

Overview of the PIC 16F648A Processor: Part 1

EE 361L

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Abstract: This report is the first of a three part series that discusses the features of the PIC 16F648A processor, which is from Microchip (www.microchip.com). The reports will refer to the data sheet of the processor. Each report takes about 30-60 minutes to read (this report will take 60 minutes).

In this report, we review the basics of computer organization and technologies, and then cover some of the basic features of the processor. We also present a simple application of the processor to illustrate concepts. Finally, we will discuss bit-wise logic operations that will be used in this lab.

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1 Introduction to Computers and Computer Terminology

The PIC 16F648A is a 18-pin computer in a chip. Figure 1-1 shows its picture and circuit diagram.



Figure 1.1. A picture and circuit diagram of the PIC 16F648A.

The PIC 16F648A, like all computers, has three basic hardware components as shown in Figure 1.2:

- Central processing unit (CPU): which runs the *program*, a collection of instructions that does some task.
- Memory: which stores the program and holds variable values
- Input/Output (IO): which is how the chip interacts with the rest of the world.

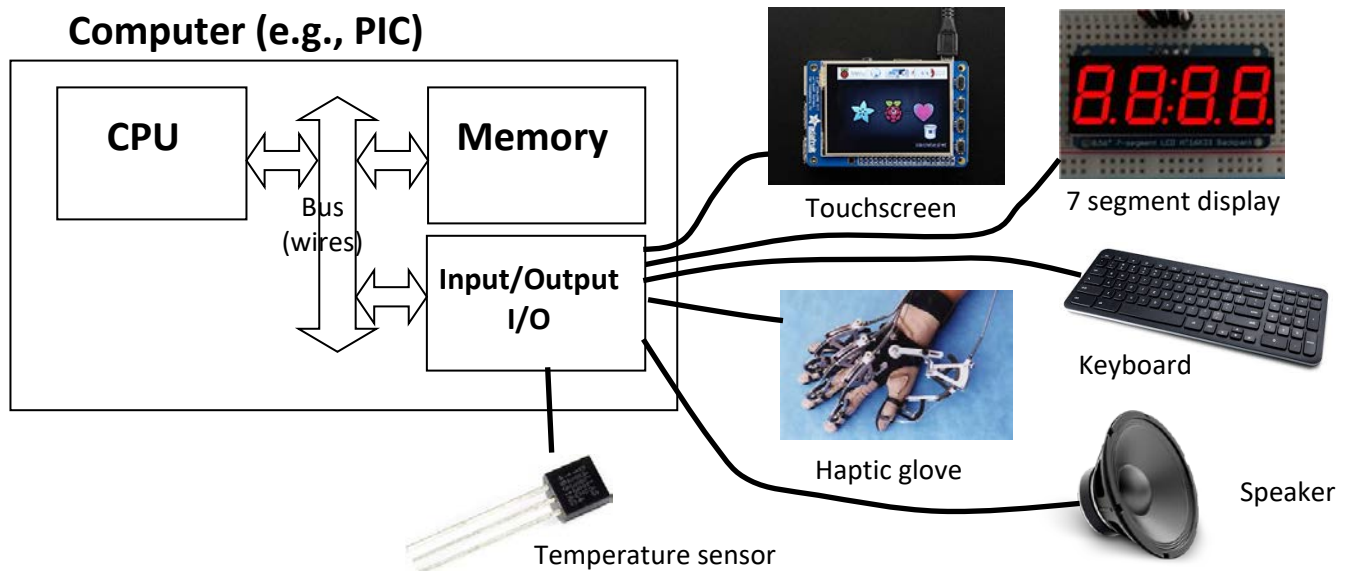


Figure 1.2. Block diagram of a computer.

In Sections 1.1 and 1.2, we will go over basic concepts of computers. Then from Section 2, we will cover specifics about the PIC 16F648A.

1.1 Programs

A program can be written using a high level language like C, such as in Figure 1.3.

```
main( )
{ int i;
  int n;
  n = 0;
  for (i=0; i<10; i++) n = n*(n+1);
  return();
}
```

Figure 1.3. Simple C language program.

This program has C language instructions such as “for” and “return”; variables such as “i” and “n”; and data constants such as “10” and “0”. Note that variables can be read and written to.

However, the processor cannot run this program since it can only execute simpler instructions called *machine instructions*. Rather, the “high-level” C program must be *compiled* to create a *machine program* (or *executable code* or *machine code*), which is composed of machine instructions and can be executed by the processor. The machine instructions are from a *machine language*. For example, Intel processors follow the x86 machine language. The PIC has a different machine language with 35 instructions.

A C language *compiler* (such as cc or gcc) is software that reads a C program, and then converts it to a machine program, composed of machine instructions. A C program is sometimes referred to as a *source code* because it can be compiled by different compilers, that are specific to different “target” processors. This will result in different machine programs.

Machine instructions are strings of bits, which are difficult to read by humans. *Assembly language* is another way to write machine programs that can be read by humans. In assembly language, each machine instruction has a *mnemonic*, which is a representation of an instruction that is easier to read. As an example, the PIC machine instruction 00000011000001 has the mnemonic CLRF 1. This instruction refers to a variable numbered “1”. The instruction will clear the variable to the value 0. Note that the mnemonic CLRF 1 is easier to read than the machine instruction 00000011000001.

Assembly language programs are written in text, and they need to be *assembled*, which is the process of converting an assembly language program to an executable program. An *assembler* is software that does the assembling.

1.2 Memory

Programs and their variables are stored in the memory of the processor. Programs are stored in *instruction memory* or *program memory*, while variables and their data are stored in *data memory*.

There are different types of memory technologies:

- *Read only memory (ROM)* can be read but not written to.
 - Some ROM technologies can be written to (or programmed) only once, at the factory.
- *Programmable ROMs (PROMs)* can be programmed by the user.
 - Many PROM technologies allow reprogramming, though the reprogramming is relatively slow.
- *Erasable PROMs (EPROMs)* can be erased by ultra violet light and then reprogrammed.
 - You may have used EPROMs in EE 260.
- *Electrically erasable PROMs (EEPROMs)* are erasable using electricity.
 - They are more convenient to reprogram since they do not require ultra violet light. A special type of EEPROM is *flash memory*, used in thumb drives, smart phones, and tablets.
- *Random access memory (RAM)* can be read and written to.

PROMs are known as *non-volatile memory* since the circuit can be turned off and the data is still retained. RAM is referred to as *volatile memory* since when turned off, all the data is lost.

2 Processor Data Sheet

The PIC 16F684A has a data sheet. Page 3 of the data sheet has a list of the PIC's features. The following are some of these features:

- 35 single-word instructions
- Interrupt capability
- 18 pin dual-in line package
- Internal and external oscillator options
- Power-saving Sleep mode
- Watchdog Timer with independent oscillator for reliable operation
- In-Circuit Serial Programming (ICSP)
- Power-on Reset
- Wide operating voltage range (2.0v - 5.5v)

High-Performance RISC CPU:

- Operating speeds from DC – 20 MHz
- Interrupt capability
- 8-level deep hardware stack
- Direct, Indirect and Relative Addressing modes
- 35 single-word instructions:
 - All instructions single cycle except branches

Special Microcontroller Features:

- Internal and external oscillator options:
 - Precision internal 4 MHz oscillator factory calibrated to $\pm 1\%$
 - Low-power internal 48 kHz oscillator
 - External Oscillator support for crystals and resonators

Low-Power Features:

- Standby Current:
 - 100 nA @ 2.0V, typical
- Operating Current:
 - 12 μ A @ 32 kHz, 2.0V, typical
 - 120 μ A @ 1 MHz, 2.0V, typical
- Watchdog Timer Current:
 - 1 μ A @ 2.0V, typical
- Timer1 Oscillator Current:
 - 1.2 μ A @ 32 kHz, 2.0V, typical
- Dual-speed Internal Oscillator:
 - Run-time selectable between 4 MHz and 48 kHz
 - 4 μ s wake-up from Sleep, 3.0V, typical

Figure 2.1. Snapshot of the top portion of page 3 of the datasheet.

Figure 2.2 has the pin diagram of the PIC which is from page 4 of the datasheet. Note that many of the pins have multiple names. For example, Pin 2 has the label RA3/AN3/CMP. This means Pin 2 has one of four possible functions:

- RA3 is an IO port
- AN3 is an input for an analog comparator
- CMP1 is an output for comparator.

A programmer can choose one of the three functions through the source code of the program. An explanation of these pins is given on pages 13-14 of the datasheet. A portion of pages 13 and 14 is shown in Figure 2.3. We will only cover a subset of these functions.

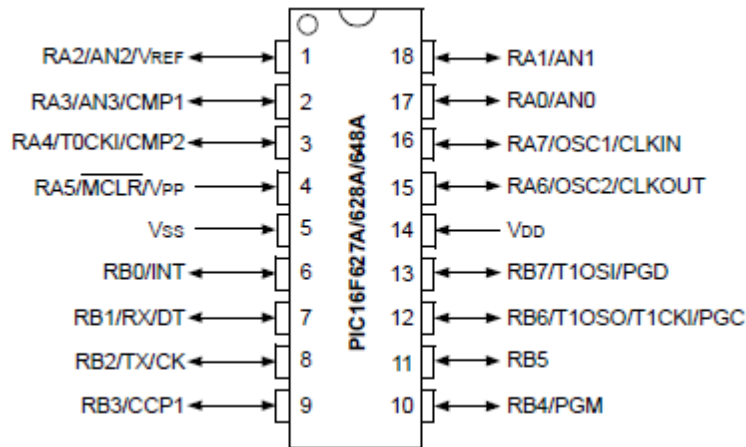


Figure 2.2. Pin diagram of the PIC from the data sheet.

TABLE 3-2: PIC16F627A/628A/648A PINOUT DESCRIPTION

Name	Function	Input Type	Output Type	Description
RA0/AN0	RA0	ST	CMOS	Bidirectional I/O port
	AN0	AN	—	Analog comparator input
RA1/AN1	RA1	ST	CMOS	Bidirectional I/O port
	AN1	AN	—	Analog comparator input
RA2/AN2/VREF	RA2	ST	CMOS	Bidirectional I/O port
	AN2	AN	—	Analog comparator input
	VREF	—	AN	VREF output
RA3/AN3/CMP1	RA3	ST	CMOS	Bidirectional I/O port
	AN3	AN	—	Analog comparator input
	CMP1	—	CMOS	Comparator 1 output

Figure 2.3. A portion of pages 13 and 14 from the data sheet.

Figure 2.4 has a schematic diagram of the processor (it comes from Page 12 of the data sheet). The figure highlights the basic components of the processor (see Figure 1.2 to review the basic components of a computer).

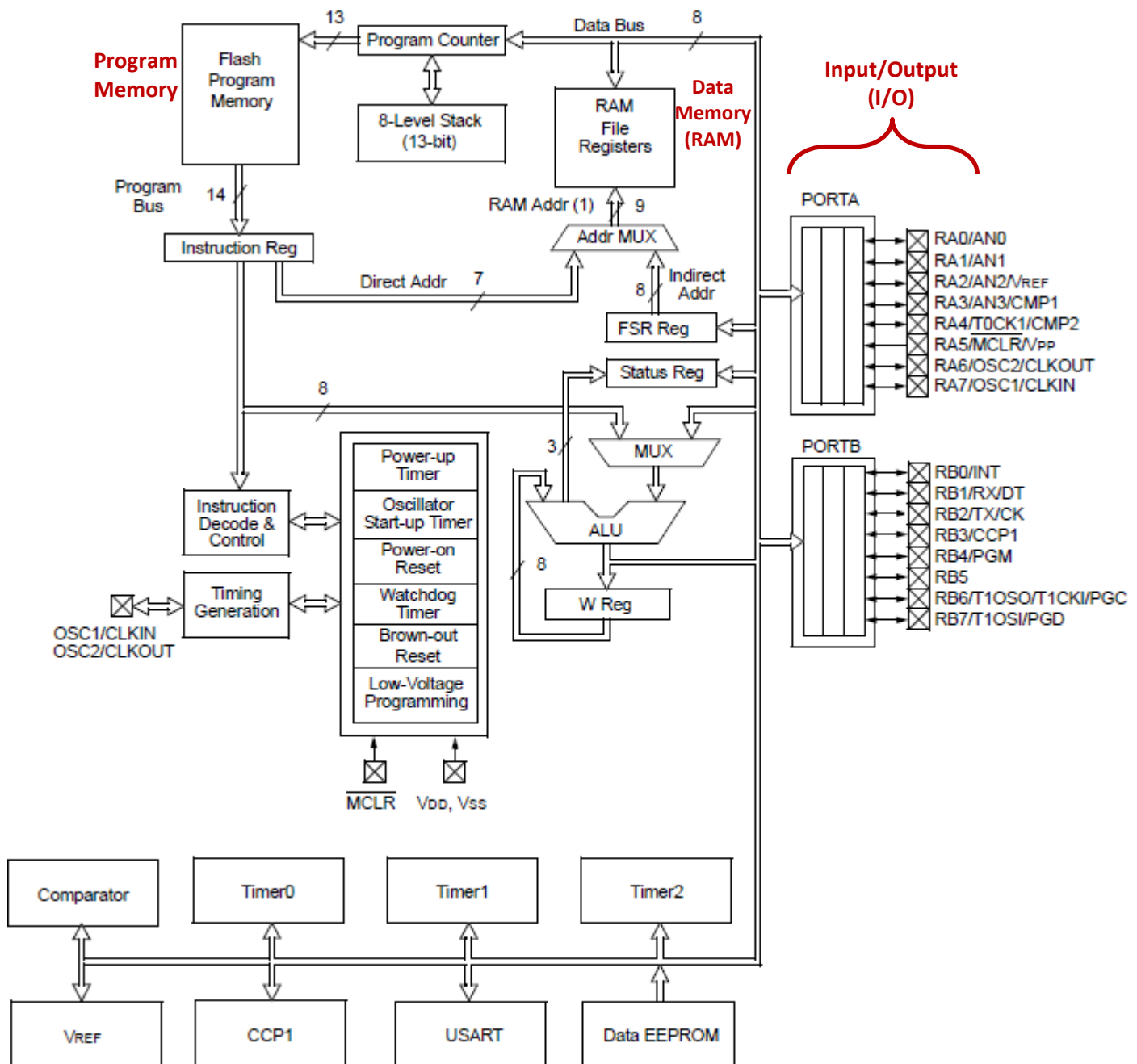
The processor has its memory divided into

- *Program memory*
 - It stores the instructions of the program; an instruction is referred to as an *operation*.
 - It is implemented with 4096 x 14 bits of flash memory
 - Each machine instruction is 14 bits, so program memory can store up to 4096 instructions
- *Data memory* (or in this case the RAM).
 - Data memory is implemented with 256 bytes of RAM
 - Each data is 1 byte, so the computer can store up to 256 data values. Data is referred to as an *operand*.
 - Each RAM byte can be used as a variable. For example, in Figure 1.3, the dummy variable “i” in the for-loop can be implemented in a RAM byte.
 - Note that there is also data memory in EEPROM, but we won’t be using this.

The processor has Input/Output (I/O) via PORTA and PORTB. Each port actually has 8 individual ports that can transfer 1 bit of information between the processor and the outside world.

The rest of the processor is the CPU. The following are some notable component of the CPU.

- **8-level stack:** This is used to implement functions. We will discuss stacks in the EE 361 lecture later in the semester. There is a *program counter* (PC) which is used to keep track of which instruction the processor is currently executing.
- **Power-up Timer, Oscillator Start-up Timer, Power-on Reset, Watchdog Timer, and Brown-out Reset:** These components deal with resetting the processor. For example, the Brown-out Reset deals the following situation. When the source voltage to the processor is too low, e.g., instead at full 5v the power temporarily goes to say 1.8v, the processor’s circuits may not behave properly. As a result, the processor will not behave correctly even when full power is restored. The Brown-out Reset will detect this low power situation and automatically reset the processor so it runs properly again.
- **Timer Generation and Internal Timing Block:** These are the sources of the clock signal for the processor. The PIC like all processors is a synchronous digital circuit and operates on a clock signal. The PIC has multiple options for clock signals. It can use an internally generated clock signal or an external source. The internal signal is convenient but less accurate. An external signal can be generated using a crystal. For this lab, we will use an oscillator crystal as shown in Figure 2.5.
- **Timer0, Timer1, and Timer2:** These are basically counter circuits, similar to the 74163 circuits from EE 260. We will use one of these in a future lab assignment.
- **Data EEPROM, Analog Comparator, USART:** The EEPROM is non-volatile data storage, which means that the data is stored even when the power goes off. We will ignore these for EE 361L since we won’t be using any of these blocks.



Note 1: Higher order bits are from the Status register.

Figure 2.4. Block diagram of the PIC from the data sheet.



Figure 2.5. Oscillator crystals.

3 Example Application

In the next subsection, we will discuss a simple, example application. The application has the PIC processor drive an LED so that it blinks periodically. The application uses IO ports. The program of the application is written in C language but there is also an assembly language portion. In Subsection 3.2, we will explain some of the assembly language instructions.

3.1 Blinking LED Program

The following program called the “Blinking LED program” is a simple example that has IO. It assumes that an LED is attached to pin RA1, and that the PIC turns the LED on and off. The RA1 pin is part of the 8-bit wide PORTA. The bits of PORTA are RA7, RA6,..., RA0. PORTA can be treated as a variable in software.

```
main( ) // BLINKING LED program
{
    // Set PORTA so that RA2 is an output, and the other ports are inputs.
    TRISA = 0x04; // Prefix "0x" means hexadecimal. Note that "0" is a zero, not the
                  // alphabet "O"
                  // Note that 0x04 is 00000100 in binary
    while(1) { // Loop forever
        PORTA = 0x00; // Output 0 to RA2
        PORTA = 0x04; // Output 1 to RA2
    }
}
```

PORTA is *bidirectional* which means its bits can be configured to be inputs or outputs. These bits can be configured in software by another variable TRISA; and in particular

- Setting a bit in TRISA to 0 will make the corresponding bit in PORTA an output.
- Setting a bit in TRISA to 1 will make the corresponding bit in PORTA an input.

The bits of TRISA are TRISA7, TRISA6, ..., TRISA0. For $k = 0, 1, \dots, 7$, TRISA $_k$ configures RA $_k$. Thus, if TRISA2 = 1 then RA2 is an output. In the program, bit RA2 is configured to be an output by having TRISA equal the bits 00000100 using the instruction:

TRISA = 0x04.

This instruction will configure RA2 to be an output, while the rest of the ports in PORTA (i.e., RA7, RA6,..., RA3, RA1, RA0) are inputs.

The number “0x04” is a *hexadecimal* number, where the prefix “0x” indicates hexadecimal. The following is a short description of hexadecimal numbers:

- The *base* of hexadecimal numbers is 16
- Each digit represents a value from 0 to 15.
- The digits are 0, 1, 2, ..., 9, A, B, ..., F, where the digits A = 10, B = 11, ..., F = 15.
- A hexadecimal number $h_{n-1}h_{n-2}...h_0$ has value $h_{n-1} \times 16^{n-1} + h_{n-2} \times 16^{n-2} + ... + h_0 \times 16^0$.

Hexadecimal numbers are a convenient way to represent binary numbers. Each hexadecimal digit represents four bits. For example, the hexadecimal number 0xF5 can be converted to binary by converting each digit to four bits. Note that 0xF equals 15 (decimal), which in binary is 1111, and 0x5 equals 5 (decimal), which in binary is 0101. The representation of F5 in binary is 11110101. The following table converts hexadecimal digits to binary numbers.

Hex	Binary	Hex	Binary	Hex	Binary	Hex	Binary
0	0000	4	0100	8	1000	c	1100
1	0001	5	0101	9	1001	d	1101
2	0010	6	0110	a	1010	e	1110
3	0011	7	0111	b	1011	f	1111

The instruction TRISA = 0x04 indicates that the ports are configured using the binary string 0000 0100 (which equals 0x04). Thus, RA2 is configured to be an input while all the other ports are configured to be outputs.

TRISA is implemented by a hardware register. Such registers are often called *control registers*. To the C compiler for the PIC, “TRISA” and “PORTA” are variables with special names.

After the Blinking LED program configures PORTA to inputs and outputs, it goes into an infinite loop, continually setting pin RA2 to the value 0 and then 1. There is a problem with this program. Since the processor is running so fast, the LED will blink very quickly, too fast for humans to detect. This will make the LED appear to be continually on. This can be solved by adding a time delay. The next program, “Blinking LED 2” (shown below), is an example of this method.

```
main( ) // BLINKING LED 2 program
{
    // Set PORTA so that RA2 is an output, and the other ports are inputs.
    TRISA = 0x04; // Prefix "0x" means hexadecimal. Note that "0" is a zero, not the
                  // alphabet "O"
                  // Note that 0x04 is 00000100 in binary
    while(1) { // Loop forever
        PORTA = 0x00; // Output 0 to RA2
        delay1sec();  // Delay 1 second
        PORTA = 0x04; // Output 1 to RA2
        delay1sec();  // Delay 1 second
    }
}
```

The Blinking LED 2 program uses a function “delay1sec”, which provides a 1 second delay. Next, we will discuss implementing this function.

The following implementation is a naive approach. It assumes a 1 MHz clock (though in the actual lab, the clock rate may be different). The function has a for-loop that goes through 1 million passes.

```
void delay1sec( ) // A delay of 1 second
{
    int n;
    n = 0;
    while (n < 1000000){ // 1000000 = 1 million passes of the while loop
        n++;
    }
}
```

If each pass takes one clock cycle (1 μ s) then the for-loop will cause 1 second of delay. However, this function will not work for the following reasons:

- Each line of C will translate into multiple lines of machine instructions. It is difficult to estimate the number of instructions without compiling.
- Machine instructions can take multiple clock cycles, and some instructions will take different clock cycles depending on the situation.
- The variable “n” is stored in a memory cell (register), and this cell has a limited size of 8 bits. Its value ranges from -128 to +127 (using *twos complement arithmetic*; if you don’t know twos complement, we will discuss this in lecture later). Thus, “n” cannot be implemented correctly in the while-loop, which requires a range of up to 1 million.

Next, we will implement the 1 second delay using two functions. The first function “delay1sec” calls a second function “delay1ms”, that has a 1 millisecond delay. The function “delay1sec” calls “delay1ms” for 1000 times.

The following is “delay1sec”. The C instruction “for” and calculations such as “n++” take clock cycles too but but just a small percentage compared to “delay1ms”.

```
void delay1sec( ) // A delay of 1 second
{ int n,m;
  for (n=0; n<10; n++) {
    for (m=0; m<100; m++) delay1ms( );
  }
}
```

Figure 3.1 has the “delay1ms” C function which also has assembly language instructions. The compiler for the PIC allows a program to have a mix of C language and assembly language. By writing most of the function in assembly language, we can control the number of clock cycles.

The figure shows how the assembly language portion is delimited. It also explains the “DELAY_LOOP” label. The assembly language portion is a delay loop. It is composed of the assembly language instructions CLRWDT, NOP, DECFSZ, and GOTO. (The PIC has 35 machine instructions, which are presented in Section 15 in the data sheet, page 117.)

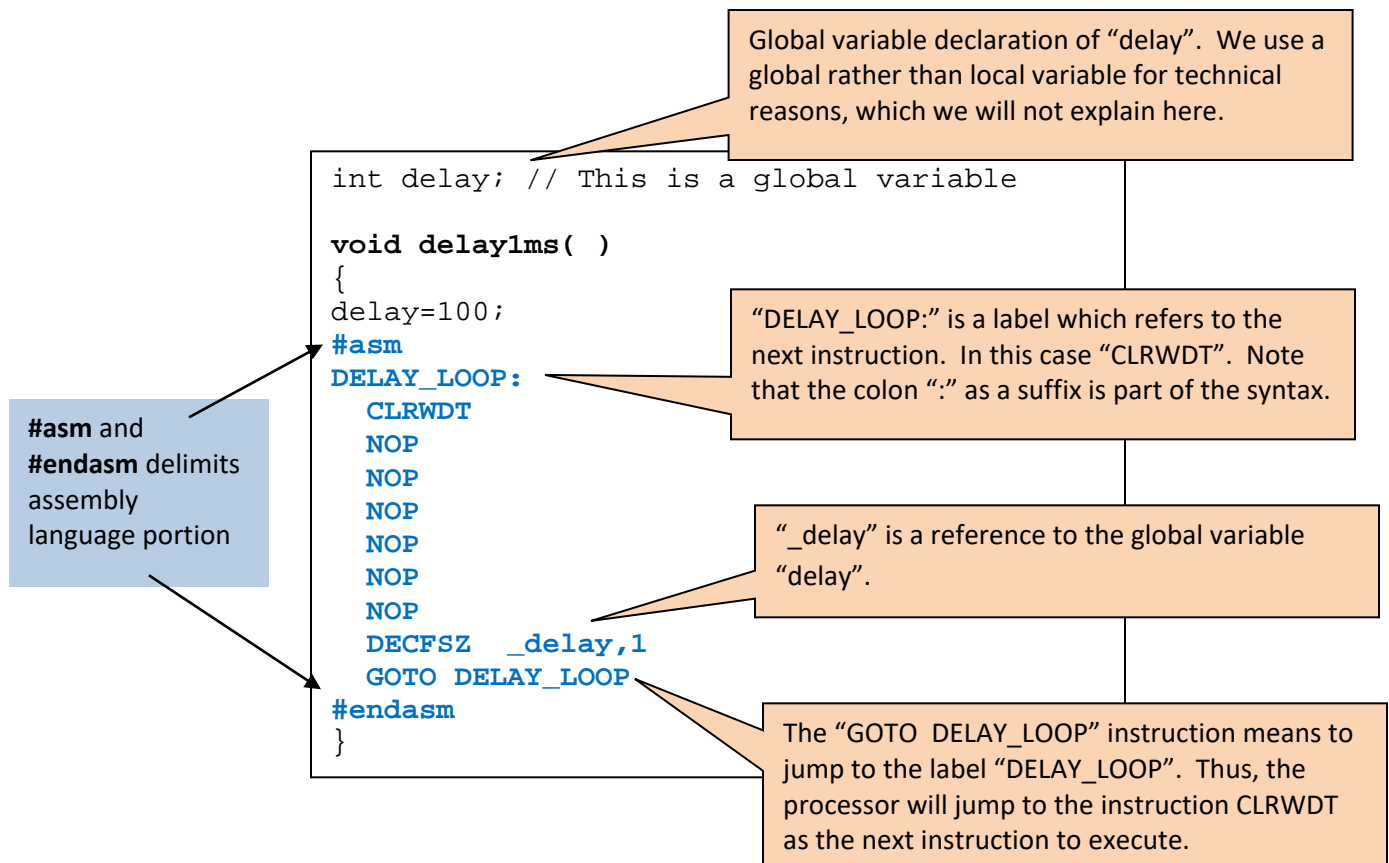


Figure 3.1. delay1ms function with explanations.

Next, we will explain the machine instructions in Figure 3.1.

3.2 Description of Some PIC Machine Instructions

A summary of the instructions of the PIC is shown in Figure 3.2, which is Table 15-2 of the datasheet.

Mnemonic, Operands		Description	Cycles	14-Bit Opcode				Status Affected	Notes
				MSb		LSb			
BYTE-ORIENTED FILE REGISTER OPERATIONS									
ADDWF	f, d	Add W and f	1	00	0111	dfff	ffff	C,DC,Z	1, 2
ANDWF	f, d	AND W with f	1	00	0101	dfff	ffff	Z	1, 2
CLRF	f	Clear f	1	00	0001	1fff	ffff	Z	2
CLRW	—	Clear W	1	00	0001	0xxx	xxxx	Z	
COMF	f, d	Complement f	1	00	1001	dfff	ffff	Z	1, 2
DECF	f, d	Decrement f	1	00	0011	dfff	ffff	Z	1, 2
DECFSZ	f, d	Decrement f, Skip if 0	1(2)	00	1011	dfff	ffff		1, 2, 3
INCF	f, d	Increment f	1	00	1010	dfff	ffff	Z	1, 2
INCFSZ	f, d	Increment f, Skip if 0	1(2)	00	1111	dfff	ffff		1, 2, 3
IORWF	f, d	Inclusive OR W with f	1	00	0100	dfff	ffff	Z	1, 2
MOVF	f, d	Move f	1	00	1000	dfff	ffff	Z	1, 2
MOVWF	f	Move W to f	1	00	0000	1fff	ffff		
NOP	—	No Operation	1	00	0000	0xx0	0000		
RLF	f, d	Rotate Left f through Carry	1	00	1101	dfff	ffff	C	1, 2
RRF	f, d	Rotate Right f through Carry	1	00	1100	dfff	ffff	C	1, 2
SUBWF	f, d	Subtract W from f	1	00	0010	dfff	ffff	C,DC,Z	1, 2
SWAPF	f, d	Swap nibbles in f	1	00	1110	dfff	ffff		1, 2
XORWF	f, d	Exclusive OR W with f	1	00	0110	dfff	ffff	Z	1, 2
BIT-ORIENTED FILE REGISTER OPERATIONS									
BCF	f, b	Bit Clear f	1	01	00bb	bfff	ffff		1, 2
BSF	f, b	Bit Set f	1	01	01bb	bfff	ffff		1, 2
BTFSZ	f, b	Bit Test f, Skip if Clear	1(2)	01	10bb	bfff	ffff		3
BTSS	f, b	Bit Test f, Skip if Set	1(2)	01	11bb	bfff	ffff		3
LITERAL AND CONTROL OPERATIONS									
ADDLW	k	Add literal and W	1	11	111x	kkkk	kkkk	C,DC,Z	
ANDLW	k	AND literal with W	1	11	1001	kkkk	kkkk	Z	
CALL	k	Call subroutine	2	10	0kkk	kkkk	kkkk		
CLRWDT	—	Clear Watchdog Timer	1	00	0000	0110	0100	$\overline{\text{TO}}$, $\overline{\text{PD}}$	
GOTO	k	Go to address	2	10	1kkk	kkkk	kkkk		
IORLW	k	Inclusive OR literal with W	1	11	1000	kkkk	kkkk	Z	
MOVLW	k	Move literal to W	1	11	00xx	kkkk	kkkk		
RETFIE	—	Return from interrupt	2	00	0000	0000	1001		
RETLW	k	Return with literal in W	2	11	01xx	kkkk	kkkk		
RETURN	—	Return from Subroutine	2	00	0000	0000	1000		
SLEEP	—	Go into Standby mode	1	00	0000	0110	0011	$\overline{\text{TO}}$, $\overline{\text{PD}}$	
SUBLW	k	Subtract W from literal	1	11	110x	kkkk	kkkk	C,DC,Z	
XORLW	k	Exclusive OR literal with W	1	11	1010	kkkk	kkkk	Z	

- Note** 1: When an I/O register is modified as a function of itself (e.g., `MOVF PORTB, 1`), the value used will be that value present on the pins themselves. For example, if the data latch is '1' for a pin configured as input and is driven low by an external device, the data will be written back with a '0'.
- 2: If this instruction is executed on the TMR0 register (and, where applicable, d = 1), the prescaler will be cleared if assigned to the Timer0 Module.
- 3: If Program Counter (PC) is modified or a conditional test is true, the instruction requires two cycles. The second cycle is executed as a NOP.

Figure 3.2. Summary of PIC instructions from page 118 of datasheet.

We will now discuss the particular instructions in the program in Figure 3.1. Following a short description of an instruction, there is a snapshot from the datasheet about the instruction.

- **NOP:** The simplest instruction is NOP (for “no operation”), which does nothing except to use up a clock cycle. Figure 3.3 shows that “NOP” is the assembly language mnemonic, and that the machine instruction is the 14-bit string 00 0000 0xx0 0000. The figure also shows that it uses 1 clock cycle.

NOP	No Operation			
Syntax:	[<i>label</i>] NOP			
Operands:	None			
Operation:	No operation			
Status Affected:	None			
Encoding:	00	0000	0xxx0	0000
Description:	No operation.			
Words:	1			
Cycles:	1			
<u>Example</u>	NOP			

Figure 3.3. Snapshot from page 126 of the datasheet.

- **GOTO:** The instruction GOTO has the syntax GOTO <label> . The <label> indicates the position of another instruction. For the delay10us() function, the label DELAY_LOOP corresponds to the CLRWDT instruction. When the PIC processor executes this GOTO instruction, it will jump to the DELAY_LOOP label. The description in the datasheet is shown in Figure 3.4.

GOTO		Unconditional Branch				
Syntax:	[<i>label</i>] GOTO k					
Operands:	0 ≤ k ≤ 2047					
Operation:	k → PC<10:0> PCLATH<4:3> → PC<12:11>					
Status Affected:	None					
Encoding:	10		1kkk	kkkk	kkkk	
Description:	GOTO is an unconditional branch. The eleven-bit immediate value is loaded into PC bits <10:0>. The upper bits of PC are loaded from PCLATH<4:3>. GOTO is a two-cycle instruction.					
Words:	1					
Cycles:	2					
<u>Example</u>	GOTO THERE					
	After Instruction					
	PC = Address THERE					

Figure 3.4. Snapshot from page 123 of the datasheet.

- **CLRWDT:** The instruction CLRWDT clears the *Watch Dog Timer* (snapshot of the description in the datasheet is shown in Figure 3.5). The Watch Dog Timer is a module within the PIC. Watch Dog Timers are useful for computers that need to keep running forever. These timers basically run on their own, keeping track of how much time has elapsed. When these timers have elapsed for a pre-specified period, they *time out*, which in turn, causes the computer to reset.

CLRWDWT		Clear Watchdog Timer							
Syntax:	[<i>label</i>] CLRWDWT								
Operands:	None								
Operation:	00h → WDT 0 → WDT prescaler, 1 → \overline{TO} 1 → \overline{PD}								
Status Affected:	\overline{TO} , \overline{PD}								
Encoding:	<table border="1"><tr><td>00</td><td>0000</td><td>0110</td><td>0100</td></tr></table>					00	0000	0110	0100
00	0000	0110	0100						
Description:	CLRWDWT instruction resets the Watchdog Timer. It also resets the prescaler of the WDT. Status bits \overline{TO} and \overline{PD} are set.								
Words:	1								
Cycles:	1								
<u>Example</u>	CLRWDWT Before Instruction WDT counter = ? After Instruction WDT counter = 0x00 WDT prescaler = 0 \overline{TO} = 1 \overline{PD} = 1								

Figure 3.5. Snapshot from page 122 of the datasheet.

Watch dog timers are often used on computers that continually run a very specific task, e.g., controlling a traffic light. Now if the computer got stuck for some reason, and there is no one to reset it, it stays stuck. To avoid getting stuck forever, a computer can use a Watch Dog Timer to automatically reset it. Then the program must be written so that it periodically resets the timer to keep from timing out and resetting prematurely. This is sometimes referred to as “petting the dog”. The analogy is that you must regularly pet the dog to keep it happy. Our delay function will pet the dog every pass through the loop. Here is more information about Watch Dog Timers:

http://en.wikipedia.org/wiki/Watchdog_timer

A related machine instruction of CLRWDT is CLRF shown in Figure 3.6. Here, “F” (or “f”) is a variable, which is realized by a hardware register. This instruction clears the variable F. CLRF has the machine instruction 00 0001 1fff ffff, where “fff ffff” is a binary number that indicates the register F. CLRWDT is a separate function because the watch dog timer is special hardware.

CLRW	Clear W				
Syntax:	[<i>label</i>] CLRW				
Operands:	None				
Operation:	00h → (W) 1 → Z				
Status Affected:	Z				
Encoding:	<table><tr><td>00</td><td>0001</td><td>0000</td><td>0011</td></tr></table>	00	0001	0000	0011
00	0001	0000	0011		
Description:	W register is cleared. Zero bit (Z) is set.				
Words:	1				
Cycles:	1				
<u>Example</u>	CLRW Before Instruction W = 0x5A After Instruction W = 0x00 Z = 1				

Figure 3.6. Snapshot from page 122 of the datasheet.

- **DECFSZ:** The final machine instruction in the delay loop is DECFSZ _delay,1. Figure 3.7 has a description of DECFSZ f,d, where “f” is a variable (which holds data or operand), and “d” is a value which is either 0 or 1. In our case, “f” is the global variable “delay”. Note that in assembly language the C variable “delay” is “_delay”. In our case, “d” is equal to 1.

In Figure 3.1, the instruction is used as follows:

```
DECFSZ _delay,1
GOTO DELAY_LOOP
```

According to Figure 3.7, when the processor executes “DECFSZ _delay,1”, it first decrements the variable “delay” by 1. Since “d” has been set to 1, the decremented value is stored back into the global variable “delay”. Next, the processor checks the result. If the result is 0 (i.e., global variable “delay” is zero) then the next instruction (GOTO) is skipped. Otherwise, the processor proceeds to execute the next instruction.

DECFSZ		Decrement f, Skip if 0																		
Syntax:	[label] DECFSZ f,d																			
Operands:	$0 \leq f \leq 127$ $d \in [0,1]$																			
Operation:	$(f) - 1 \rightarrow (\text{dest});$ skip if result = 0																			
Status Affected:	None																			
Encoding:	<table border="1"><tr><td>00</td><td>1011</td><td>dfff</td><td>ffff</td></tr></table>					00	1011	dfff	ffff											
00	1011	dfff	ffff																	
Description:	<p>The contents of register 'f' are decremented. If 'd' is '0', the result is placed in the W register. If 'd' is '1', the result is placed back in register 'f'. If the result is '0', the next instruction, which is already fetched, is discarded. A NOP is executed instead making it a two-cycle instruction.</p>																			
Words:	1																			
Cycles:	1(2)																			
Example	<table><tr><td>HERE</td><td>DECFSZ</td><td>REG1, 1</td></tr><tr><td></td><td>GOTO</td><td>LOOP</td></tr><tr><td>CONTINUE</td><td>•</td><td></td></tr><tr><td></td><td>•</td><td></td></tr><tr><td></td><td>•</td><td></td></tr></table> <p>Before Instruction PC = address HERE</p> <p>After Instruction REG1 = REG1 - 1 if REG1 = 0, PC = address CONTINUE if REG1 ≠ 0, PC = address HERE+1</p>					HERE	DECFSZ	REG1, 1		GOTO	LOOP	CONTINUE	•			•			•	
HERE	DECFSZ	REG1, 1																		
	GOTO	LOOP																		
CONTINUE	•																			
	•																			
	•																			

Figure 3.7. The description of DECFSZ from the data sheet, page 123.

3.3 Delay Analysis of delay1ms

Figure 3.8 shows the function “delay1ms” with an explanation of the number of clock cycles it uses. It has the following components:

- The C instruction “delay = 100” initializes the variable “delay”.
- The assembly language portion is a delay loop. Each time the delay loop is passed, the instruction DECFSZ decrements “delay”. Thus, the loop goes through 100 passes.

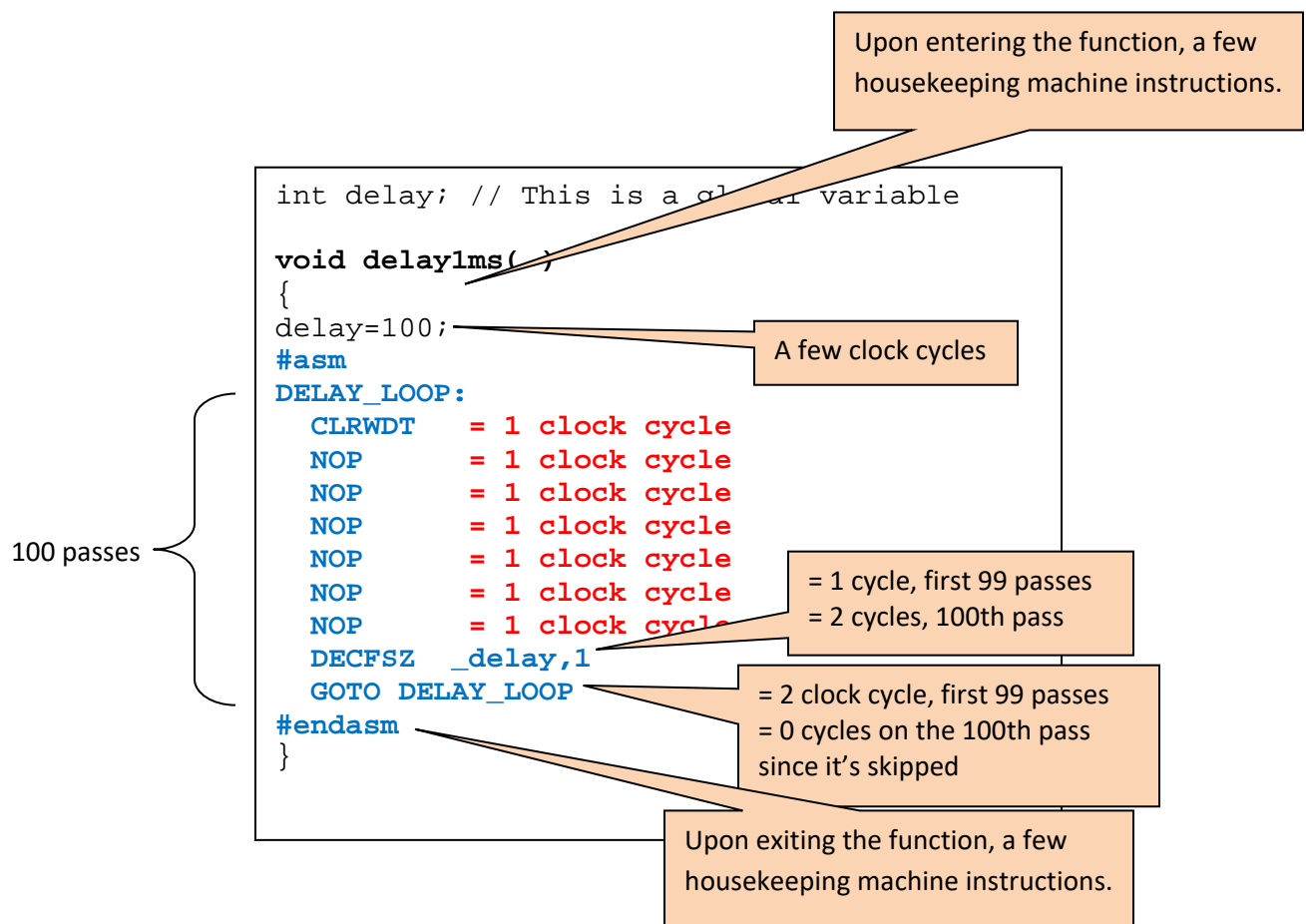


Figure 3.8. delay1ms function with clock cycles.

Figure 3.2 shows the number of clock cycles per instruction (recall this is from “Table 15-2” on page 118 of the datasheet).

Let us consider the delay in Figure 3.8. Each pass will execute CLRWDT once, NOP six times, DECFSZ once, and GOTO once (though GOTO is skipped on the 100th pass). From Figure 3.2, CLRWDT, NOP, and GOTO each take one clock cycle. DECFSZ takes one cycle for the first 99 passes but 2 cycles on the last pass.

Therefore, during the first 99 passes, each pass has 10 cycles composed of

- One CLRWDT = 1 cycle
- 6 NOPs = 6 cycles
- 1 DECFSZ = 1 cycle
- 1 GOTO = 2 cycles

During the 100th pass, there is 9 cycles composed of CLRWDT (1 cycle), NOPs (7 cycles), DECFSZ (2 cycles), and GOTO (0 cycles because its skipped). The 100th pass also uses 10 clock cycles, composed of CRWDT (1 cycle), NOP (6 cycles), and DECFSZ (2 cycles).

Thus, the total number of clock cycles is 999. Since each clock cycle is 1 μ s, the total delay is $999 \times 1 \mu$ s, which is approximately 1 millisecond.

This accounts for most of the clock cycles but not all. There are clock cycles to execute “delay = 100” and clock cycles to implement housekeeping operations for the function, e.g., returning from the function call. But the number of these cycles is small compared to 999 clock cycles of the delay loop. Thus, we ignore them and assume that the function has a delay of “approximately” 1 ms.

Note that the program has been designed so that the number of NOPs is just enough to cause a 1 ms delay. If we wanted more or less delay we would add or delete NOPs.

3.4 Hardware

In this subsection, we will discuss how to configure the hardware for this application. First, we will use a crystal oscillator. This is shown in the data sheet on page 99 as shown in Figure 3.9 below. Note that there is a (possible) series resistor RS, but we won't need this, and in particular, the resistor is replaced by a wire. There are also two capacitors. Note that the two pins of the processor that are used are OSC1 and OSC2, which are pins 16 and 15, respectively.

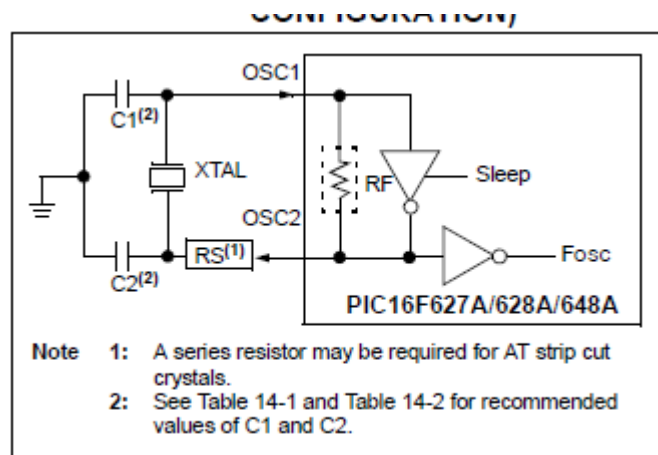


Figure 3.9. Crystal oscillator configuration from the PIC data sheet.

Second, we need to connect the LED to port RA2, and this is pin 1 in Figure 2.2.

Third, we need to connect VSS and VDD to Ground and 5 volts, respectively. (Actually, the processor has a wide operating voltage range from 2.0 to 5.5 volts.) The pins for VSS and VDD are 5 and 14, respectively.

Finally, we'd like to be able to program the processor while it's running. This is called in-circuit serial programming (ICSP, which is a Microchip Inc trademark). Note that this is done with pins 12 and 13.

How to set up the ICSP is discussed in the MPLab Manual. It's also shown in page 114 of the data sheet.

4 Important Pins

Here is a list of important pins.

- PORTA (RA0 – RA7) and PORTB (RB0 – RB7): Bidirectional I/O ports.
- OSC1 and OSC2: Inputs for the crystal oscillator.
- INT: External interrupt. We'll learn more about interrupts later. Some of the pins of PORTB can also function as interrupts.
- PGC and PGD: ICSP programming Clock and Data. Used in in-circuit programming
- VSS: Ground reference.
- VDD: Power supply.
- $\overline{\text{MCLR}}$: Master clear (it should have an overbar over MCLR but I couldn't get it to work on word doc). When configured this is an active-low Reset to the processor.

Note that, at various places, there is a reference to Schmidt triggers in the data sheet. Appendix A describes what a Schmidt trigger is.

5 Registers

- PORTA and PORTB: Bidirectional ports RA and RB and some of the ports can be configured as interrupts.
- TRISA and TRISB: Programming these registers with 0s and 1s can configure the RA and RB ports as outputs and inputs respectively. Its value on reset is 1s, which implies the default on the I/O ports is as inputs.
- OPTION_REG: This is to configure ports and the timer circuit TMR0. We'll use this later. It's default value on Reset is to disable the functions, which is fine for now.
- INTCON: This configures the interrupts. We'll consider this later on another lab assignment. It's default value on Reset is to disable the interrupts, which is fine for now.
- PIE1 and PIR1: These are configuration registers for components we won't use so ignore.
- PCON: This is the power control register. We won't be using this either so we'll ignore it.

6 Logic Operations

Let us review logic operations. Recall that there are three basic logic operations: AND, OR, and COMPLEMENT (sometimes called NOT). Their truth tables are shown in Figure 6.1.

AND		
Inputs		Output
0	0	0
0	1	0
1	0	0
1	1	1

OR		
Inputs		Output
0	0	0
0	1	1
1	0	1
1	1	1

COMPLEMENT		
Input		Output
0		1
1		0

Figure 6.1. Logic operation truth tables.

The C language has bit-wise logic operators: “&” (AND), “|” (OR), and “~” (COMPLEMENT)

To understand what these operators do, let us discuss an example where all operands are 6 bits. Consider the C language instruction

$m = n \& 5$.

Let the

- 6 bits of m be m_5, m_4, \dots, m_0
- 6 bits of n be n_5, n_4, \dots, n_0 .

Also note that the decimal value 5 is 000101 in binary. The bit-wise AND operation “&” will do eight AND operations, and in particular,

$m_5 = n_5 \text{ AND } 0$
 $m_4 = n_4 \text{ AND } 0$
 $m_3 = n_3 \text{ AND } 0$
 $m_2 = n_2 \text{ AND } 1$
 $m_1 = n_1 \text{ AND } 1$
 $m_0 = n_0 \text{ AND } 0$

Similarly,

$m = n | 5$

results in

$$m_5 = n_5 \text{ OR } 0$$

$$m_4 = n_4 \text{ OR } 0$$

$$m_3 = n_3 \text{ OR } 0$$

$$m_2 = n_2 \text{ OR } 1$$

$$m_1 = n_1 \text{ OR } 0$$

$$m_0 = n_0 \text{ OR } 1$$

Likewise, the bit-wise complement operation “ \sim ” will just flip all the bits.

The logic operations can be very useful in processors. The AND operation can clear bits to 0, and the OR operation can set bits to 1. For example, $m = n \& 5$ results in

$$m = (0, 0, 0, n_2, 0, n_0)$$

Here, the binary value for 5 is (0 0 0 1 0 1), and so bits 0 and 2 are “1” while the rest of the bits are “0”.

Note that if you AND a bit “ b ” with “0” then the result is always “0”; while if you AND a bit “ b ” with “1” then the result is the bit “ b ” again. Thus, the operation $m = n \& 5$ will clear all bits except bits 0 and 2. The bit string (0 0 0 1 0 1) is referred to a *mask* because it will mask out bits.

Similarly, the bit-wise OR operation “ $|$ ” can be used to set bits to “1”. Here, “0” results in an unchanged value, while “1” results in a bit being set to “1”.

Some other useful C language operators are the left bit-shift “ $<<$ ” and the right bit-shift “ $>>$ ”. Let us go over the left shift operation first. Consider the C language instruction

$$m = n << 2$$

This means that the value of $n = (n_5, n_4, \dots, n_0)$ should be shifted to the left by 2 bit positions. This results in $m = (n_3, n_2, n_1, n_0, 0, 0)$.

The right shift “ $>>$ ” works in a similar way except the bits are shifted to the right.

Now as a review, we will give some examples that combine all of the operations above. Consider the C language instructions

```
d = 1 << 3; // Here, 1 in binary is 000001; and when shifted to the left by 3, we have d = 001000
m = m | d; // Here, d is used as a mask; so bit 3 is set to "1", and all other bits are left alone.
           // Thus, m = (m5, m4, 1, m2, m1, m0)
```

We can rewrite this more compactly by the single line

```
m = m | (1 << 3);           or alternatively      m |= (1 << 3);
```

Note that these lines will set m3 to 1, and leave the rest of variable m unchanged. If instead we wanted to set m4 to 1, we could write

```
m |= (1 << 4);
```

Now we will show how the bit-wise AND operation can be used to clear bits to "0". Consider the C language instructions

```
d = 1 << 3; // This leaves d = 001000
d = ~d;     // Then d = 110111
m = m & d; // Since d is a mask, bit 3 is cleared to "0" and the rest of the bits are left alone.
           // Thus, m = (0, 0, m3, 0, 0, 0)
```

We can rewrite this more compactly by the single line

```
m = m & ~(1 << 3);           or alternatively      m &= ~(1 << 3);
```

Note that these lines will clear m3 to 0, and leaving the rest of variable m unchanged. If instead we wanted to clear m4, we could write

```
m &= ~(1 << 4);
```

Finally, note that we usually use the term

- "clear" to mean setting a value to "0"
- "set" to mean setting a value to 1.

Though this is not a standard terminology, it is used in technical documents frequently. Sometimes documents will just state "set" or "clear".

Appendix A Schmidt Trigger

Schmidt triggers are a circuit technology that will sharpen the rise and fall of digital signals. To illustrate this, consider the Schmidt trigger circuit in Figure A.1. The circuit has two threshold voltage values: low and high. If the input signal goes above the high threshold, the output signal goes high, and similarly for the low threshold. In the figure, the input signal is pretty ugly with lots of bumps, and where the rise and fall is not steep at all. But notice the output has sharp rise and falls. So the Schmidt trigger can be used to “clean up” ugly input signals. You can find more information about Schmidt triggers on the Internet:

http://en.wikipedia.org/wiki/Schmitt_trigger

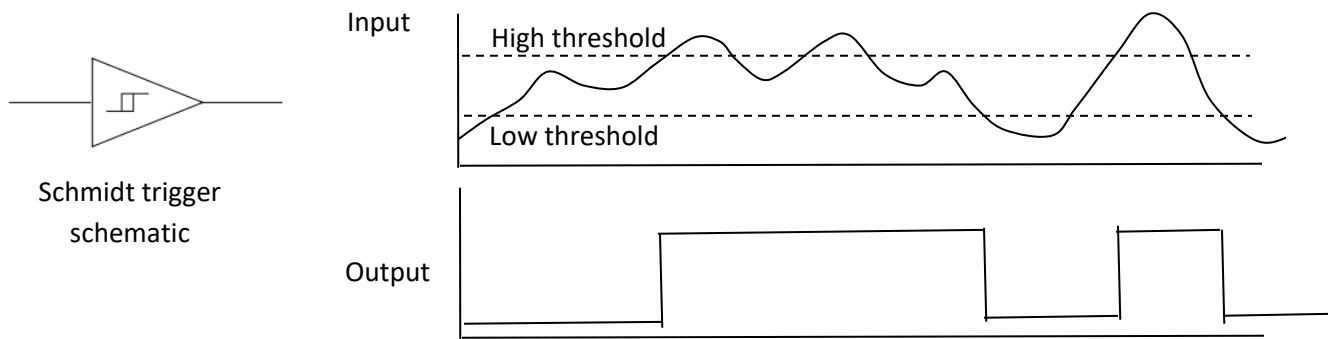


Figure A.1. Schmidt trigger.