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HEW

Embedded C Programming II (ECProgramII)

Introduction

In this second part of the application note, it will emphasize on “how-to”. Examples on access of peripherals and external memory are provided to give programmers another perspective of programming in embedded environment.

The examples used will be based on High-performance Embedded Workshop (HEW) Version 2 (SLP/TINY C Compiler version 5.0), and H8 SLP & H8/300H are used as the targets for explanation. However this explained fundamental concept would be applicable to other compilers and MCU series.

Target

All

Contents

1. Recapitulate of Part 1

The topics covered in “Embedded C Programming I” are:

- Generated C files and sections of HEW.
- Effect of C initialization on each variable characteristics and storage areas
- Utilization of Stack and Heap.
- Usage of preprocessor directives (Macro, conditional compilation and etc).
- Usage of Extended functions (Pragma, intrinsic functions and etc).
- Usage of available library.
- Effect of a function call on the stack and registers.
- Management of section by HEW.
- Comparison of similar operation.
- Information on flow of project compilation, linking and debugging.
- Suggested programming techniques.

In this second part of Embedded C programming, the emphasis is on how to control the embedded microcontroller unit (MCU), to access peripherals, ports and external memory.

2. Access of Peripherals and Ports

A microcontroller unit (MCU) contains the main processor core and other different peripherals to fulfill an application needs. Thus the characteristics of each peripheral may not be similar in different MCU.

- Timer
  - 8-bit, 16-bit, external trigger…
- Serial port
  - Asynchronous, Synchronous, I^2C, SPI conformance…
- PWM
  - 8-bit, 10-bit, number of channels…
- Port
  - High current, bi-directional, with pull-up enable, …
- ADC
  - 10-bit, interrupt trigger, multiplex channels…

2.1 General Peripheral Setting

The detailed setting of each peripheral is beyond the scope of discussion. However, the basic accessing method using C program will be highlighted in this document.

Generally the setting for each peripheral is straightforward. Each peripheral detail can be referred to in each respective section of the hardware manual. General highlight of precautious are:

1. Some peripherals may be sharing the same pin-out of the MCU. Thus user must make their decision based on the hardware schematic and MCU characteristic.
2. Some peripherals may not be operational under certain operating mode of the MCU.
3. Each peripheral may have a few controlling registers. Do not miss any of them.
4. Some registers may be responsible for few peripherals. Thus when accessing one register, programmers must be careful not to affect operation of other peripherals.

NOTE: All related registers will be explained in each peripheral section of the hardware manual. The same register will be mentioned again in another related peripheral section.

5. Programmers must follow the manual's suggested procedures of initialization or access.
6. Programmers must understand their target hardware operation, and access the peripherals accordingly.
   i. It may be necessary to set the port data register before setting the direction register. If otherwise, the default output (High) may cause fault triggering.
   ii. It may be necessary to access the port data register in byte form instead of bit. If otherwise the control or monitoring events may not be synchronized.
7. Programmers should read up any Technical Update or revised items of User manual, to obtain the latest information.

2.2 Example

The following example is illustrated to highlight the extra care that is required for embedded programming:

Example:

Table 1 Intruder Alarm Operation Description

Project :	An Intruder Alarm
Description :	When there is an intrusion (Port 3_0 detected low), - A message will be sent out through the serial port. - An Alarm/LED will be set and The alarm/LED can be cleared via a switch.

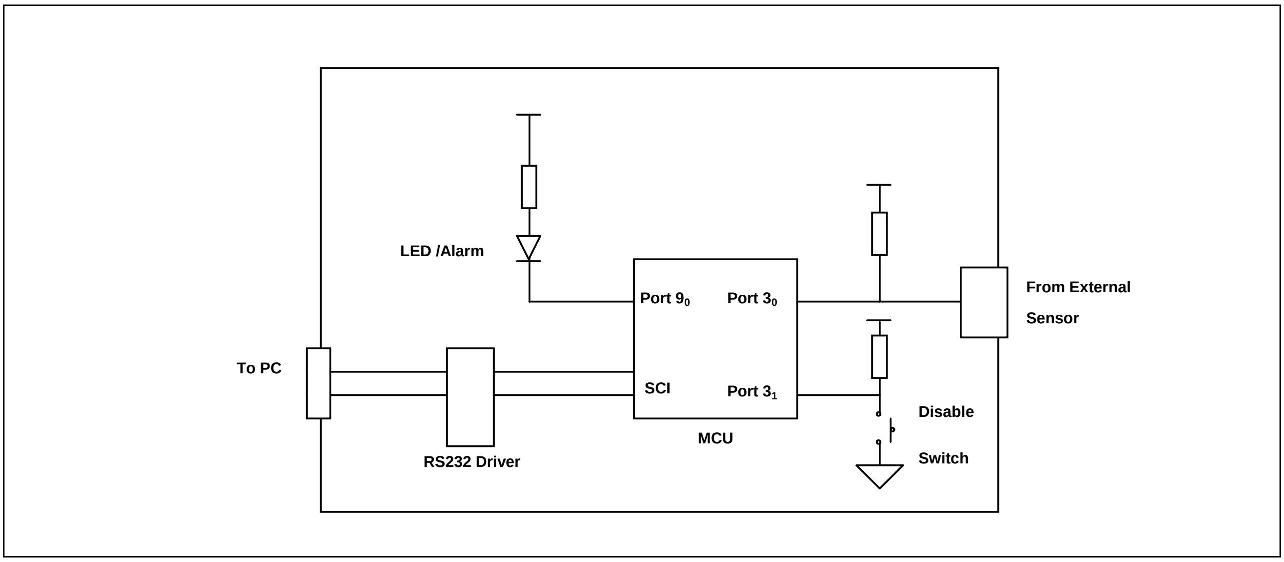


Figure 1 Block Diagram of an intruder alarm

Table 2 Port Usage of intruder alarm

Peripherals	Condition	Function
Port 3_0	Input	Intrusion detection
Port 3_1	Input	Disable switch
Port 9_0	Output	Alarm/LED
Serial Port 1	Asyn 9600 bps, 1 start, 8 data, 1 stop, No parity	Communicate Channel

- Port 9 is used for driving LED as it has a large current drive (25mA) for the LED. If another port is used, a transistor driver will be needed.
- The example uses SLP H8/38024 as the controller. By invoking HEW project generation, the basic code structure, which consists of all peripherals and ports definition, will be generated.

- HEW will generate
  - o Reset routine.c
  - o main() project.c
  - o iodefine.h

Please refer the detail of HEW code generation in Application Note: "HEW Code Generation" or HEW user's manual

- In this example, only the main project C file will be modified.

2.2.1 Port and Peripheral Definition File

- The following is extracted from the iodefine.h.

```
struct st_io {                          /* struct I/O   */
…
…
  union {                               /* PDR3           */
        unsigned char BYTE;             /*  Byte Access   */
        struct {                        /*  Bit Access    */
             unsigned char P37:1;       /*   P37          */
             unsigned char P36:1;       /*   P36          */
             unsigned char P35:1;       /*   P35          */
             unsigned char P34:1;       /*   P34          */
             unsigned char P33:1;       /*   P33          */
             unsigned char P32:1;       /*   P32          */
             unsigned char P31:1;       /*   P31          */
             unsigned char P30:1;       /*   P30          */
             } BIT;                     /*                */
        } PDR3;                         /*                */
…
…
     union {                            /* PDR9           */
        unsigned char BYTE;             /*  Byte Access   */
        struct {                        /*  Bit Access    */
             unsigned char :2;          /*                */
             unsigned char P95:1;       /*   P95          */
             unsigned char P94:1;       /*   P94          */
             unsigned char P93:1;       /*   P93          */
             unsigned char P92:1;       /*   P92          */
             unsigned char P91:1;       /*   P91          */
             unsigned char P90:1;       /*   P90          */
             } BIT;                     /*                */
        } PDR9;                          /*               */
…
…
     union {                            /* PCR3           */
        unsigned char BYTE;             /*  Byte Access   */
        struct {                        /*  Bit Access    */
             unsigned char PCR37:1;     /*   PCR37        */
             unsigned char PCR36:1;     /*   PCR36        */
             unsigned char PCR35:1;     /*   PCR35        */
             unsigned char PCR34:1;     /*   PCR34        */
             unsigned char PCR33:1;     /*   PCR33        */
             unsigned char PCR32:1;     /*   PCR32        */
             unsigned char PCR31:1;     /*   PCR31        */
             unsigned char PCR30:1;     /*   PCR30        */
             } BIT;                     /*                */
        } PCR3;                         /*                */
```

```
…
…
    union {                                  /* PMR9          */
        unsigned char BYTE;                  /*  Byte Access  */
        struct {                             /*  Bit Access   */
            unsigned char :4;                /*               */
            unsigned char PIOFF:1;           /*   PIOFF       */
            unsigned char :1;                /*               */
            unsigned char PWM2:1;            /*   PWM2        */
            unsigned char PWM1:1;            /*   PWM1        */
            } BIT;                           /*               */
        } PMR9;                              /*               */
…
…
};                                           /*               */
…
…
#define P_SCI3 (*(volatile struct st_sci3 *)0x0000FF91)     /* SCI3 Address    */
#define P_IO (*(volatile struct st_io *)0x0000FFC8)         /* I/O Address     */
…
…
```

Observation

- The structure/union declaration is based on the information provided in the MCU hardware user manual (Refer to Figure 1)
- The “volatile “ keyword is used in the declaration for all the peripherals and ports.
- The structure/union declaration will enable the use of “bit manipulation” assembly instruction.

2.2.2 Initialization of Port

- It is essential to initialize the hardware peripherals at power up state.
  - This routine can be called either in the reset routine (if it is critical to setup the peripherals early), or main routine. HEW will generate a Hardware_Setup() function if this feature is enabled in the project generation.
- In this example, a init_io() routine is written to:
  - Initialize the Port 3 and 9.

Table 3 Port Register

Name	Abbr.	R/W	Initial Value	Address
Port Data Register 9	PDR9	R/W	H' FF	H' FFDC
Port Mode Register 9	PMR9	R/W	-	H' FFEC

```
void init_io(void)
{
        // Setting for General Application

        P_IO.PCR3.BYTE = 0x00;          //P37..P31 : inputs
        P_IO.PUCR3.BYTE = 0x00;         //Turn off the MOS pull-up

        //PMR3 : |AEVL|AEVH|---|---|---|TMOFH|TMOFL|---|
        //AEVL = 0 : P37 as I/O
        //AEVH = 0 : P36 as I/O
        //TMOFH = 0: P32 as I/O
        //TMOFL = 0: P31 as I/O

        P_IO.PMR3.BYTE = 0x00;

        //PMR9 : |---|---|---|---|PIOFF|---|PWM2|PWM1|
        //PIOFF = 0 : large-current port step-up circuit is turned on
        //PWM1 = PWM2 = 0 : P90 and P91 functions as P_IO output pin

        P_IO.PMR9.BYTE = 0xF0;

        set_imask_ccr(0);
}
```

2.2.3 Initialization of Serial Port

The init_sci() routine is to initialize the Serial port. This routine can be integrated with the init_io() routine.

This function set the serial port to operate at Asynchronous mode at 9600 baud rate.

The following are the relevant registers for serial port initialization.

Table 4 Serial Port Register

Name	Abbr.	R/W	Initial Value	Address
Serial Mode Register	SMR	R/W	H' 00	H' FFA8
Bit Rate Register	BRR	R/W	H' FF	H' FFA9
Serial Control Register	SCR3	R/W	H' 00	H' FFAA
Transmit Data Register	TDR	R/W	H' FF	H' FFAB
Serial Status Register	SSR	R/W	H' 84	H' FFAC
Receive Data Register	RDR	R	H' 00	H' FFAD
Transmit Shift Register	TSR	Protected	-	-
Receive Shift Register	RSR	Protected	-	-
Bit Rate Counter	BRC	Protected	-	-
Clock Stop Register 1	CKSTPR1	R/W	H' FF	H' FFFA
Serial Port Control Register	SPCR	R/W	H' FF	H' FF91

```
void init_sci(void)
{

        //SCR3 : |TIE|RIE|TE|RE|MPIE|TEIE|CKE1|CKE0|
        //TIE : Transmit interrupt enable
        //RIE : Receive interrupt enable
        //TE  : Transmit enable
        //RE  : Receive enable
        //MPIE : Multiprocessor interrupt enable
        //TEIE : Transmit end interrupt enable
        //CKE1 = CKE0 = 0
        //asynchronous mode, internal clock source, SCK32 functions as I/O port

        P_SCI3.SCR3.BYTE = 0x30;

        //SMR : |COM|CHR|PE|PM|STOP|MP|CKS1|CKS0| : |0|0|0|0|0|0|0|0|
        //COM : Communication Mode  : 0 : asynchronous mode
        //CHR : Character Length    : 0 : character length = 8 bits
        //PE  : Parity Enable       : 0 : parity bit addition and checking disabled
        //PM  : Parity Mode         : 0 : even parity (no effect since parity is already disabled)
        //STOP: Stop Bit Length     : 0 : 1 stop bit
        //MP  : Multiprocessor Mode : 0 : multiprocessor communication function disabled
        //|CKS1|CKS0| : Clock Select: |0|0| : clock source for baud rate generator = clk

        P_SCI3.SMR.BYTE = 0x00;

        // Startup default to 9600bps
        // n = 0
        // N = 25
        // for OSC = 16 MHz

        P_SCI3.BRR = 25;
```

```
        //SPCR : |---|---|SPC32|---|SCINV3|SCINV2|---|---| : |1|1|1|0|0|0|0|0|
        //SPC32 = 1 : P42 functions as TXD32 output pin
        //need to set TE bit in SCR3 after setting this bit to 1
        //SCINV3 = 0 : TXD32 output data is not inverted
        //SCINV2= 0 : RXD32 input data is not inverted
        //Bits 7 and 6 are reserved and always read as 1
        //Bits 4, 1 and 0 are reserved and only 0 can be written to these bits

        P_SCI3.SPCR.BYTE = 0xE0;

        //SSR  : |TDRE|RDRF|OER|FER|PER|TEND|MPBR|MPBT|
        //TDRE : transmit data register empty
        //RDRF : receive data register full
        //OER  : overrun error
        //FER  : framing error
        //PER  : parity error
        //TEND : transmit end
        //MPBR : Multiprocessor bit receive
        //MPBT : Multiprocessor bit transfer

        P_SCI3.SSR.BYTE = 0x84;          //Initialise upon reset to 0x84
}
```

In this peripheral initialization, calculation of the parameter is required.

- N for BRR is calculated based on :

$$N = \frac{OSC}{(64 \times 2^{2n} \times B)} - 1$$

Where
B: Bit rate (bit/s)
N: Baud rate generator BRR setting ($0 \le N \le 255$)
OSC: Value of $\varnothing_{OSC}$ (Hz)
n: Baud rate generator input clock number (n= 0, 2 or 3)

Table 5 SCI setting for N and n

	OSC					
	10 MHz			16 MHz		
Bit Rate (bit/s)	**n**	**N**	**Error %**	**n**	**N**	**Error %**
110	2	88	-0.25	2	141	-.02
150	2	64	0.16	2	103	0.16
200	2	48	-0.35	2	77	0.16
250	2	38	0.16	2	64	-0.79
300	-	-	-	2	51	0.16
600	-	-	-	2	25	0.16
1200	0	129	0.16	0	207	0.16
2400	0	64	0.16	0	103	0.16
4800	-	-	-	0	51	0.16
9600	-	-	-	0	25	0.16
19200	-	-	-	0	12	0.16
31250	0	4	0	0	7	0

2.2.4 Main Routine

The main routine is executed after the reset routine. The input/output port and serial port are initialized before the infinite loop is entered. The program will check for intruder (Port 3_0) and switch (Port 3_1). Once condition is met, the respective action will be executed.

<machine.h> is included, as the intrinsic function (set_imask_ccr()) is used.

```
#include "iodefine.h"
#include <machine.h>

void send_message(void);
void sci_charput(char OutputChar);
void init_sci(void);
void init_io(void);
void abort(void);

void main(void)
{
        unsigned int delay;

        init_io();
        init_sci();

        P_IO.PDR9.BYTE = 0xFF;                  //Turn-off All LED

        while(1)
        {
                if(!P_IO.PDR3.BIT.P30)          //detected intrusion
                {       P_IO.PDR9.BIT.P92 = 0;  //Turn-on alarm/LED
                        send_message();         //call for help through serial port
                }

                if(!P_IO.PDR3.BIT.P31)          //clear alarm
                        P_IO.PDR9.BIT.P92 = 1;  //Turn-off alarm/LED

        }
}
```

2.2.5 Send Message

The following two routines are to send message in the form of "character", to the external world via the serial port

```
void send_message(void)
{
        sci_charput('H');
        sci_charput('E');
        sci_charput('L');
        sci_charput('P');
        sci_charput(' ');
}
```

```
void sci_charput(char OutputChar)      //Serial Port
{
        while ((P_SCI3.SSR.BIT.TDRE) == 0);
        P_SCI3.TDR = OutputChar;
        P_SCI3.SSR.BIT.TDRE = 0;
}
```

The routine checks for the ready flag before it sends the variable "OutputChar" to the serial buffer.

2.2.6 Summary & Improvement

The program does not have many tasks. Therefore the polling method to check for the intruder and switch may not cause many resources wastage. If too many tasks are executing, it may be wise to use interrupt to signify an intruder access. The sending of message through the polling method is also taking up much CPU time. (The serial port is operating at 9600bps). The interrupt method may be more efficient. In this example, the bouncing effect of the switch is ignored. The debouncing can be improved using software mean by performing a double check.

3. Access of External Memory

For lower-end MCUs, such as the SLP, which have no external bus interface, usage of serial interface protocol to access external memory will be preferred as this uses lesser pin count. The common memory used is I^2C or SPI E^2PROM. If such interface peripheral is not available, programmer will need to write the algorithm based on the interface and memory specification.

Please refer to Application Note on "Interfacing to EEPROM with I2C Emulation"

For higher-end MCUs, such as the H8/300H, which is catered to support external memory, programmers will have to make several settings in order to make this external memory work seamlessly with the main system coding.

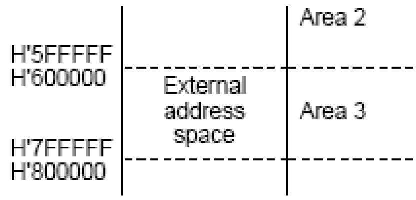


Figure 2 Area 3 Mapping

For the access of external memory, other than the physical hardware consideration, the following settings are to be considered when accessing external memory.

(Physical hardware interface consideration is not discussed in this document)

1. Section declaration
2. Bus State Controller (BSC)

- Must be initialized before the memory can be used.
- The following are the key points to note when memory connection is concerned
    - i. Wait states
    - ii. Bus width
    - iii. Area
    - iv. Refresh cycle (For DRAM)

3. Access Method

3.1 Example

The following example illustrates the settings required to access the external memory:

Example:

Table 6 Area 3 Interface Information

Memory	ROM
Area	Area 3 of H8/3048 in advanced mode H'60 0000 - H'7F FFFF

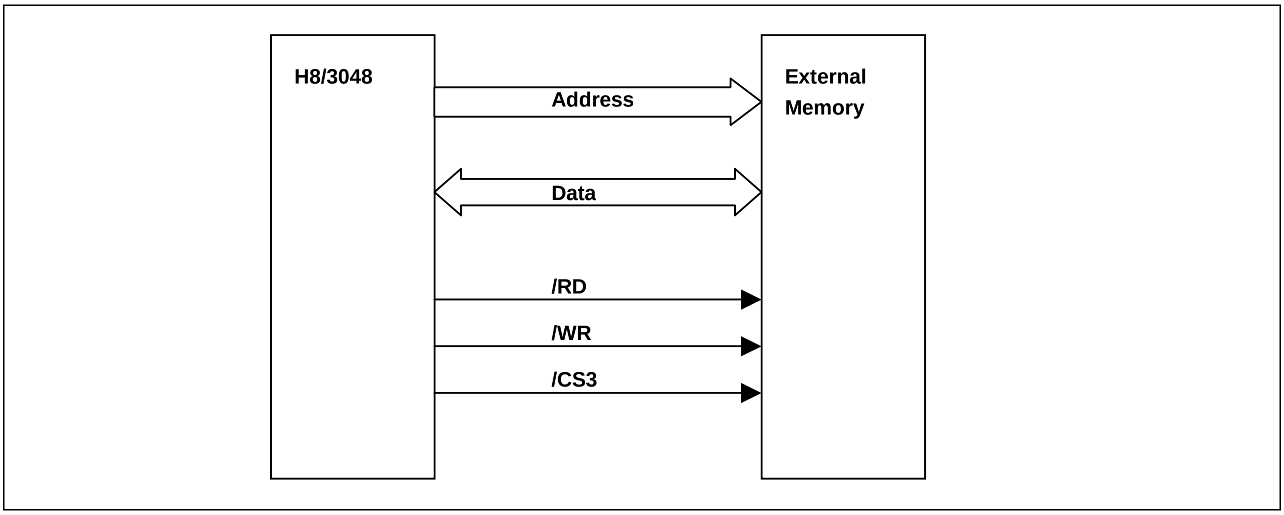


Figure 3 MCU Interface to ROM

3.1.1 Section Declaration

The objective of setting the section is to notify the compiler that the relevant code and data are to be stored in a specific area. In this case, the external memory is located at area 3.

Assuming that the external memory is a ROM, and a program section and a constant section are to be stored.

There are two steps to achieve this:

1. In the project file:

Declare the section

```
#pragma section extmem
const char ExtData[] = "hello";
int total(int a, int b)
{
        return (a+b);
}
#pragma section
```

In this case, Data "ExtData" and Function "total" are declared within the section "extmem".

The Linker will look for **C**extmem(Constant) and **P**extmem(Program) section declarations.

NOTE: if other variables are declared, the linker will look for the respective sections.

2. In HEW section setting

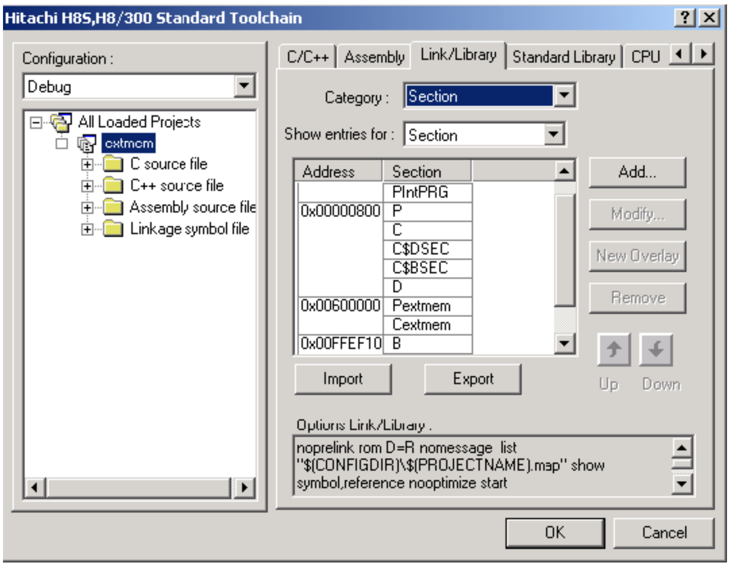


Figure 4 HEW Section Setting

The section can be declared in the [Section] Category of the Link/Library tab.

- Place the cursor at the [Address] Column and Click on [Add…] button.
    - Key in the Address: H'60 0000
- Place the cursor at the [Section] Column and Click on [Add…] button.
    - Key in the section name: Pextmem
- Place the cursor at the [Section] Column and Click on [Add…] button.
    - Key in the section name: Cextmem

The above steps will ensure that the compiled program will be located in the designated area.

To verify the output, the map file can be generated. ([List] Category of the Link/Library tab)

P	00000800	000008e1	e2	2
C$DSEC	000008e2	000008ed	c	2
C$BSEC	000008ee	000008f5	8	2
D	000008f6	000008f9	4	2
Pextmem	**00600000**	**00600003**	4	2
Cextmem	**00600004**	**00600009**	6	2
B	00ffef10	00fff32f	420	2
R	00fff330	00fff333	4	2
S	00fffd00	00fffeff	200	2

Figure 5 HEW Generated Map File

3.1.2 Bus State Controller (BSC)

Both the hardware and linker must be set correctly. However, the access to the external memory may not be successful unless the bus state controller is properly initialized.

The following are the key points to note when memory connection is concerned:

i. Wait states (1-5 Software wait states or hardware wait state)

ii. Bus width (8 or 16 bit depending on operating mode, access area, & setting)

iii. Area

iv. Refresh cycle (For DRAM)

These settings must match the hardware wiring and memory characteristic.

3.1.3 Code & Data Access Method

The current example has shown one example of external memory accessed.

The "extmem" section contain ROM based data and code. Thus users have to split their final compiled project into two parts in order to program into the MCU & external ROM:

a. H8/3048 internal ROM

b. External ROM.

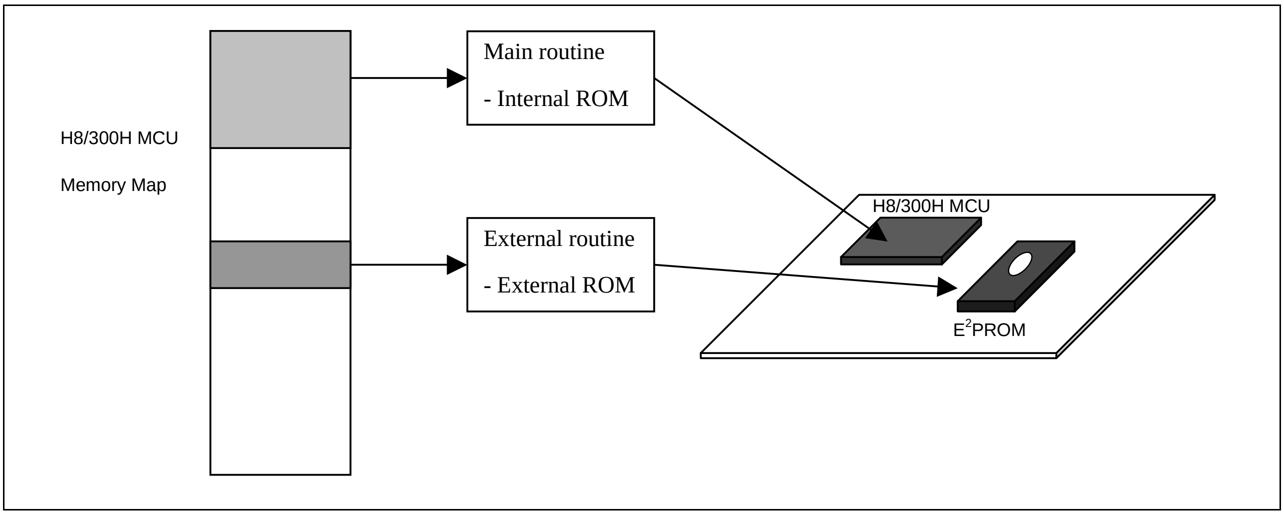


Figure 6 Illustration of Mapping & Physical device

The other possible scenarios are:

1. Needs to access Data in external memory area
   a. This can be a external ASIC containing data
2. MCU will copy the compiled code from one area to another area for faster execution
   a. EEPROM to DRAM
   b. Internal ROM to Internal RAM

3.1.3.1 Access External Data

By making a pointer to the external address space:

```
#define EXT_DATA        (*(unsigned long *)0x0600000)      /* Area 3 Address  */
#define EXT_DATA_PTR    ((unsigned long *)0x0600000)       /* Area 3 Address  */
```

Programmer can read or write the external memory seamlessly.

```
Read_data = EXT_DATA;
Read_data = *(EXT_DATA_PTR++);
```

3.1.3.2 Copy Memory from Section to Section

The following provides an alternative method to copy code/data from one area to another.

These may be done for:

- Faster execution in an area (copy from E2PROM to DRAM)
- Flashing purposes (copy from flash to internal RAM)

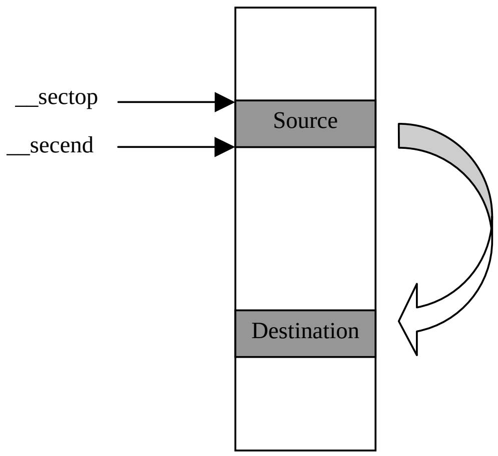
```
//Copy contents from section "Source" to section "Destination"


char *S_TOP;
char *S_END;
char *D_TOP;

void copy_section(void)
{
        char *p, *q;

        S_TOP = (char *)__sectop ("Source");
        S_END = (char *)__secend("Source");
        D_TOP = (char *)__sectop("Destination");

        for( p=S_TOP, q=D_TOP ; p<S_END ; p++, q++ )
                *q= *p;
}
```



To enable easy debugging, programmers may like to use the overlay feature that is available in HEW.

3.1.3.3 Execution of External Function

The following are examples of external function calling methods.

i. Function pointer with no passing parameter.

```
typedef   void                 (*extFnPtr)(void);

#define   EXT_ADDR_PTR         0x0600000
#define   EXT_FN_PTR_ADDR      (unsigned long *)(EXT_ADDR_PTR)

static    const extFnPtr       Ext_Fn = (extFnPtr)(EXT_FN_PTR_ADDR)

…
(*Ext_Fn)();      // Call the external function, which is located in the external memory (0x06000000)
…
```

ii. Function pointer with passing parameters.

```
typedef   void                 (*extFnPtr)(char *, char);

#define   EXT_ADDR_PTR         0x0600000
#define   EXT_FN_PTR_ADDR      *(unsigned long *)(EXT_ADDR_PTR)

#define   EXT_FN               (extFnPtr)(EXT_FN_PTR_ADDR)

…
char *p;
char var;
…
(*EXT_FN)(p, var);
…
```

4. Conclusion

The emphasis of this document is to illustrate the ports, peripherals and external memory access methodology. It also creates the awareness of the basic hardware knowledge needed for firmware programming.

Reference

H8/38024 Hardware User Manual (Renesas)

H8/3048 Hardware User Manual (Renesas)

HEW C/C++ Compiler, Assembler, Optimizing Linkage Editor manual (Renesas)

A book on C by Al Kelley Ira Pohl (Addison –Wesley)

The Practice of Programming by Brain W.Kernighan & Rob Pike (Addison –Wesley)

Fundamentals of Embedded Software where C and Assembly Meet by Daniel W.Lewis (Prentice Hall)

Programming Embedded Systems in C and C++ by Michael Barr (O'REILLY)

Writing Solid Code by Steve Maguire (Microsoft Press)

Revision Record

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		Page	Summary
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