not permitted)
Timer interrupt factor	TMCSR0 register	0 (There is no timer interrupt factor.)
	UF (bit2)	1 (There is a timer interrupt factor.)
Timer operation permission	TMCSR0 register	0 (Not permitted)
	CNTE (bit1)	1 (Permitted)
Timer software start	TMCSR0 register	0 (No effect)
	TRG (bit0)	1 (Start)

* Count clock cycle (16 μs) = 32 / Internal operation frequency (2 MHz)

6.2.2 Creation and execution of the program

Let us now create the actual program. According to the procedure described in Appendix A.1, open the source file "main.c" in sample.prj and input the program that is the circled part in Figure 6-4 **Example of program code (main routine)** and Figure 6-5 **Example of program code (interrupt routine)**. Use all files except main.c without any changes. After the program is input, "build" the program according to the procedure described in Appendix A.2.

If an error is output, reconfirm that the program accords to the contents of Figure 6-4 **Example of program code (main routine)** and Figure 6-5 **Example of program code (interrupt routine)**. When the "build" is succeeded, "ACCEMIC MDE" starts automatically.

When the "ACCEMIC MDE" window appears, execute the program and check the operation. For the procedure of the program execution, see Appendix A.3. When the program starts correctly, check LED5. Blinking LED5 indicates the normal operation.

```

void main(void)
{
    IO_PDR1.byte=0xEF;
    IO_DDR1.byte=0x1F;
    __set_il(7);
    __EI();
    IO_ICR03.byte=0x06;
    IO_TMR[0]=0xF424;
    IO_TMCSR0.bit.CSL=2;
    IO_TMCSR0.bit.RELD=1;
    IO_TMCSR0.bit.INTE=1;
    IO_TMCSR0.bit.CNTE=1;
    IO_TMCSR0.bit.TRG=1;
    while(1);
}

```

← (1) LED5 on setting P14=Low
 ← (2) P10 to P14 output setting
 ← (3) CPU interrupt level setting
 ← (4) Interrupt permission
 ← (5) Timer interrupt level setting
 ← (6) Timer count value setting
 ← (7) Timer count clock setting
 ← (8) Timer count repeat setting
 ← (9) Timer interrupt permission
 ← (10) Timer operation permission (wait for a start factor)
 ← (11) Software start factor of timer (starts operation)
 ← (12) Infinite loop

} --- Program code to be added ---

Figure 6-4 Example of program code (main routine)

```

__interrupt void reload_int(void)
{
    IO_TMCSR0.bit.UF = 0;
    IO_PDR1.bit.P14=~IO_PDR1.bit.P14;
}

```

← (12) Clearing interrupt factor
 ← (13) LED-on/off switching

} --- Program code to be added ---

Figure 6-5 Example of program code (interrupt routine)

The reload_int function in Figure 6-5 **Example of program code (interrupt routine)** is to be executed when an interrupt of the 16-bit reload timer is generated. It is normally required to register the interrupt routine on the vector table so that the reload_int function is executed when an interrupt of the 16-bit reload timer is generated. In this sample project, however, it has already been registered, so it can be used without registration. In the above code, there are some expressions such as "IO_XXX.byte" and "IO_YYY.bit". These are the useful description formats, which are defined in the IO header file. For more information, see the Appendix.

7 “Let's use the A/D converter.”

This section describes the processing to convert the analog signals input to the microcomputer into the digital signals by using the A/D converter and to load the digital signals into the microcomputer.

This Starter Kit can control the value of the voltage applied to the analog pin for the A/D converter by using the volume tab mounted on the board. Let's input the analog signal to the microcomputer by using this tab. The input analog signal can be converted into the digital signal by the A/D converter and processed by the microcomputer.

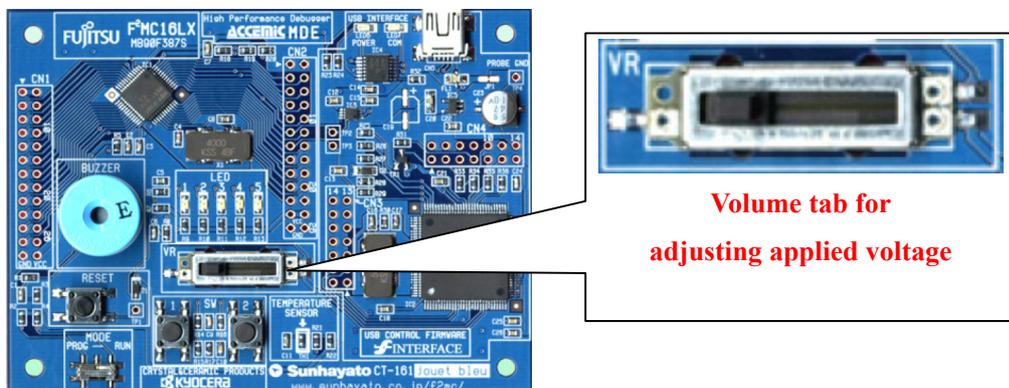


Figure 7-1 Adjustment of applied voltage with volume tab

7.1 Analog and Digital

Do you know the difference between analog and digital? Those are explained as follows in a dictionary.

Table 7.1 Analog and digital

	Definition in a dictionary
Analog	Expressing states of a material or system according to its physical quantity that varies continuously
Digital	Expressing states of a material or system according to discrete signals such as numbers or characters

Although you read the above definitions, you may have a hard time picturing them. Intuitively speaking, initially, everything is in analog value. At the moment a person tries to determine the size or variety of the analog value, the quantity becomes digital value. In other words, a digital value exists only when an analog value exists. A digital value is what an analog value is divided into some levels for easier handling and converted to easier

understandable form.

Figure 7-2 **Low accurate digital conversion** shows an example of analog and digital signals. The blue line indicates an analog signal, and the black line indicates a digital signal. The digital signal in this figure is a low accurate A/D conversion result.

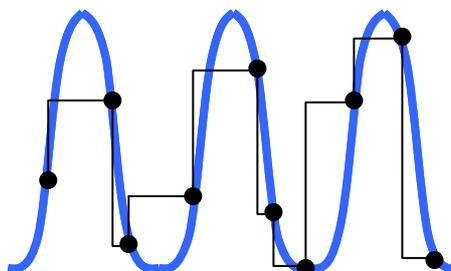


Figure 7-2 Low accurate digital conversion

7.1.1 Outline of A/D converter

A digital value is a value into which an analog value is divided according to a standard based on a certain rule. The A/D converter is mounted on the microcomputer to perform this conversion. For this conversion, the important factor is resolution. This resolution is, like the resolution of photograph, a scale of how small the analog value is to be resolved and converted to the digital value. For example, a school record that is evaluated on a scale of one to five can be a poor accurate digital value. In contrast, a school record that is evaluated on full mark of a 1000-point scale can be a highly accurate digital value.

The microcomputer mounted on this Starter Kit contains the A/D converter that has 10-bit resolution (8-bit resolution is also available). Having the 10-bit resolution means that it can resolve an analog value into 2^{10} , or 1024, levels to convert it to a digital value (with 8-bit resolution, the value is resolved into 2^8 , or 256, levels). The higher the resolution is, the more highly the A/D conversion can be accurate. The following shows the 1-bit voltage accuracy (at 5 V) with 10-bit resolution and 8-bit resolution.

1-bit voltage accuracy (at 5 V)

10-bit resolution: $5 \text{ V}/1024 = \text{approximately } 0.00488 \text{ V}$

8-bit resolution: $5 \text{ V}/256 = \text{approximately } 0.01953 \text{ V}$

7.1.2 Scheme of volume tab

Figure 7-3 Variable resistor shows the symbol of a variable resistor. The volume is the variable resistor that you use in an experiment in a science class. This Starter Kit uses the circuit configuration shown in



Figure 7-3 Variable resistor

Figure 7-4 Peripheral circuitry of voltage adjustment. By using this tab, the voltage is changed and applied to the target pin of the A/D conversion. The applied voltage is digitized into 1024 levels so that it can be used as an internal signal.

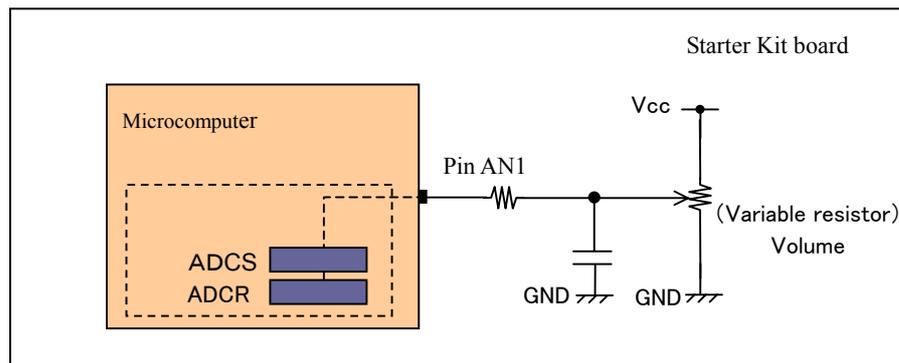


Figure 7-4 Peripheral circuitry of voltage adjustment tab

7.2 How to create and execute a program to display potential

Let's create a program to display the potential based on the contents so far. Input the adjusted voltage, convert the analog signal to digital, and obtain the digital value. Also, light the LED to display the potential.

7.2.1 Outline of program to be created

Let us now create the actual program. The contents of the program are to use the A/D converter to digitalize the potential of the applied voltage and to determine the number of LEDs to be lighted according to the potential. The main operation of the program is described below. The flow of the program is shown in Figure 7-5 **Flow of the program**.

- (1) Perform initialization (such as initial settings of the A/D converter).
- (2) Start the A/D conversion (to obtain the applied voltage by using the A/D converter).
- (3) The A/D conversion is completed. (The A/D converted values are obtained.)
- (4) Light the LEDs according to the obtained A/D converted values. (Determine the number of LEDs to be lighted.)
- (5) Then, repeat (2) to (4).

First, in the program, set up the output pin of the LED and the input pin to be used for the A/D converter. Then, make the settings regarding the A/D converter operations such as the sampling time of the A/D conversion, operation mode, and A/D input channels. In this section, the sampling time is set to $128/\phi$, the comparing time is set to $176/\phi$, the resolution is set to 8-bit, and the A/D conversion channel to be used is set to Ch0 only, and the operation mode is set to the continuous conversion mode. " ϕ " indicates the internal operation frequency of the microcomputer. Table 7.2 **Register settings of A/D converter** shows the values to be written to the register for the settings.

Table 7.2 Register settings of A/D converter

Item	Register (bit)	Setting value (contents)
A/D conversion started	ADCS: H (bit 9)	1 (A/D conversion started)
A/D interrupt permission	ADCS:H (bit 13)	1 (permitted), 0 (not permitted)
A/D interrupt factor cleared	ADCS: H (bit 14)	0 (factor cleared)
A/D conversion stopped	ADCS:H (bit 15)	0 (A/D conversion is forcibly stopped)
A/D conversion end Ch	ADCS: L (bits 0 to 2)	0 (Select Ch0)
A/D conversion start Ch	ADCS: L (bits 3 to 5)	0 (Select Ch0)
A/D conversion mode setting	ADCS: L (bits 6 to 7)	2 (Continuous conversion mode)
Comparing time selection	ADCR: H (bits 11 to 12)	3 ($176/\phi$)
Sampling time selection	ADCR: H (bits 13 to 14)	3 ($128/\phi$)
A/D resolution selection	ADCR: H (bit 15)	1 (8-bit resolution)
Analog input permission	ADER (bits 0 to 7)	01h (Input permitted from Ch0 only)

*The sampling time includes the time for loading the A/D input voltage after the A/D conversion starts.

*The comparing time is the time to perform comparison operations of the sampled A/D voltage and the standard voltage of the A/D converter and to convert it to a digital value.

After that, permit interruptions of A/D converter. This is the end of the operation settings of the A/D converter. Start the A/D conversion. In this program, the operation mode of the A/D converter is set to the continuous conversion mode. The operation of the A/D converter is as follows accordingly.

A/D converter is activated (A/D conversion starts) ⇒ A/D conversion ends ⇒ A/D conversion starts - - -

The operation repeats as shown above. When the A/D conversion ends, an interrupt of the A/D converter is generated, and an interrupt routine is called. In the interrupt routine, the interrupt factor is cleared, the A/D value is obtained, and the LEDs are lighted according to the obtained A/D value, which is the volume size. The correspondence between the volume size and the number of LEDs lighted is as shown in Table 7.3 **LED lighting according to volume** .

Table 7.3 LED lighting according to volume level

Applied voltage	Obtained A/D value	LED lighting
0 to 0.83 V	0 to 43	 No LED is on.
0.83 to 1.67 V	43 to 85	 LED1 is on.
1.67 to 2.50 V	85 to 128	 LEDs 1 to 2 are on.
2.50 to 3.33 V	128 to 171	 LEDs 1 to 3 are on.
3.33 to 4.17 V	171 to 213	 LEDs 1 to 4 are on.
4.17 to 5.00 V	213 to 255	 All LEDs are on.

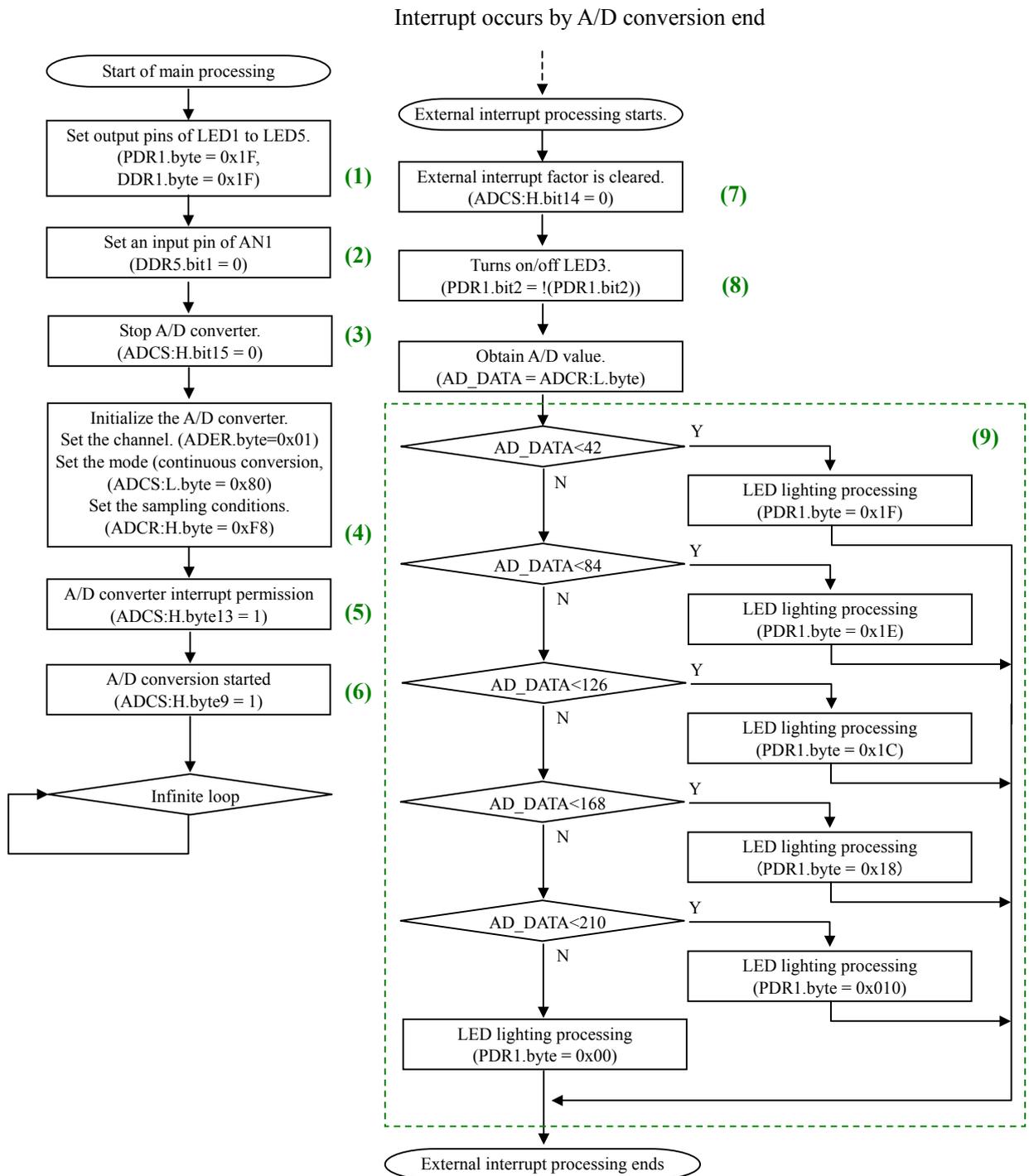


Figure 7-5 Flow of the program

7.2.2 Creation and execution of the program

Let us now create the actual program. According to the procedure described in Appendix A.1, open the source file "main.c" in the "sample.prj," and input the program that is the circled part in Figures A.1 and A.1. Use all files except main.c without any changes. After the program is input, "build" the program according to the procedure described in Appendix A.2. If an error is output, reconfirm that the program accords to the contents of Figure 6-4 **Example of program code (main routine)** and Figure 6-4 **Example of program code (main routine)**. When the "build" is succeeded, "ACCEMIC MDE" starts automatically.

When the "ACCEMIC MDE" window appears, execute the program and check the operation. For the procedure of the program execution, see Appendix A.3. When the program starts correctly, check the operation. It can be confirmed that the LEDs 1 to 5 are lighted according to the size of the applied voltage that has been adjusted on the volume.

```

void main(void)
{
    ----- Program code to be added -----
    __set_irq(7);
    __EI();

    IO_PDR1.byte = 0x1F;
    IO_DDR1.byte = 0x1F;

    IO_DDR5.bit.D50 = 0;
    IO_ICR03.byte = 0x06;

    IO_ADCSH.bit.BUSY = 0;

    IO_ADER.byte = 0x01;
    IO_ADCSL.byte = 0x80;
    IO_ADCRLH.byte.ADCRH = 0xF8;

    IO_ADCSH.bit.INTE = 1;
    IO_ADCSH.bit.STRT = 1;

    while(1);
}

```

← (1) Port 1 (LED control) output setting

← (2) Port 5 (AD input) input setting

← (3) Stop A/D converter.

← (4) A/D converter initialization
 - A/D converter channel setting
 - A/D converter mode setting
 - A/D sampling condition setting

← (5) A/D conversion
 interrupt permission

← (6) A/D conversion starts

Figure 7-6 Example of program code (main routine)

```

__interrupt void ADC_int(void)
{
    Program code to be added
    unsigned char AD_DATA;

    IO_ADCSH.bit.INT = 0;
    AD_DATA = IO_ADCRLH.DATA8;

    if(AD_DATA > 171){
        IO_PDR1.byte = 0x1F;
    }
    else if(AD_DATA > 142){
        IO_PDR1.byte = 0x1E;
    }
    else if(AD_DATA > 113){
        IO_PDR1.byte = 0x1C;
    }
    else if(AD_DATA > 87){
        IO_PDR1.byte = 0x18;
    }
    else if(AD_DATA > 66){
        IO_PDR1.byte = 0x10;
    }
    else {
        IO_PDR1.byte = 0x00;
    }
}

```

(7) Clearing interrupt factor

 (8) Obtain A/D converted value.

 (9) LED control based on AD value.

Figure 7-7 Example of program code (interrupt routine)

The ADC_int function is to be executed when an interrupt of the A/D converter is generated. It is generally required to register the interrupt routine on the vector table so that the ADC_int function is executed when an interrupt of the A/D converter is generated. In this sample project, however, it has already been registered, so it can be used without the registration.

In the above code, there are some expressions such as "IO_XXX.byte" or "IO_YYY.bit." These are the useful description formats, which are defined in the IO header file. For more information, see the Appendix.

8 “Let's use the temperature sensor.”

Most of the microcomputer application systems contain various sensors to detect the external information. There are various sensors for different purposes and requirements, and one of those various sensors is the temperature sensor. The temperature sensor is, as its name suggests, a sensor to detect changes in temperature. Examples of what the temperature sensor is used for include the temperature control features of air conditioners and refrigerators. In this way, various sensors are used for household appliances.

This Starter Kit contains the temperature sensor. This chapter describes how to detect temperature by using this temperature sensor.

8.1 What is a temperature sensor?

The temperature sensor is a sensor to detect temperature changes. Simply stated it is a thermometer to measure temperature. There are various methods to measure temperature. One of those methods uses a mercurial thermometer, and another one uses a radiation thermometer that enables contactless measurement. Table 8.1 **Temperature measuring method** shows the general methods for measuring temperature. Of course it depends on the purposes or requirements, however, most of the systems containing microcomputers use the thermocouple thermometer or thermistor. This Starter Kit also uses the thermistor as its temperature sensor.

Table 8.1 Temperature measuring method

Category	Method and its feature
Mercurial/alcohol thermometer	This method uses thermal expansion of mercury or alcohol to detect temperature. This method is used for many thermometers and clinical thermometers.
Thermocouple thermometer	This sensor uses the Seebeck effect. It contains the two-contact circuit using two different metals, and when there is a difference in temperature between two contact points, it generates thermal electromotive force. It can measure the wide-range temperature.
Thermistor	This sensor uses the resistance thermometer bulb that uses the temperature characteristic of semiconductor. It is in heavy usage.
Radiation thermometer	The infrared energy emitted by an object varies with temperature. The radiation thermometer uses this principle for measuring temperature. It enables contactless measurement.

The thermistor is the resistor using the temperature characteristic of semiconductor. The resistance value of the temperature sensor varies with temperature. This Starter Kit contains the TDK's NTC thermistor (NTCG164BH103) for its temperature sensor. NTC stands for Negative Temperature Coefficient, and this thermistor has negative characteristic of the resistance value, which is reduced as the temperature rises. This section describes the concrete method of detecting temperature by using this temperature sensor.

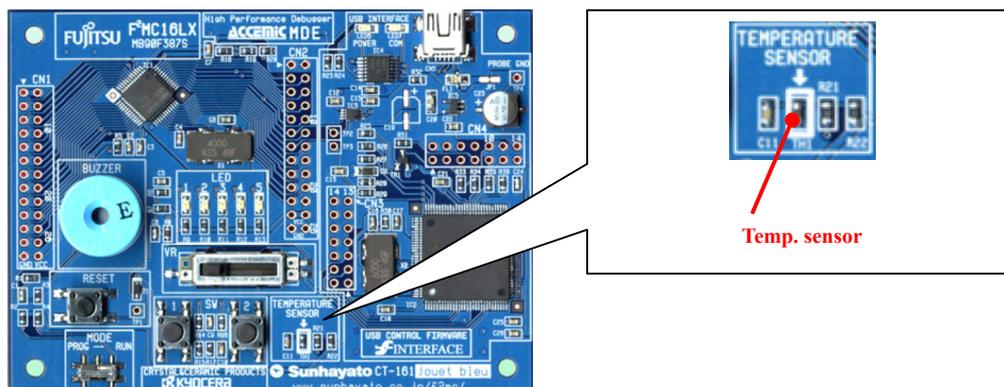


Figure 8-1 Temperature sensor (NTCG164BH103)

8.2 How to detect temperatures by using "temperature sensor"

To use the temperature sensor and detect temperature, it is necessary to understand the specifications of the sensor. The specifications of the sensor to be used (NTCG164BH103) can be confirmed on the sensor data sheet, which is issued from the manufacturer. The data sheet of the temperature sensor contains the information required for measurement. For this time, the relationship between the measured temperature and the state of the sensor (resistance value) is especially important. According to the data sheet, the relationship between the temperature from 5 to 50 °C and the resistances are shown in Table 8.2 **Relationship between measured temperature and resistance of NTCG164BH103.**

Table 8.2 Relationship between measured temperature and resistance of NTCG164BH103

Temperature[°C]	Resistance value[kΩ]	Temperature[°C]	Resistance value[kΩ]
5	26.250	30	7.997
10	20.390	35	6.437
15	15.960	40	5.213
20	12.590	45	4.248
25	10.000	50	3.481

Figure 8-2 Peripheral circuit diagram of "temperature sensor" (image)

shows the peripheral circuit diagram of the "temperature sensor" on the Starter Kit board. In this circuit, when the resistance of the "temperature sensor" changes, the input voltage of the A/D converter of the microcomputer also changes. Suppose the resistance of the "temperature sensor" is R_{TH} . Then, the input voltage of the A/D converter V_{AN1} can be calculated by using the following formula. (The necessary knowledge to calculate it is only Ohm's law.)

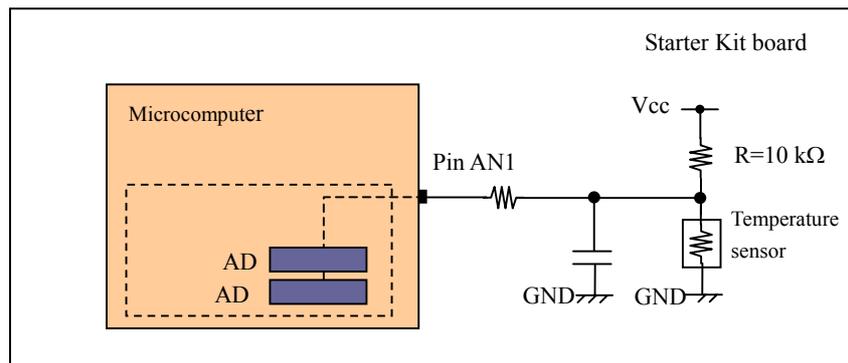


Figure 8-2 Peripheral circuit diagram of "temperature sensor" (image)

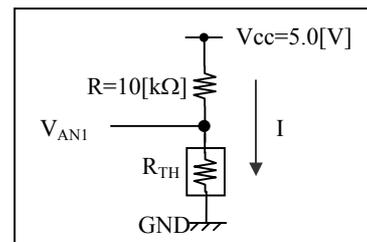
[Input voltage of the A/D converter]

According to the Ohm's law, the current in the circuit I is as shown below:

$$I = \frac{V_{CC}}{R + R_{TH}}$$

Therefore, V_{AN1} is

$$V_{AN1} = R_{TH} \times I = \frac{R_{TH} \times V_{CC}}{R + R_{TH}}$$



Because $R=10[k\Omega]$ and $V_{CC}=5.0[V]$,

the input voltage to the A/D converter $V_{AN1}[V]$ can be obtained by using the following formula.

$$V_{AN1} = \frac{5.0 \times R_{TH}}{10000 + R_{TH}}$$

Table 8.3 Relationship between the measured temperature of Starter Kit and A/D input voltage summarizes the relationship between the measured temperature from 5 to 50 °C and

the input voltage of the A/D converter. By measuring the input voltage of the A/D converter, the temperature can be known accordingly.

Table 8.3 Relationship between the measured temperature of Starter Kit and A/D input voltage

Temperature [°C]	A/D input voltage: V_{ANI} [V]	Temperature [°C]	A/D input voltage: V_{ANI} [V]
5	3.62	30	2.22
10	3.35	35	1.96
15	3.07	40	1.71
20	2.79	45	1.49
25	2.50	50	1.29

8.3 How to create and execute a program to display temperature

The following section explains how to create a program to detect temperature by using the sensor. For how to use the A/D converter, apply the contents of the previous chapter. For checking the detected temperature visually, the lighting of the AD input LED is controlled.

8.3.1 Outline of the program to be created

Let us now create the actual program. The contents of the program are to use the A/D converter to obtain the temperature information of the sensor, and to control the lighting of the LED (to change the lighting pattern) according to the obtained value. For processing related to the A/D converter, create the program based on the program of the volume control A/D converter that is created in the previous chapter. The main operation of the program is described below. The flow of the program is shown in Figure 8-3 Flow of the program

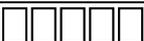
- (1) After the program is started, performs the initialization (such as initial settings of the A/D converter).
- (2) Starts A/D conversion (to obtain the sensor information using the A/D converter).
- (3) The A/D conversion is completed. (The A/D converted values are obtained.)
- (4) According to the obtained A/D converted values, controls the LED lighting.
- (5) Then, repeat (2) to (4).

In the flow of the main processing of the program, first set up the output pin of the LED and the input pin to be used for the A/D converter. The settings of the pins are explained in the previous chapter. Then, make the settings related to the A/D converter. The settings to be made are about the same as the previous chapter. The only difference is that the channel of the A/D converter to be used is set to "1" (Channel 0 is used in the previous chapter). The operation mode of the A/D converter is set to the continuous conversion mode that is also used in the previous chapter. The operation of the A/D converter is as follows accordingly.

A/D converter is activated (A/D conversion starts) ⇒ A/D conversion ends ⇒ A/D conversion starts - - -

When the A/D conversion ends, an interrupt of the A/D converter is generated, and an interrupt routine is called. In the interrupt routine, the interrupt factor is cleared, the A/D value is obtained, and the LEDs are lighted according to the obtained A/D value. The LED lighting processing is as shown in Table 8.4 LED lighting processing.

Table 8.4 LED lighting processing

Obtained A/D value	LED lighting	Remarks
0 to 65	 All LEDs are on.	50 °C or higher
66 to 86	 LEDs 1 to 4 are on.	40 °C or higher but lower than 50 °C
87 to 112	 LEDs 1 to 3 are on.	30 °C or higher but lower than 40 °C
113 to 141	 LEDs 1 to 2 are on.	20 °C or higher but lower than 30 °C
142 to 170	 LED 1 is on.	10 °C or higher but lower than 20 °C
171 to 255	 No LED is on.	Lower than 10 °C

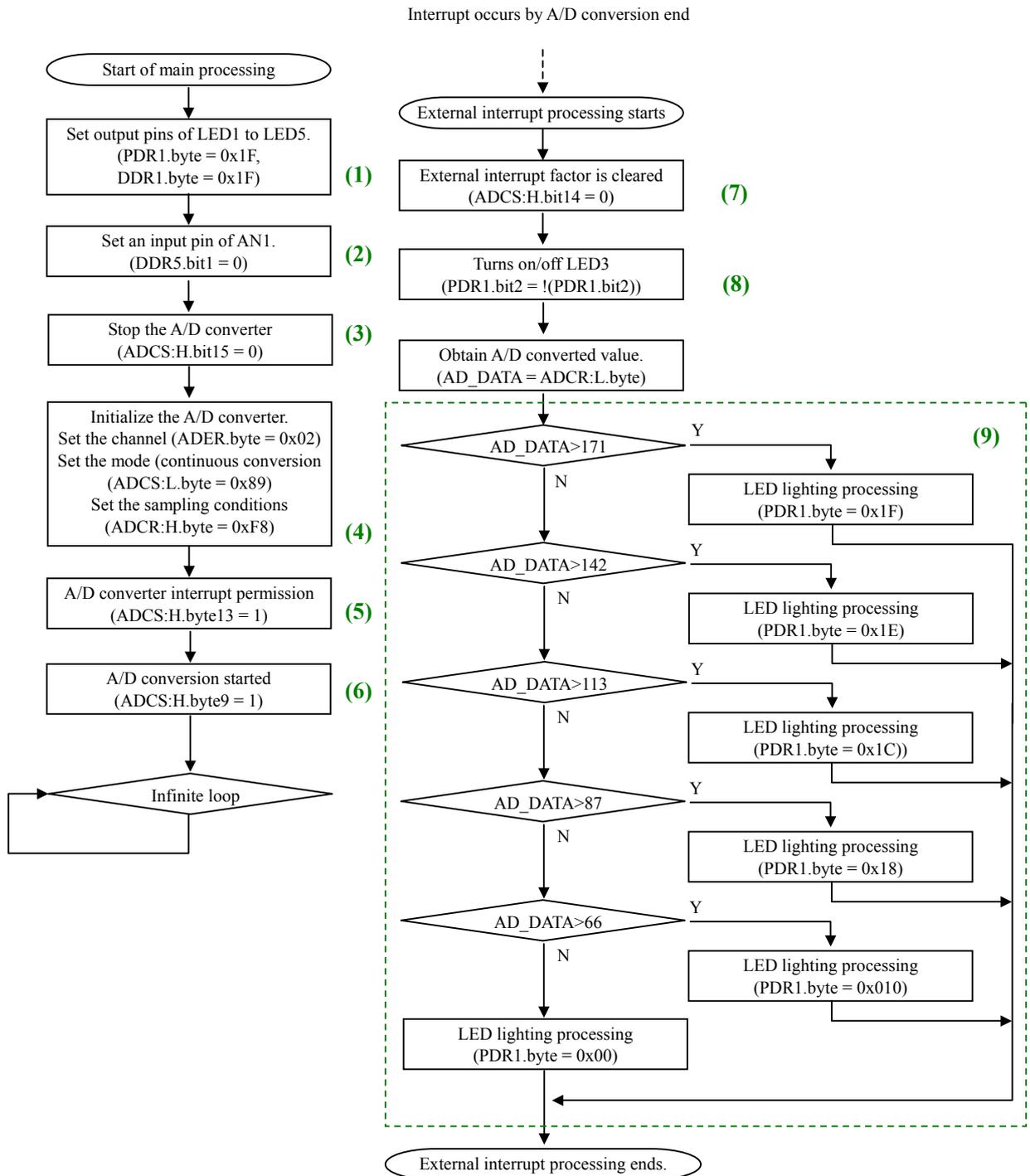


Figure 8-3 Flow of the program

8.3.2 Creation and execution of the program

Let us now create the actual program. According to the procedure described in Appendix A.1, open the source file "main.c" in "sample.prj," and input the program that is the circled part in Figure 8-4 **Example of program code (main routine)**

and Figure 8-5 **Example of program code (interrupt routine)**

Use all files except main.c without any changes. After the program is input, "build" the program according to the procedure described in Appendix A.2. If an error is output, reconfirm that the contents of the program are correct. When the "build" is successful, "ACCEMIC MDE" starts automatically.

When the "ACCEMIC MDE" window appears, execute the program and check the operation. For the procedure of the program execution, see Appendix A.3. When the program starts correctly, check the LEDs. When the temperature of the room where the operation is performed is between 10 and 20 °C, LED 1 and LED 2 are supposed to be on. The number of LEDs lighted varies with the temperature detected by the sensor. For example, warm up the sensor part using your fingers. When warming up the peripheral part of the sensor, be aware of the temperature. When it gets hot, it may damage the board.

```

void main(void)
{
    ----- Program code to be added -----
    __set_il(7);
    __EI();

    IO_PDR1.byte = 0x1F;
    IO_DDR1.byte = 0x1F;

    IO_DDR5.bit.D51 = 0;
    IO_ICR03.byte = 0x06;

    IO_ADCSH.bit.BUSY = 0;

    IO_ADER.byte = 0x02;
    IO_ADCSL.byte = 0x89;
    IO_ADCRLH.byte.ADCRH = 0xF8;

    IO_ADCSH.bit.INTE = 1;
    IO_ADCSH.bit.STRT = 1;

    while(1);
}

```

← (1) Port 1 (LED control) output setting

← (2) Port 5 (AD input) input setting

← (3) Stop A/D converter

← (4) A/D converter initialization
 - A/D converter channel setting
 - A/D converter mode setting
 - A/D sampling condition setting

← (5) A/D conversion
 interrupt permission

← (6) A/D conversion starts.

Figure 8-4 Example of program code (main routine)

```

__interrupt void ADC_int(void)
{
    Program code to be added
    unsigned char AD_DATA;

    IO_ADCSH.bit.INT = 0;
    AD_DATA = IO_ADCRLH.DATA8;

    if(AD_DATA > 171){
        IO_PDR1.byte = 0x1F;
    }
    else if(AD_DATA > 142){
        IO_PDR1.byte = 0x1E;
    }
    else if(AD_DATA > 113){
        IO_PDR1.byte = 0x1C;
    }
    else if(AD_DATA > 87){
        IO_PDR1.byte = 0x18;
    }
    else if(AD_DATA > 66){
        IO_PDR1.byte = 0x10;
    }
    else {
        IO_PDR1.byte = 0x00;
    }
}

```

(7) Clearing interrupt factor
 (8) Obtain A/D converted value
 (9) LED control based on AD value

Figure 8-5 Example of program code (interrupt routine)

The ADC_int function is to be executed when an interrupt of the A/D converter is generated. It is normally required to register the interrupt routine on the vector table so that the ADC_int function is executed when an interrupt of the A/D converter is generated. In this sample project, however, it has already been registered, so it can be used without registration.

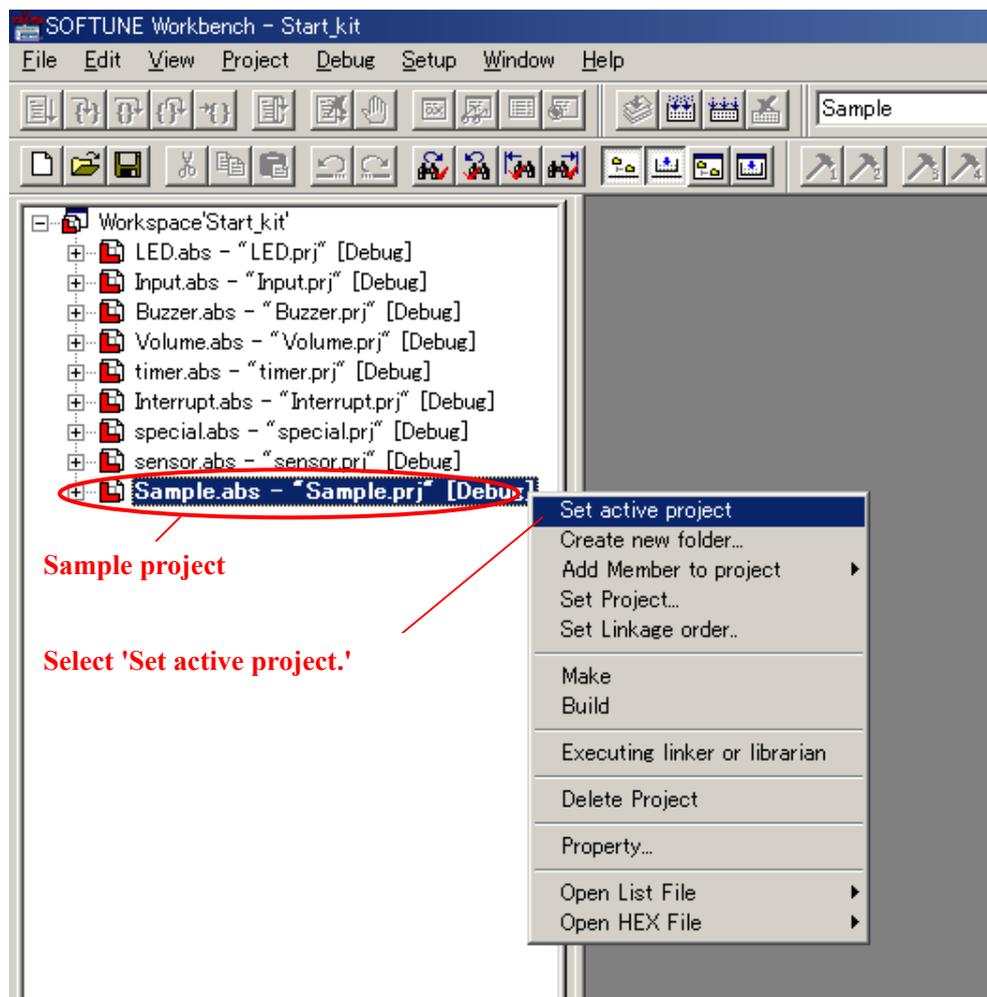
In the above code, there are expressions such as "IO_XXX.byte" or "IO_YYY.bit." These are the useful description formats, which are defined in the IO header file. For more information, see the Appendix.

A Appendix (Program Creation Procedure)

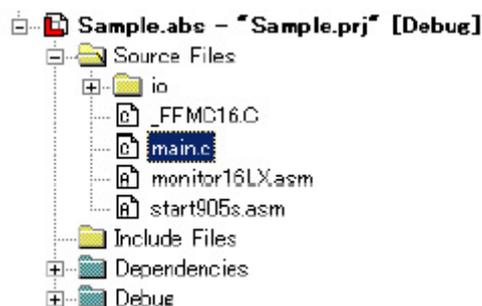
A.1 Program Creation Procedure

This appendix explains the procedure you should follow when creating an actual program. First, start up SOFTUNE as instructed in Item 1.1.5, "Starting and setting up of SOFTUNE," (pages 15 to 17), and open the Start_kit.wsp file. Use the sample project provided for easy creation of software.

To use the sample project, select "Sample.prj" in the list, right-click to open a submenu, and select 'Set active project' from the submenu. Then, the string including "Sample.prj" is displayed in boldface in the list, and debugging of the sample project is enabled.



Click on "Sample.prj" to show the list of folders below. Click on "main.c" under the Source Files folder to open the main.c file.



After the main.c file is opened, create your program in the section indicated by the red dotted line below.

```

#include "_ffmc16.h"
#include "extern.h"
// #include "monitor.h"

void main(void)
{
    
}

/* Vector Table */

#pragma section INTVECT,locate=0xffffc00

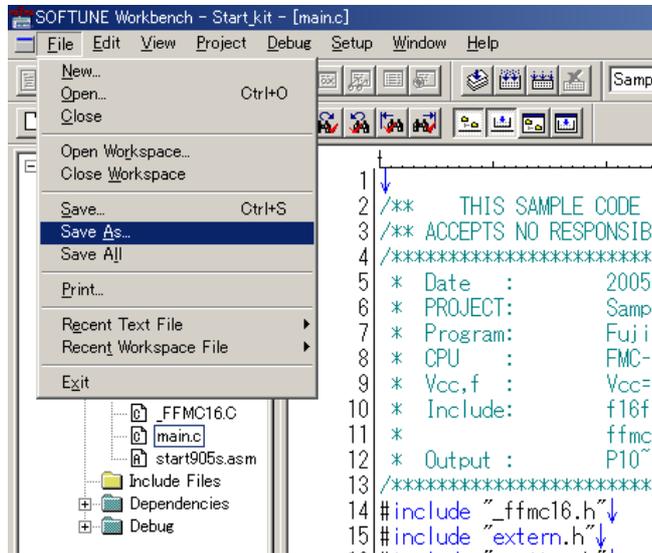
#pragma intvect _start          0x8  0x0    // Reset Vector
    
```

← Input the program to be created here.

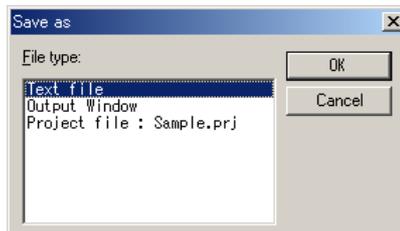
If another program has already been input to the main.c file, delete the lines from the above program list section enclosed by the red dotted line before creating your new program. If you need to save the already input program, perform the procedure below to save the program as a backup file before deleting the program.

<Program (source file) backup procedure>

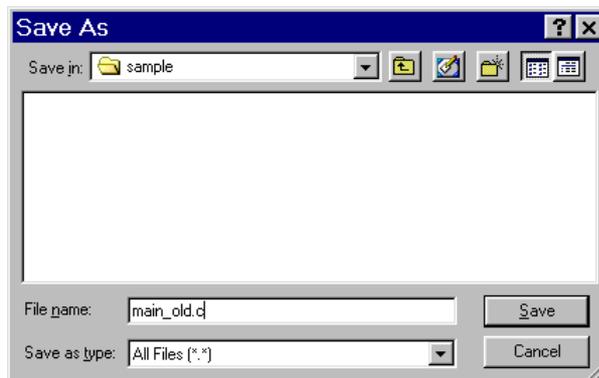
While editing a source file, select 'Save As...(A)' from the File menu.



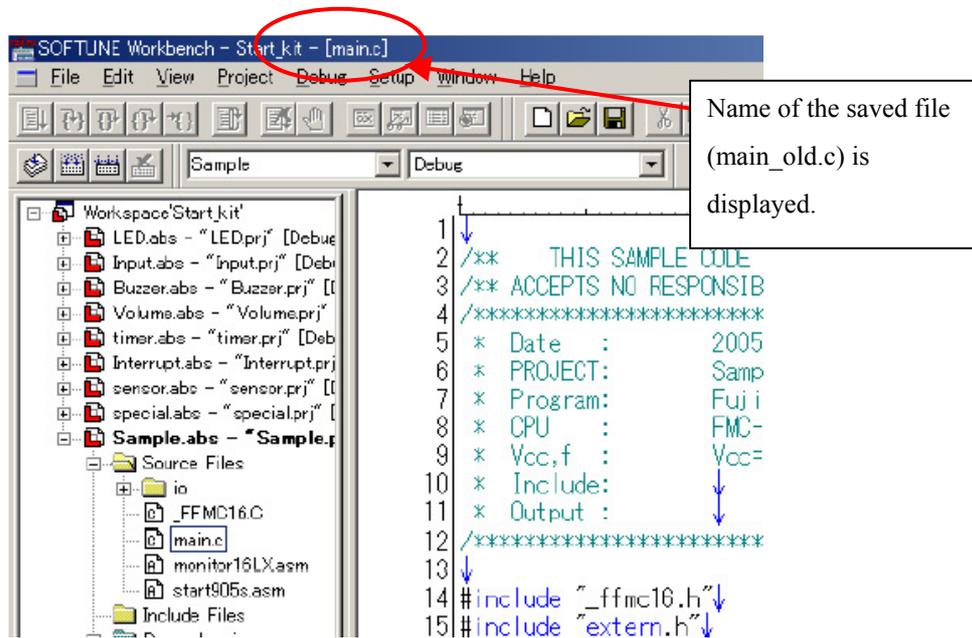
The dialog box below appears. Select Text file, and then click 'OK.'



Next, the dialog box below appears. Select the folder to save the program in the Save in field, specify the file name in the File name field, and then click 'Save.'



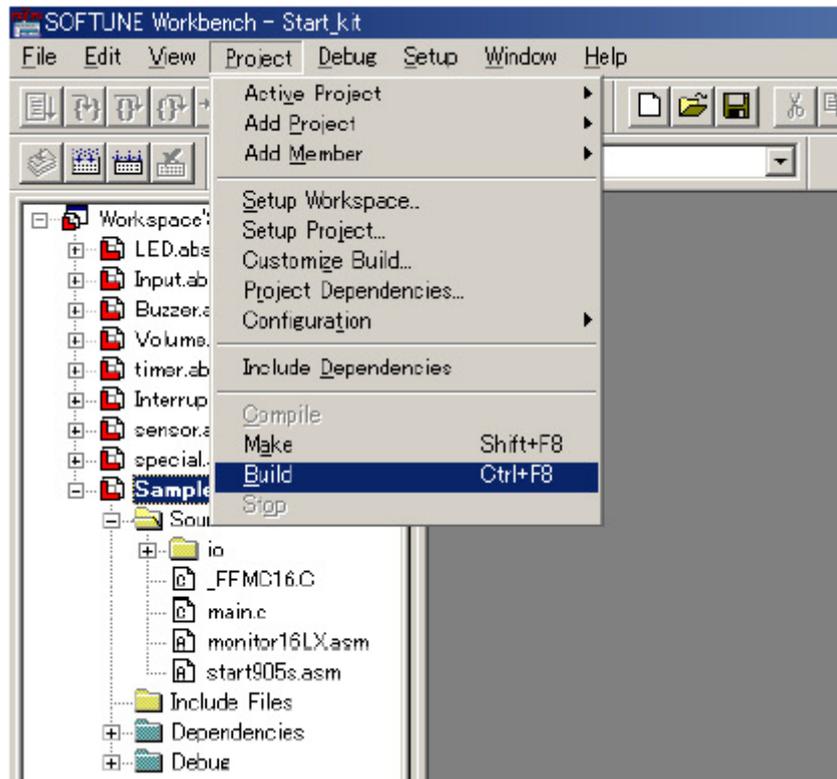
The saved file is still displayed. Close the displayed file.



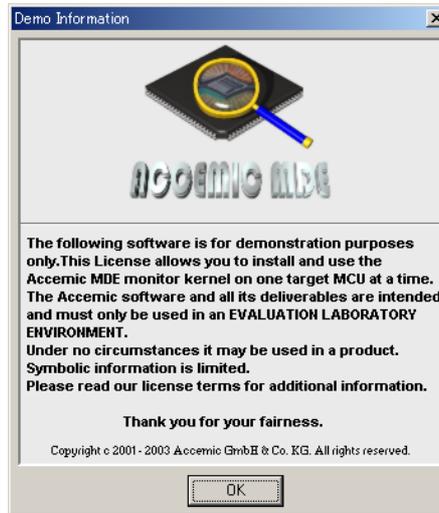
After closing the saved file, find the original file name of the saved file ("main_old.c in this example) in the Source Files folder under "Sample.prj" in the list, and then click on the original file name to open the file. In this status, you can edit the source file.

A.2 Program Building Procedure

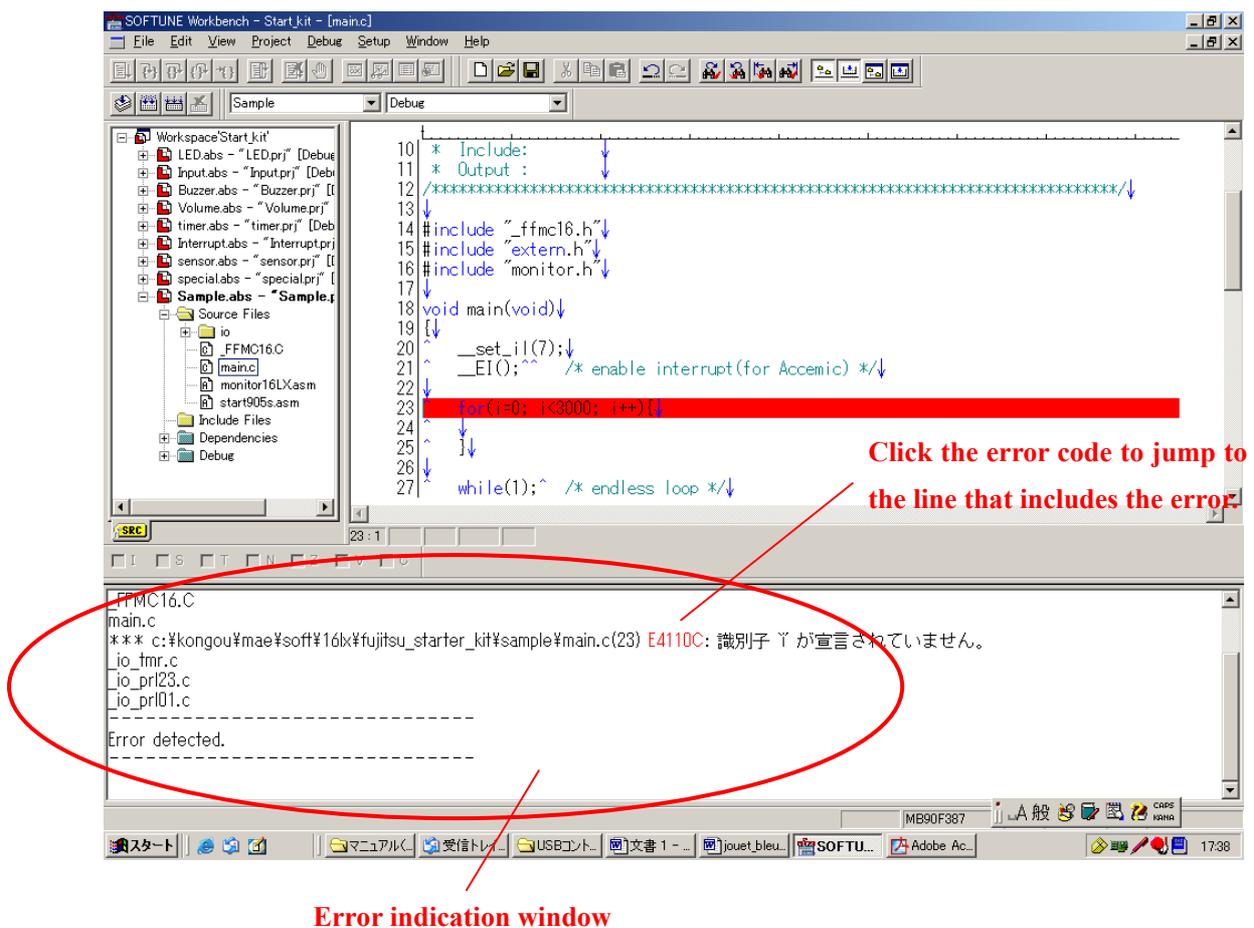
After creating a program, confirm that the board is connected to the personal computer by the USB cable, and then start the procedure to build the program.



If no error is found in the created program, ACCEMIC MDE starts automatically and displays the information shown below for 10 s. This information is displayed only by the trial version of ACCEMIC MDE (not displayed by the product version). An 'OK' button appears 10 s later. Click the OK button.

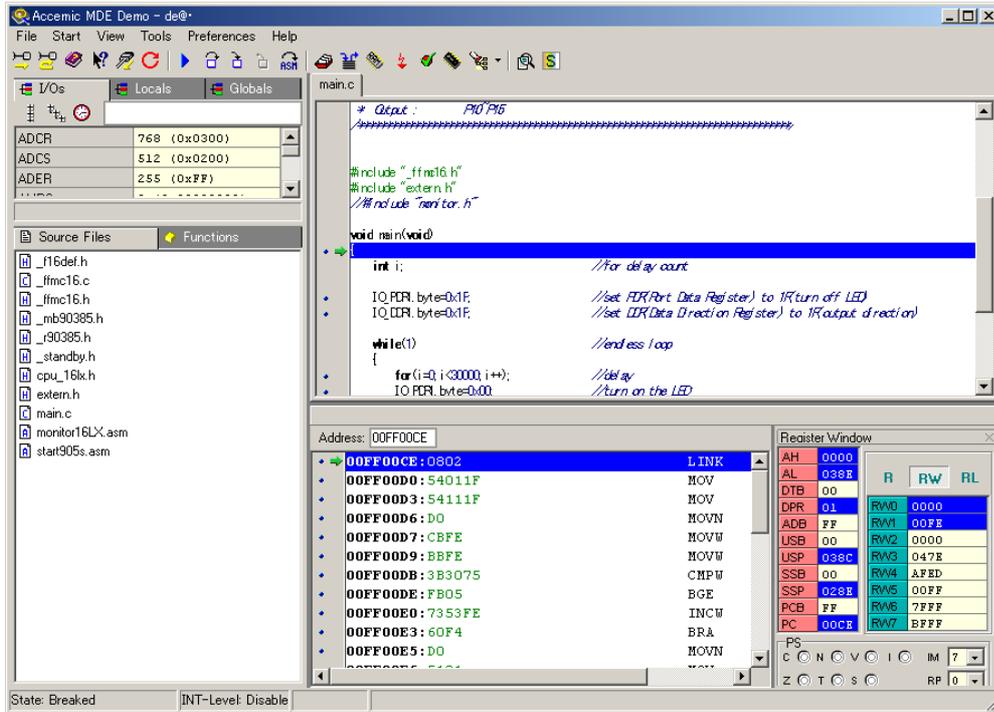


If an error is found in the created program, the error is indicated as shown below. Correct the indicated error, and perform 'building' again.



A.3 Program Execution Method

Execute the created program and check that it performs the intended operation. After ACCEMIC MDE has started, the window as shown below appears:



Use the buttons shown below to control the program.

Function	Button	Operation (when clicked)
Continuous execution		Starts and runs the program continuously.
Stop		Stops the running program.
Reset		Resets the microcomputer.

B Appendix (Method To Write/Read Values in Registers)

B.1 About the Method To Write/Read Values in Registers

The sample program codes presented in this document include such descriptions as "IO_XXX.byte" and "IO_YYY.bit". These are the convenient formats of description defined in the I-O header file. You can use these description formats after setting up Softune Workbench, the development environment provided by the Starter Kit.

An actual C-language program contains the descriptions of instructions to write values to various registers to specify microcomputer operation. The above description formats enable you to write values to registers in C language. For example, assume the instruction to write 0xff to the port 1 data register (PDR1), which is allocated at address 0x000001. The instruction is described in C language as follows:

```
*((volatile char *)0x000001) = 0xFF;
```

It is not immediately obvious what kind of processing the above description specifies. If you use one of the description formats defined in the I-O header file, you can write the same instruction as follows:

```
IO_PDR1.byte = 0xff;
```

You can use this description because the following operation is defined in a separate file:

Substituting a value for variable "IO_PDR1.byte" = Writing the value to PDR1 register at address 0x000001

It is now immediately clear that the description specifies the processing to write 0xff to the PDR1 register. The I-O header file contains the definitions of these description formats for the registers of the microcomputer built in the Starter Kit.

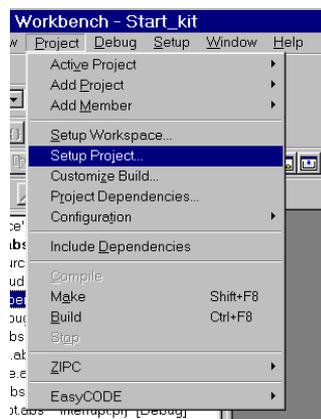
C Appendix (Method To Change the Include Path)

C.1 About the Method To Change the Include Path

A necessary include path is specified for each sample program.

A sample program requires the specified include path to reference sample I-O register files.

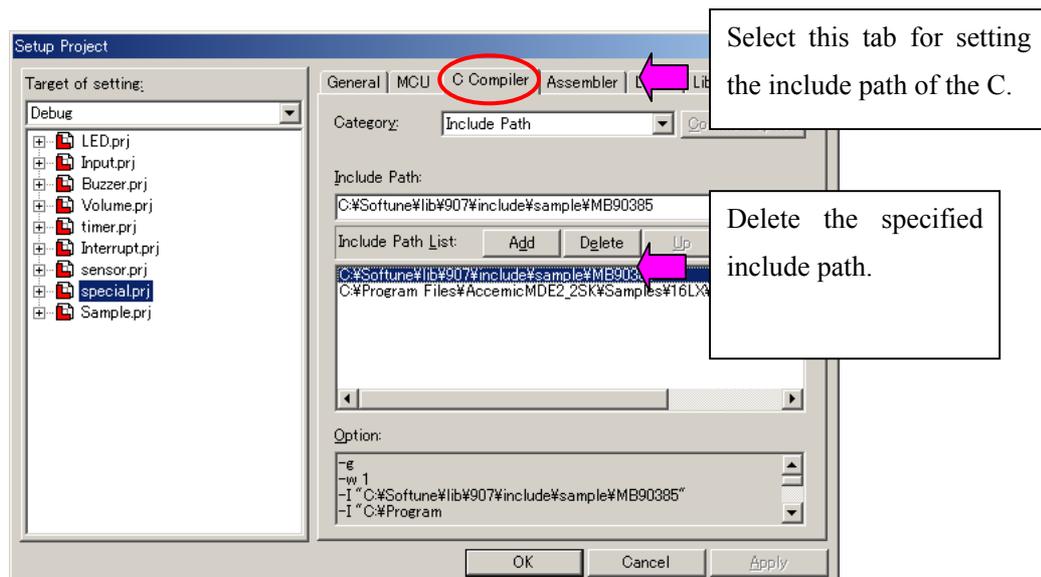
If the installation folder of SOFTUNE or ACCEMIC MDE is changed, change the include path settings of the C compiler and the assembler before using the sample program.

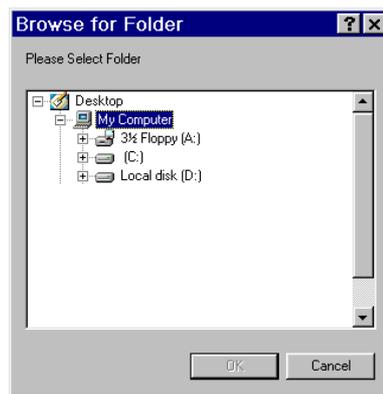
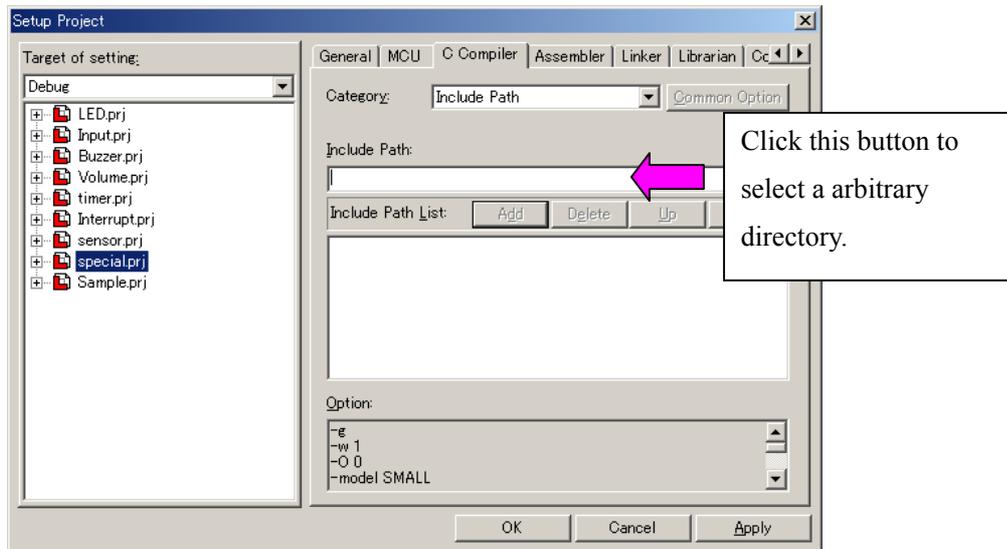


Select "Project setting(J)" under "Project(P)."

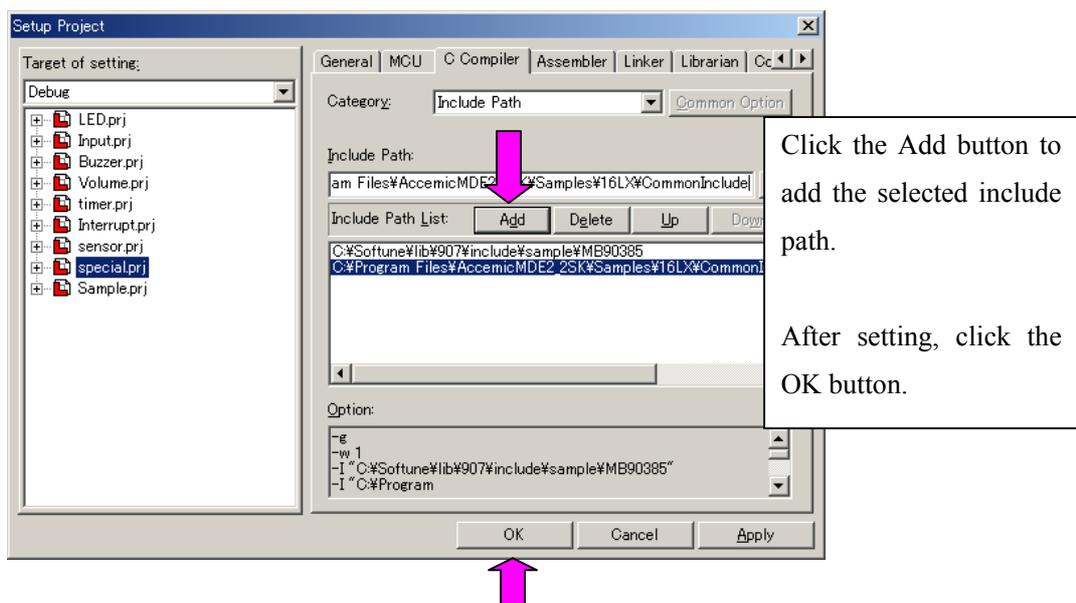
Change the include path settings of the C compiler and the assembler as shown below.

The following window shows the include path setting of the C compiler.





Select a folder.



Use the same procedure for setting the include path of the assembler.

