# Chapter 10

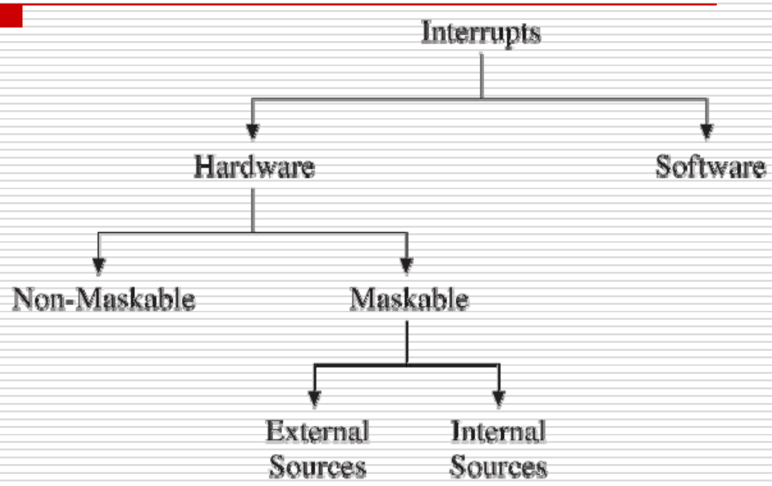
## Interrupts

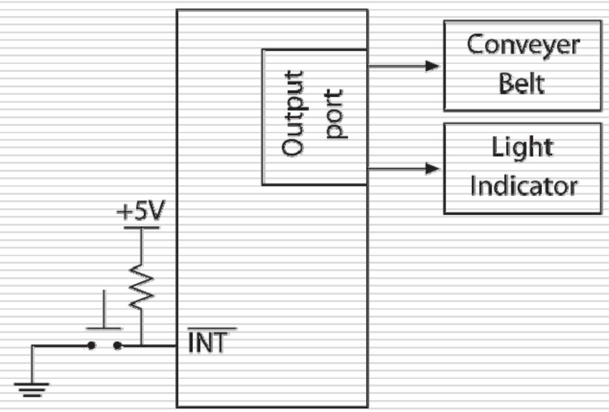
# Basic Concepts in Interrupts

- An interrupt is a communication process set up in a microprocessor or microcontroller in which:
  - An internal or external device requests the MPU to stop the processing
    - The MPU acknowledges the request
    - Attends to the request
    - Goes back to processing where it was interrupted

# Types of Interrupts

- Hardware interrupts
  - Maskable: can be masked or disabled
    - Two groups: external and internal interrupts
      - External through designated I/O pins
      - Internal by Timers, A/D, etc.
  - Non-maskable: cannot be disabled
- Software interrupts: generally used when the situation requires stop processing and start all over
  - Examples: divide by zero or stack overflow
  - Generally, microcontrollers do not include software interrupts



# MPU Response to Interrupts (1 of 2)

- When the interrupt process is enabled, the MPU, during execution, checks the interrupt request flag just before the end of each instruction.
- If the interrupt request is present, the MPU:
  - Completes the execution of the instruction
  - Resets the interrupt flag
  - Saves the address of the program counter on the stack
    - Some interrupt processes also save contents of MPU registers on the stack.
  - Stops the execution

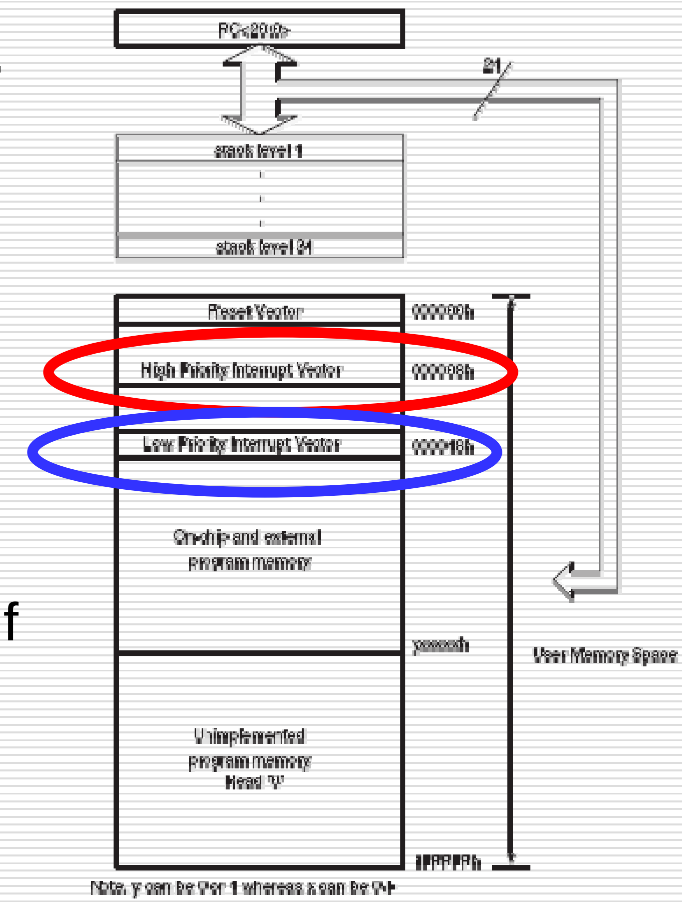
# MPU Response to Interrupts (2 of 2)

- To restart the execution, the MPU needs to be redirected to the memory location where the interrupt request can be met.
  - Accomplished by interrupt vectors
- The set of instructions written to meet the request (or to accomplish the task) is called an interrupt service routine (ISR).
- Once the request is accomplished, the MPU should find its way back to the instruction, next memory location where it was interrupted.
  - Accomplished by a specific return instruction

```
Main code
....
Setup interrupt vectors
....
HERE: GOTO HERE


ORG 0x100
INT1_ISR: ISR code
....
....
RETFIE

END
```

# Interrupt Vectors

- Direct the MPU to the location where the interrupt request is accomplished.
- They are:
  - Defined memory location where a specific memory location/s is assigned to the interrupt request
  - Defined vector location where specific memory locations assigned to store the vector addresses of the ISRs
  - Specified by external hardware: The interrupt vector address (or a part of it) is provided through external hardware using an interrupt acknowledge signal.

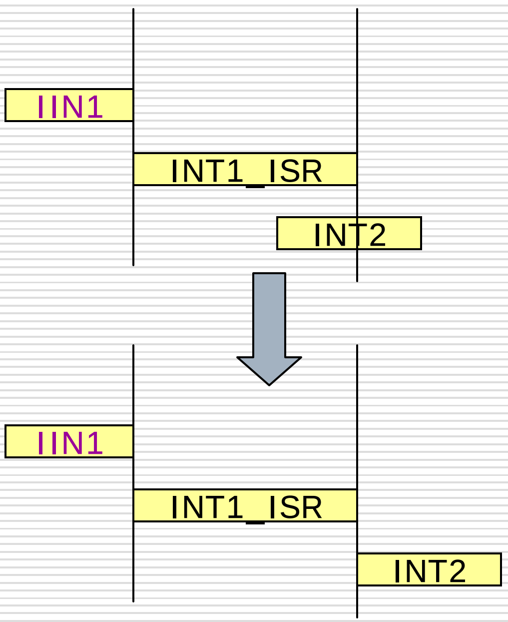


# Interrupt Service Routine (ISR)

- A group of instructions that accomplishes the task requested by the interrupting source
- Similar to a subroutine except that the ISR must be terminated in a Return instruction specially designed for interrupts
  - The Return instruction, when executed, finds the return address on the stack and redirects the program execution where the program was interrupted.
  - Some Return instructions are designed to retrieve the contents of MPU registers if saved as a part of the interrupts.
  - →RETFIE FAST (1/0)

# Interrupt Priorities

- Rationale for priorities
  - Multiple interrupt sources exist in a system, and more than one interrupt requests can arrive simultaneously.
    - Example: A/D and Timer0
  - When one request is being served (meaning when the MPU is executing an ISR), another request can arrive.
  - → the interrupt requests must be prioritized.
  - Most MCUs (and MPUs) include an interrupt priority scheme. Some are based on hardware and some use software.




**INT1 has higher priority than INT2**

# Reset as a Special Purpose Interrupt

- Reset is an external signal that enables the processor to begin execution or interrupts the processor if the processor is executing instructions.
- There are at least two types of resets in microcontroller-based systems.
  - Power-on reset and manual reset
- When the reset signal is activated, it establishes or reestablishes the initial conditions of the processor and directs the processor to a specific starting memory location.

# PIC18 Interrupts

- PIC18 Microcontroller family
  - Has multiple sources that can send interrupt requests
    - Does not have any non-maskable or software interrupts; all interrupts are maskable (can be disabled)
  - Has a priority scheme divided into two groups
    - High priority and low priority
  - Uses many Special Function Registers (SFRs) to implement the interrupt process

# PIC18 Interrupt Sources

- Divided into two groups
  - External sources and internal peripheral sources on the MCU chip
  - External sources
    - Three pins of PORTB -RB0/INTO, RB1/INT1,and RB2/INT2 (edge driven)
    - Change in logic levels of pins RB4-RB7 of PORTB can be recognized as interrupts
  - Internal sources
    - Use SFRs to setup the interrupt process....

# PIC18 Interrupt Sources

- Internal peripheral sources
  - Examples: Timers, A/D Converter, Serial I/O, and Low-Voltage Detection Module
- SFRs
  - Used to setup the interrupt process:
    - RCON — Register Control (global priority)
    - INTCON — Interrupt Control
    - INTCON2 — Interrupt Control2
    - INTCON3 — Interrupt Control3
    - PIR1 and PIR2 — Peripheral Interrupt Register1 & 2
    - PIE1 and PIE2 — Peripheral Interrupt Enable 1 & 2
    - IPR1 and IPR2 — Interrupt Priority Register 1 & 2

external interrupt sources

Handle Internal peripherals

**Click here: [Summery of Interrupt Registers]()**

# PIC18 Interrupt Sources

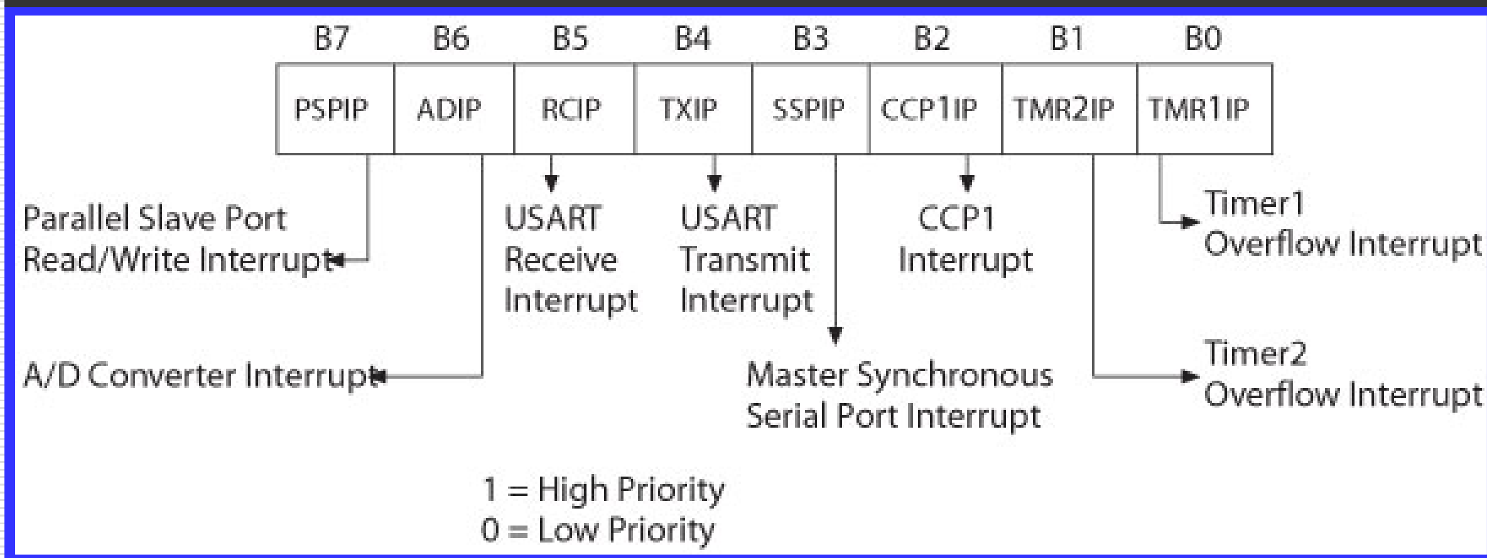
- To recognize the occurrence of an interrupt request, the MPU needs to check the following three bits:
  - The flag bit to indicate that an interrupt request is present
  - The enable bit to redirect the program execution to the interrupt vector address
  - The priority bit (if set) to select priority

# PIC18 Interrupt Sources

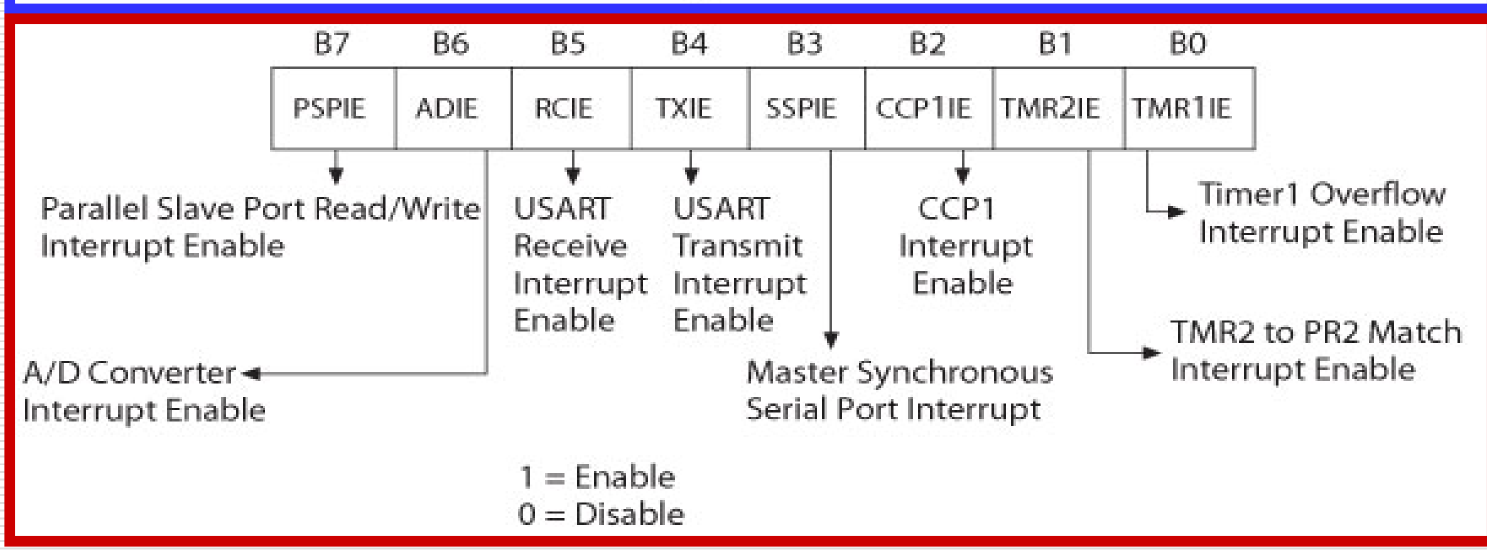
- In PIC interrupt are controlled by three bits in three different registers.
  - The IE bit is the interrupt enable bit used to enable the interrupt.
  - The IP bit is the interrupt priority bit which selects the priority (high or low).
  - The IF bit is the interrupt flag that indicates the interrupt has occurs. This bit **must be cleared** in the interrupt service function or no future interrupt will ever take effect.

| B7 | B6 | B5 | B4 | B3 | B2 | B1 | B0 |
|---|---|---|---|---|---|---|---|
| PSPIF[(1)] | ADIF | RCIF | TXIF | SSPIF | CCP1IF | TMR2IF | TMR1IF |

PIR (flag)



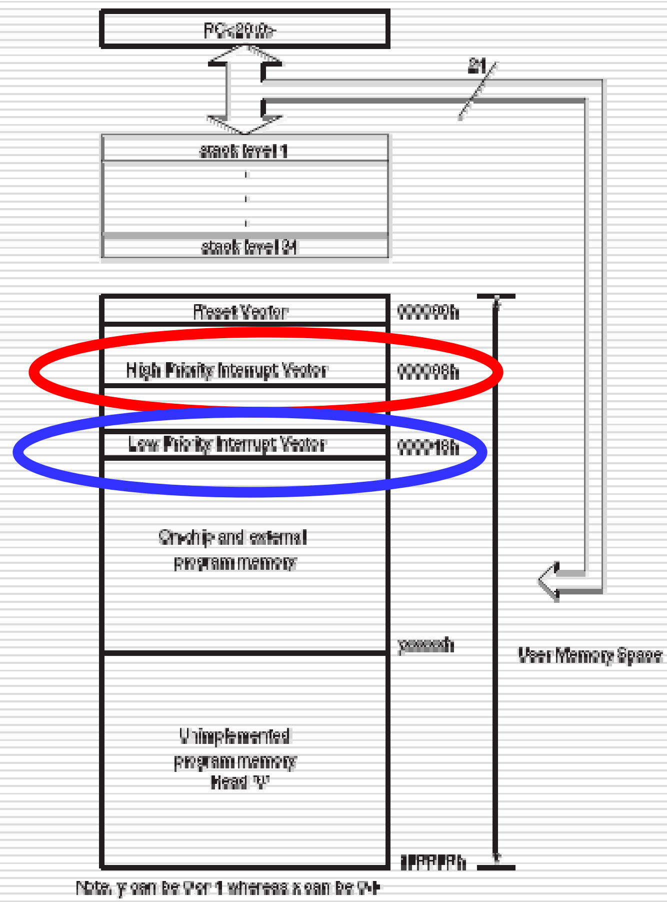

IPR (priority)
1=High Prio
0=Low Prio




PIE (peripheral)
1=Enable
0=Disable

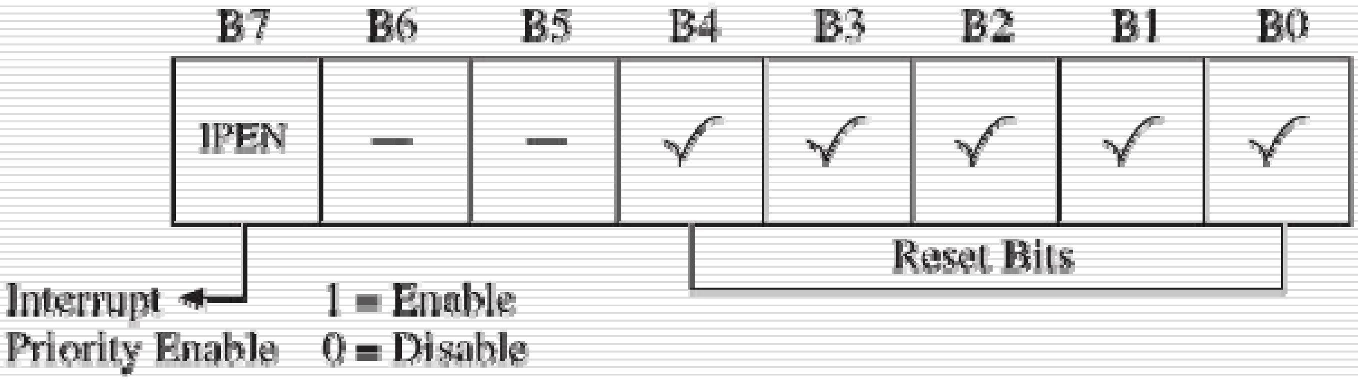
# Interrupt Priorities and RCON Register (1 of 2)

- Any interrupt can be set up as high-priority or low-priority.
  - All high-priority interrupts are directed to the interrupt vector location 000008H.
  - All low-priority interrupts are directed to the interrupt vector location 000018H.
  - A high-priority interrupt can interrupt a low-priority interrupt in progress.



# Interrupt Priorities and RCON Register (2 of 2)

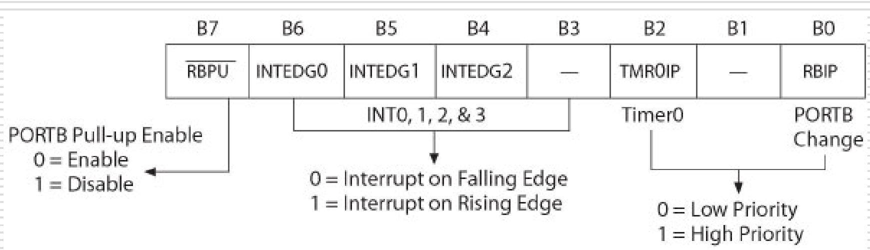
- The interrupt priority feature is enabled by Bit7 (IPEN) in RCON register.

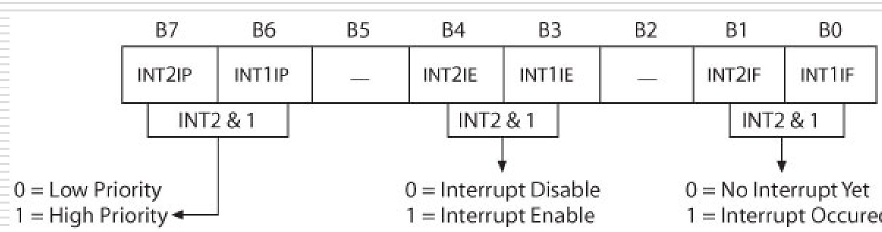


# External Interrupts and INTCON Registers (1 of 3)

- Three registers with interrupt bit specifications primarily for external interrupt sources. INTCON (3)

| B7 | B6 | B5 | B4 | B3 | B2 | B1 | B0 |
|---|---|---|---|---|---|---|---|
| GIE/GEIH | PEIE/GIEL | TMR0IE | INT0IE | RBIE | TMR0IF | INT0IF | RBIF |



# Example

- Write an instruction to setup INT1 as the high priority interrupt. (INT1 → RB1)

```
        ORG     0x00
        GOTO    MAIN

        ORG     0x0008
        GOTO    INT1_ISR

MAIN:   BSF     RCON,     IPEN
        BSF     INTCON,   GIEH
        BCF     INTCON2,  INTEDG1
        BSF     INTCON3,  INT1IP
        BSF     INTCON3,  INT1IE
        MOVLW   D'10'
        MOVWF   REG1,0
HERE:   GOTO    HERE

        ORG     0x100
INT1_ISR
        DECF    REG1,1,0
        BNZ     GOBACK
        MOVLW   D'10'
        MOVWF   REG1,0
GOBACK: RETFIE  FAST
        END
```

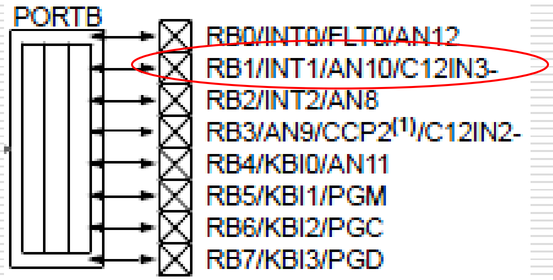
High Priority Interrupt Vector:

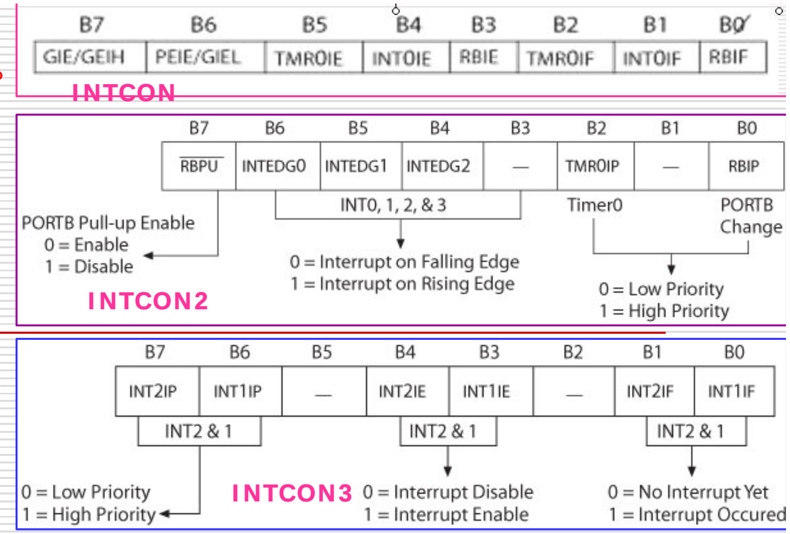
| | | | |
|---|---|---|---|
| 5 | 0008 | EF80 | GOTO 0x100 |
| 6 | 000A | F000 | NOP |
| 7 | 000C | 8ED0 | BSF 0xfd0, 0x7, ACCESS |
| 8 | 000E | 8EF2 | BSF 0xff2, 0x7, ACCESS |
| 9 | 0010 | 9AF1 | BCF 0xff1, 0x5, ACCESS |
| 10 | 0012 | 8CF0 | BSF 0xff0, 0x6, ACCESS |
| 11 | 0014 | 86F0 | BSF 0xff0, 0x3, ACCESS |
| 12 | 0016 | 0E0A | MOVLW 0xa |
| 13 | 0018 | 6E01 | MOVWF 0x1, ACCESS |
| 14 | 001A | FFFF | NOP |

ISR:

| | | | |
|---|---|---|---|
| 129 | 0100 | 0601 | DECF 0x1, F, ACCESS |
| 130 | 0102 | E102 | BNZ 0x108 |
| 131 | 0104 | 0E0A | MOVLW 0xa |
| 132 | 0106 | 6E01 | MOVWF 0x1, ACCESS |
| 133 | 0108 | 0011 | RETFIE 0x1 |
| 134 | 010A | FFFF | NOP |

# Example




- Software Setting

```
        ORG     0x00
        GOTO    MAIN

        ORG     0x0008
        GOTO    INT1_ISR

MAIN:   BSF     RCON,    IPEN
        BSF     INTCON,  GIEH
        BCF     INTCON2, INTEDG1
        BSF     INTCON3, INT1IP
        BSF     INTCON3, INT1IE
        MOVLW   D'10'
        MOVWF   REG1,0
HERE:   GOTO    HERE

        ORG     0x100
INT1_ISR
        DECF    REG1,1,0
        BNZ     GOBACK
        MOVLW   D'10'
        MOVWF   REG1,0
GOBACK: RETFIE  FAST
        END
```

If ZERO no priority (early versions)

If enabled → high priority → gates all H/L interrupts to the CPU (remember: GIEL enables all low-priorities Interrupts to the CPU

If 1 → rising edge (RB1)

If 1 → High Priority

If 1 → INT1 enabled

When INT1 goes from *high to low* value of REG1 decrements!

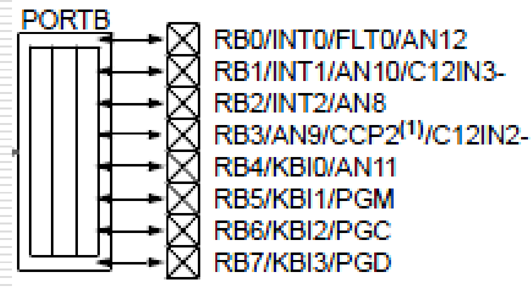
NOTE: INTCON3: FLAG bit is read only!

**Convert to C code!**

# Interrupt Setting (INT0 high priority only)

| Name | Priority Bit | Local Enable Bit | Local Flag Bit |
|---|---|---|---|
| INT0 external interrupt | * | INTCON,INT0IE | INTCON,INT0IF |
| INT1 external interrupt | INTCON3,INT1IP | INTCON3,INT1IE | INTCON3,INT1IF |
| INT2 external interrupt | INTCON3,INT2IP | INTCON3,INT2IE | INTCON3,INT2IF |
| RB port change interrupt | INTCON2,RBIP | INTCON,RBIE | INTCON,RBIF |
| TMR0 overflow interrupt | INTCON2,TMR0IP | INTCON,TMR0IE | INTCON,TMR0IF |
| TMR1 overflow interrupt | IPR1,TMR1IP | PIE1,TMR1IE | PIR1,TMR1IF |
| TMR3 overflow interrupt | IPR2,TMR3IP | PIE2,TMR3IE | PIR2,TMR3IF |
| TMR2 to match PR2 int. | IPR1,TMR2IP | PIE1,TMR2IE | PIR1,TMR2IF |
| CCP1 interrupt | IPR1,CCP1IP | PIE1,CCP1IE | PIR1,CCP1IF |
| CCP2 interrupt | IPR2,CCP2IP | PIE2,CCP2IE | PIR2,CCP2IF |
| A/D converter interrupt | IPR1,ADIP | PIE1,ADIE | PIR1,ADIF |
| USART receive interrupt | IPR1,RCIP | PIE1,RCIE | PIR1,RCIF |
| USART transmit interrupt | IPR1,TXIP | PIE1,TXIE | PIR1,TXIF |
| Sync. serial port int. | IPR1,SSPIP | PIE1,SSPIE | PIR1,SSPIF |
| Parallel slave port int. | IPR1,PSPIP | PIE1,PSPIE | PIR1,PSPIF |
| Low-voltage detect int. | IPR2,LVDIP | PIE2,LVDIE | PIR2,LVDIF |
| Bus-collision interrupt | IPR2,BCLIP | PIE2,BCLIE | PIR2,BCLIF |

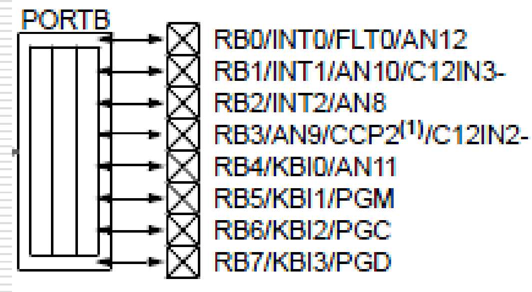
# C Code Example

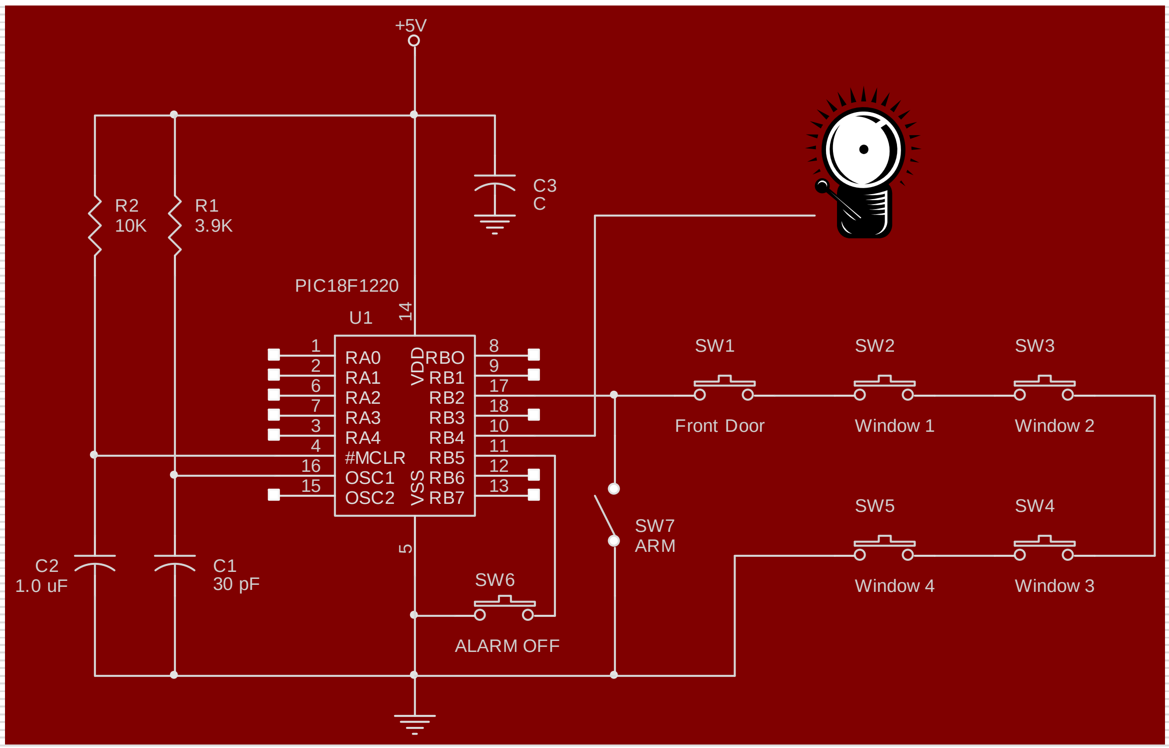



When a pulse is generated on INT0 the high priority interrupt is generated!

```
ADCON1 = 0x0F;                  // make ports pins digital

TRISB = 1;                      // make RB0 input

RCONbits.IPEN = 1;              // IPEN = 1

INTCON2bits.INTEDG0 = 0;        // make INT0 negative edge triggered
INTCONbits.INT0IE = 1;          // enable INT0
INTCONbits.GIEH = 1;            // enable high priority interrupts

// INT0 is now armed and active
```

# C Code Example – Burglar Alarm Circuit



# C Code Example – Burglar Alarm Code

```
#include <p18cxxx.h>
/* Set configuration bits
 *  - set RC oscillator
 *  - enable watchdog timer
 *  - disable low voltage programming
 *  - disable brownout reset
 *  - enable master clear
 */
#pragma config OSC = RC
#pragma config WDT = ON
#pragma config WDTPS = 4
#pragma config LVP = OFF
#pragma config BOR = OFF
#pragma config MCLRE = ON
```

```
void MyHighInt(void);
void MyLowInt(void);
#pragma interrupt MyHighInt
#pragma code high_vector=0x08
void high_vector(void)
{
        _asm GOTO MyHighInt _endasm
}

#pragma interruptlow MyLowInt
#pragma code low_vector=0x18
        // low_vector is the vector at 0x18
void low_vector(void)
{
        _asm GOTO MyLowInt _endasm
}
```

```
#pragma code
void MyHighInt(void)
{
}
void MyLowInt(void)
{
        if ( INTCON3bits.INT2IF == 1 )// is it INT2 pin?
        {
         INTCON3bits.INT2IF = 0;// clear INT2IF flag
         PORTBbits.RB4 = 1;// turn alarm ON
        }
}
```

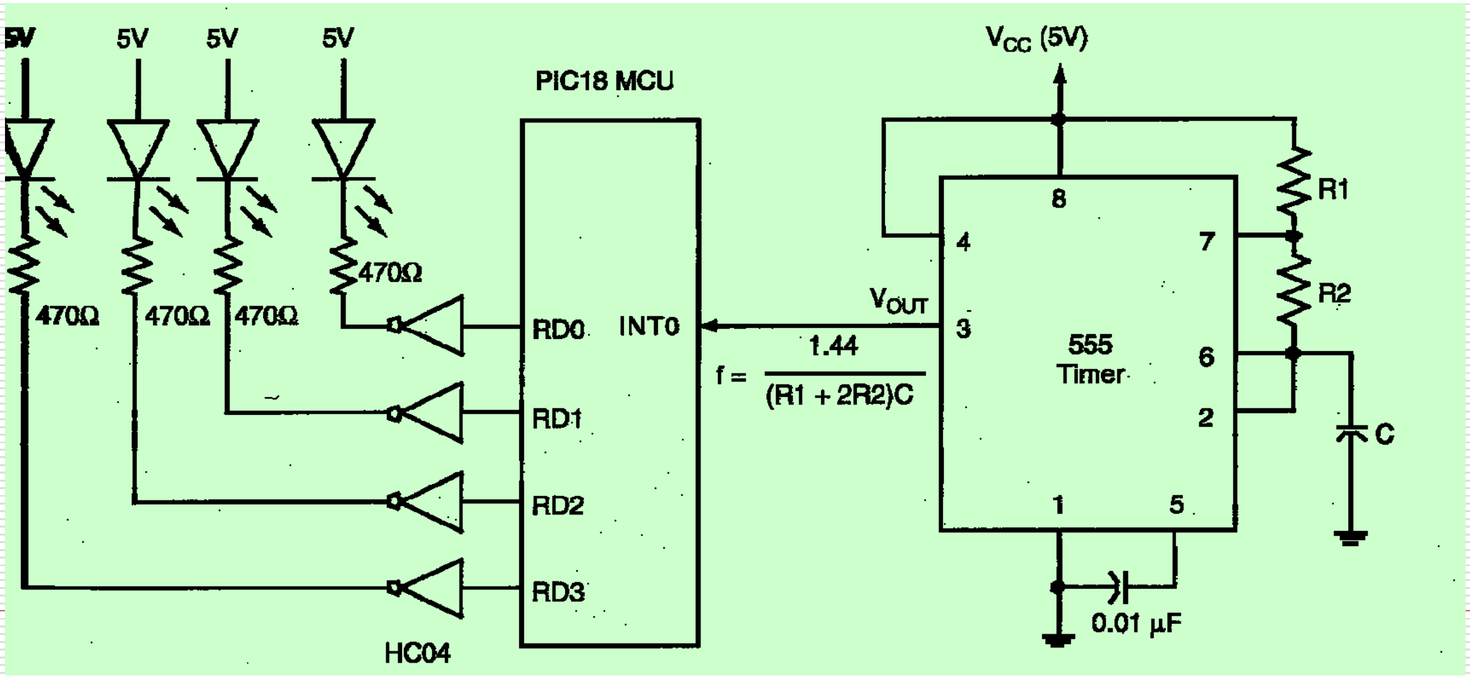
**ANSEL: ANALOG SELECT REGISTER 1 for PIC18F2XK20/4XK20**

```
// main program
void main (void)
{
        ADCON1 = 0x0F;                  // make ports pins digital
        TRISB = 0x24;                   // make RB2 and RB5 inputs
                                        // make RB4 and output
        PORTB = 0x00;                   // alarm off
        INTCON2bits.RBPU = 1;           // Port B pullups on
        RCONbits.IPEN = 1;              // IPEN = 1
        INTCON2bits.INTEDG2 = 1;        // make INT2 positive edge-trig
        INTCON3bits.INT2IP = 0;         // make INT2 low priority
        INTCON3bits.INT2IE = 1;         // enable INT2
        INTCONbits.GIEH = 1;            // enable high priority interrupts
        INTCONbits.GIEL = 1;            // enable low priority interrupts
        while( 1 )                      // main program loop
        {
                ClrWdt();               // pet spot (woof/pant)
                if ( PORTBbits.RB5 == 0 ) // pushbutton pressed
                        PORTBbits.RB4 = 0;      // alarm off
        }
}
```

**Do it in the LAB with LEDs and SWs**

# Another practical Example

Suppose you are given a circuit as shown below. Write a main program and an INT0 interrupt service routine in assembly language. The main program initializes a counter to 0, enables the INTO interrupt, and then stays in a while-loop to wait forever. The INT0 interrupts service routine simply increments the counter by 1 and outputs it to the LEDs. Whenever is incremented to 15, the service routine resets it to 0. Choose appropriate component that the PIC1 8 receives an INTO interrupt roughly every second.



# Handling Multiple Interrupt Sources

- In PIC18 MCU, all interrupt requests are directed to one of two memory locations:
  - 000008H (high-priority) or 000018 (low-priority)
- When multiple requests are directed to these locations, the interrupt source must be identified by checking the interrupt flag through software instructions.

IPR1

| PSPIP | ADIP | RCIP | TXIP | SSPIP | CCP1IP | TMR2IP | TMR1IP |
|---|---|---|---|---|---|---|---|

PIE1

| PSPIE | ADIE | RCIE | TXIE | SSPIE | CCP1IE | TMR2IE | TMR1IE |
|---|---|---|---|---|---|---|---|

# Example

```
BSF     INTCON, GIEL        ;Enable global low-priority - INTCON ,6>
BCF     IPR1, TMR1IP        ;Set Timer1 as low-priority
BSF     PIE1, TMR1IE        ;Enable Timer1 overflow interrupt
BCF     IPR1, TMR2IP        ;Set Timer2 as low-priority
BSF     PIE1, TMR2IE        ;Enable Timer2 match interrupt


BCF     PIR1, TMR1IF        ;Clear TMR1 flag
CALL    TMR1L               ;Call service subroutine

BCF     PIR1,TMR2IF         ;Clear TMR2 flag
CALL    TMR2                ;Call service subroutine
```

| Name | Priority Bit | Local Enable Bit | Local Flag Bit |
|---|---|---|---|
| RB port change interrupt | INTCON2,RBIP | INTCON,RBIE | INTCON,RBIF |
| TMR0 overflow interrupt | INTCON2,TMR0IP | INTCON,TMR0IE | INTCON,TMR0IF |
| TMR1 overflow interrupt | IPR1,TMR1IP | PIE1,TMR1IE | PIR1,TMR1IF |
| TMR3 overflow interrupt | IPR2,TMR3IP | PIE2,TMR3IE | PIR2,TMR3IF |
| TMR2 to match PR2 int. | IPR1,TMR2IP | PIE1,TMR2IE | PIR1,TMR2IF |

# Example of using multiple interrupts

INT1=High Priority / TMR1 and TMR2 Low Priority

| |
|---|
| Assign the High Priority Interrupt Vector |
| Assign the Low Priority Interrupt Vector |
| Setup the interrupt registers for external interrupt |
| Setup the interrupt registers for internal interrupts |

# Example of using multiple interrupts

## INT1=High Priority / TMR1 and TMR2 Low Priority

```
        ORG     0x00
        GOTO    MAIN

        ORG 0x0008
INTCK:
        GOTO    INT1_ISR
```

High priority

```
        ORG 0x00018
TIMERCK:
        BTFSC   PIR1,TMR1IF
        GOTO    TMR1_ISR
        BTFSC   PIR1,TMR2IF
        GOTO    TMR2_ISR
```

Low priority
Two interrupts
Check Flag

```
MAIN:

        BSF RCON,     IPEN
        BSF INTCON,   GIEH
        BSF INTCON2,  INTEDG1
        BSF INTCON3,  INT1IP
        BSF INTCON3,  INT1IE
```

INT is enabled
Edge driven

```
        BSF INTCON, GIEL
        BCF IPR1,  TMR1IP
        BSF PIE1,  TMR1IE
        BCF IPR1,  TMR2IP
        BSF PIE1,  TMR2IE
```

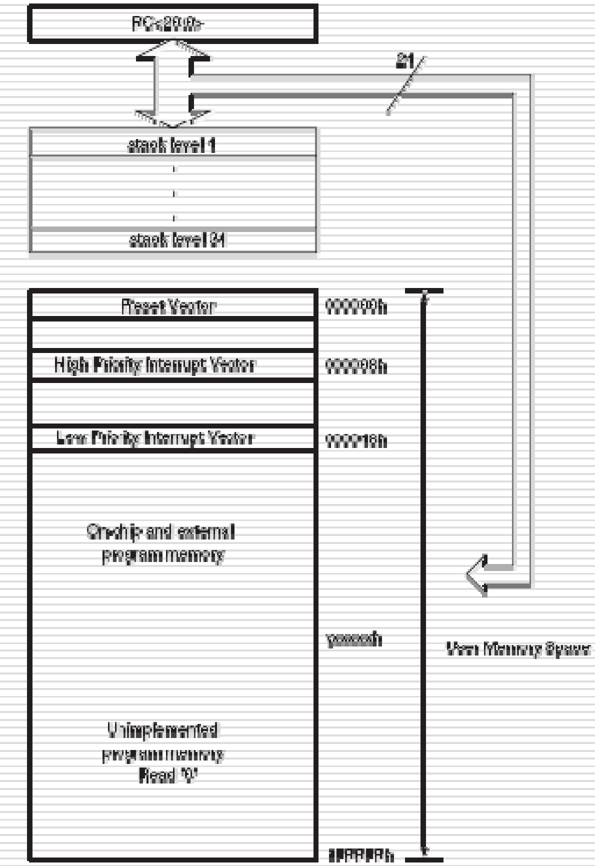
INT is enabled
Edge driven

```
0000   EF12   GOTO 0x24
0002   F000   NOP
0004   FFFF   NOP
0006   FFFF   NOP
0008   EF80   GOTO 0x100
000A   F000   NOP
000C   FFFF   NOP
000E   FFFF   NOP
0010   FFFF   NOP
0012   FFFF   NOP
0014   FFFF   NOP
0016   FFFF   NOP
0018   B09E   BTFSC 0xf9e, 0, ACCESS
001A   EF87   GOTO 0x10e
001C   F000   NOP
001E   B29E   BTFSC 0xf9e, 0x1, ACCESS
0020   EF91   GOTO 0x122
0022   F000   NOP
       0E3F   MOVLW 0x3f
       6E93   MOVWF 0xf93, ACCESS
0028   8ED0   BSF 0xfd0, 0x7, ACCESS
002A   8EF2   BSF 0xff2, 0x7, ACCESS
002C   8AF1   BSF 0xff1, 0x5, ACCESS
002E   8CF0   BSF 0xff0, 0x6, ACCESS
0030   86F0   BSF 0xff0, 0x3, ACCESS
0032   8CF2   BSF 0xff2, 0x6, ACCESS
0034   909F   BCF 0xf9f, 0, ACCESS
0036   809D   BSF 0xf9d, 0, ACCESS
0038   929F   BCF 0xf9f, 0x1, ACCESS
003A   829D   BSF 0xf9d, 0x1, ACCESS
003C   0E0A   MOVLW 0xa
003E   6E01   MOVWF 0x1, ACCESS
0040   EF20   GOTO 0x40
```

MAIN

# PIC18 Resets

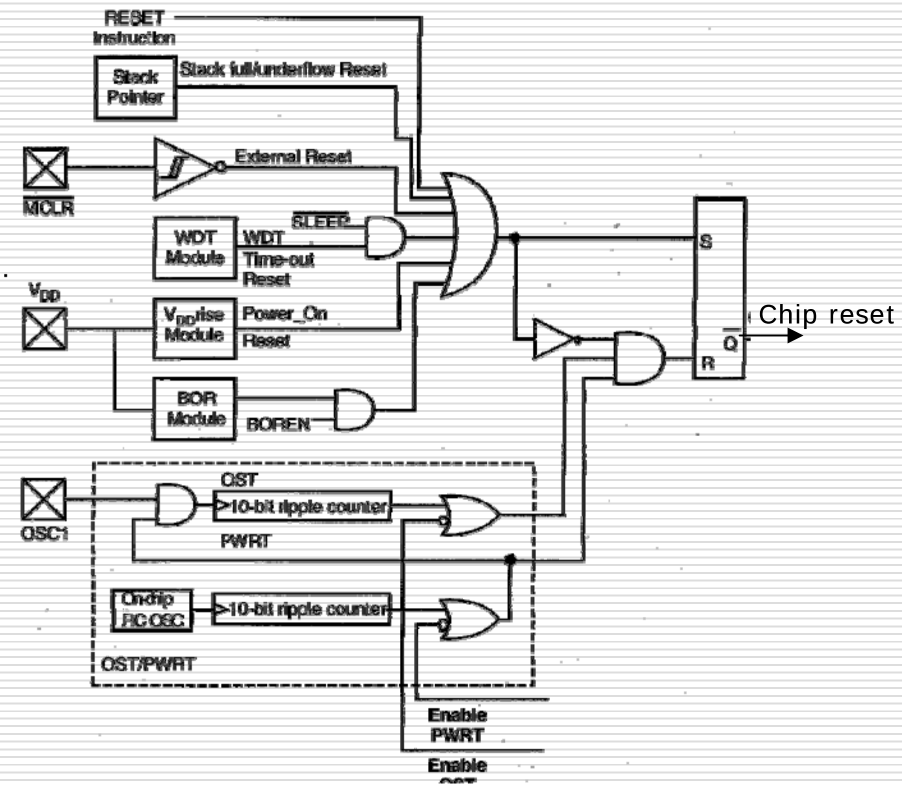
- When the reset signal is activated:
  - The MPU goes into a reset state during which the initial conditions are established.
  - The program counter is cleared to 000000 which is called the reset vector.
  - The MPU begins the execution of instructions from location 000000.



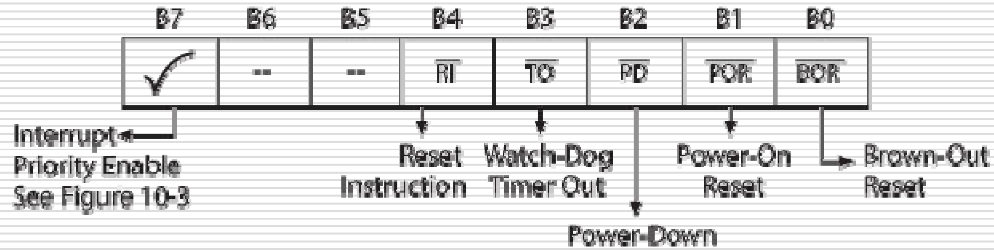

Note: y can be 0 or 1 whereas x can be 0-F

# On Chip reset circuit for PIC18

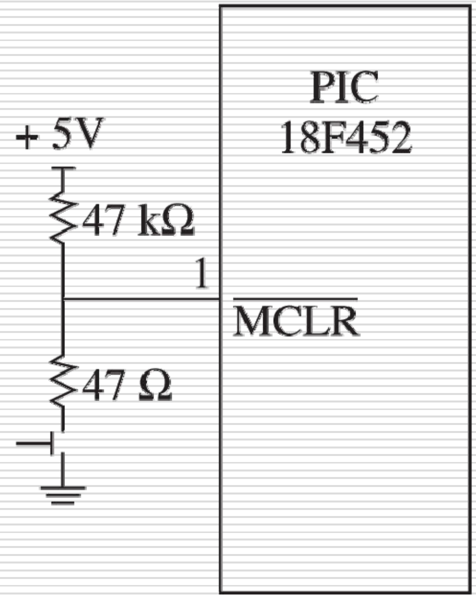
- Power-on reset (POR)
- $\overline{MCLR}$ pin reset during normal operation
- $\overline{MCLR}$ pin reset during SLEEP
- Watchdog timer (WDT) reset (during normal operation)
- Programmable brown-out reset (BOR)
- RESET instruction
- Stack full reset
- Stack underflow reset



# PIC18 Resets




- PIC18 MCU can be reset by external source such as the push-button key, or when power is turned-on, or by various internal sources.
  - Resets categorized as follows:
    - External Manual Reset Key
    - Power-on Reset (POR)
    - Watchdog Timer Reset (WDT)
    - Programmable Brown-Out Reset (BOR)
    - RESET and SLEEP Instructions
    - Stack Full and Underflow Reset




Find MCLR pin!

# Example of Reset Programming

- Identifying a power-on reset
- IF_ RCON,NOT_POR == 0 ;POR has occurred
- setf RCON ;Reinitialize all reset flags after power on
- <take action particular to power—on reset>
- ENDIF_

- Identifying a reset due to execution of a “reset” instruction
- IF_ RCON,NOT_RI == 0 ;reset’ instruction has been executed
- bsf RCON.NOT_RI ;Set bit to distinguish froe other resets
- <take appropriate action in response to “reset” instruction>
- ENDIF