Programming a PIC Microcontroller

A Short Tutorial

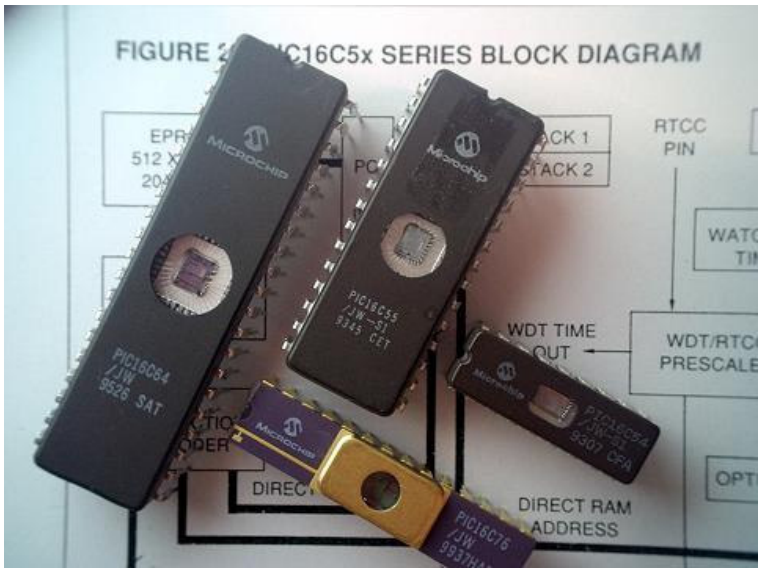

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Table of Contents

Revision Record

Name	Date	Reason For Changes	Version
Yesu Thommandru	11/17/06	Started tutorial	1.0
Yesu Thommandru	11/18/06	Finished majority of tutorial	1.1
Yesu Thommandru	11/19/06	Added breadboard images, finished and posted tutorial on Dec06-04 website.	1.2

1. Introduction

1.1 Purpose

The purpose of this document is to provide a simple, easy to use tutorial on programming PIC microcontrollers. The tutorial begins with instructions on selecting a specific PIC and ends with directions for breadboarding the microcontroller.

1.2 Document Conventions

In this document different styles of text and visuals are used to help the reader separate different types of information. General description text will be in this format, size 11 italicized Arial. Pseudo-code or source code will be written in multi-color, size 10 Courier New font as in the following example:

```
#include <stdio.h>

void main(int argc, char *argv[])
{
      printf("Star Wars!\n");
      return;
}
```

Buttons and menu items will be in standard Arial text such as Button *with the first letter underlined. Important notes and pieces of information will appear in normal text in shaded boxes as in the following example:*

NOTE: I think Darth Vader would win in a fight against Boba Fett!

1.3 Intended Audience and Reading Suggestions

The intended audience of this document is students in the Department of Electrical and Computer Engineering enrolled in EE/CprE 491 or 492 Senior Design. This document can also be used by any student or individual who wishes to learn the basics of how to program a PIC microcontroller.

There are a number of suggested readings for any users of this document. The following books are suggested for specific PIC programming tasks:

- *Introduction to microelectronic systems: the PIC 16F84 microcontroller by Martin Bates.*
- *PIC microcontroller: an intro to software and hardware interfacing by Han-Way Huang.*
- *The PIC microcontroller: your personal introductory course by John Morton.*
- *PIC microcontroller project book by John Lovine.*
- *Programming and customizing the PIC microcontroller by Myke Predko.*
- *The quintessential PIC microcontroller by Sid Katzen.*

NOTE: In my experience most of software in these books is written in Assembly and are thus not useful to students wishing to program in a high-level programming language.

1.4 References

Schildt, Herbert. C/C++ Programmer's Reference 2nd Edition. McGraw-Hill Publishing. New York, 2000.

Morton, John. PIC Your Personal Introductory Course. Newnes. Boston, 1998.

Bergquist, Carl. Guide to PICMICRO Microcontrollers. Sams Technical Publications. Indianapolis, 2001.

Predko, Myke. Handbook of Microcontrollers. McGraw-Hill Publishing. New York, 1999.

Predko, Myke. PICMicro Microcontroller Pocket Reference. McGraw-Hill. New York. 2000.

Smith, D.W. PIC in Practice. Newnes. Oxford. 2002.

Microchip.com. PIC16F877A. 2006. <http://www.microchip.com/>

MicrochipC.com PICMicros and C <http://www.microchipc.com/>

Best Microcontroller Projects <http://www.best-microcontroller-projects.com/index.html>

2. Choosing a PIC Microcontroller

2.1 Introduction

PIC microcontrollers are popular processors developed by Microchip Technology with built-in RAM, memory, internal bus, and peripherals that can be used for many applications. PIC originally stood for "Programmable Intelligent Computer" but is now generally regarded as a "Peripheral Interface Controller".

2.2 Types of PICs

PIC microcontrollers are broken up into two major categories: 8-bit microcontrollers and 16-bit microcontrollers. Each category is further subdivided into product families as shown in the following table:

8-bit MCU Product Family	16-bit MCU Product Family
PIC10 PIC12 PIC14 PIC16 PIC18	PIC24F PIC24H dsPIC30 dsPIC33

The microcontrollers in the PIC10 through PIC14 families are considered low-end microcontrollers. PIC microcontrollers in the PIC16 and PIC18 families are considered mid-level microcontrollers while 16-bit PICs are considered high-end microcontrollers.

NOTE: The majority of students and projects will require mid-level microcontrollers. The most popular PIC used in senior design is the PIC16F877/A.

Each PIC has unique features and subtle differences. The correct choice for your project depends on many factors:

- *Does the project require analog input or output?*
- *Does the project require digital input or output?*
- *How many I/O pins are required?*
- *Does the project require precise timing?*
- *How much memory does the project require?*
- *Is serial I/O required?*
- *Etc.*

PICs also come in several types of packages:

- *Plastic Dual Inline Package (PDIP)*
- *Small-Outline Transistor (SOT)*
- *Dual Flat No-lead (DFN)*
- *Mini Small Outline Package (MSOP)*
- *Thin Quad Flat Pack (TQFP)*
- *Plastic Leaded Chip Carrier (PLCC)*
- *CERamic QUADpack (CERQUAD)*

The reason for the number of packages is that there are some PICs with 100 I/O pins! The microcontrollers are basically rectangular or square shaped. The easiest package to work with is DIP or PDIP because it is easily breadboardable and can easily be soldered.

NOTE: Use a mid-level dual inline package PIC microcontroller. You will not be able to burn software into a QUAD chip and SOP chips will require Schmartboards.

3. Integrated Development Environment

In order to develop your software and organize your files you will have to use an integrated development environment. The number one IDE used with PIC microcontrollers is MPLab IDE by Microchip Technology. MPLab IDE is free and easy to use. Just go to http://www.microchip.com/ to download the latest version.

NOTE: The latest version of MPLab IDE ends in zero. e.g. v7.50. Files not ending in zero are interim versions of MPLab IDE.

You can also download the MPLab IDE User's Guide, Quick Chart, and Quick Start Guide. After you have downloaded the latest version of MPLab IDE install the software on your local drive.

4. Programming Language

PIC microcontrollers can be programmed in Assembly, C or a combination of the two. Other high-level programming languages can be used but embedded systems software is primarily written in C. The following three examples demonstrate the programming styles.

Example 1 – Assembly

```
MAIN

      clrf  PORTB       ;Clear PORTB output latches
      bsf   STATUS,RP0        ;Switch to bank 1
      movlw b'11110000' ;Load value to make lower 4 bits outputs
      movwf TRISB       ;Move value to TRISB
      bcf   STATUS,RP0        ;Switch to bank 0
LOOP
      bsf   PORTB,0           ;Turn on LED on RB0
      call  DELAY       ;Call delay routine
      bcf   PORTB,0           ;Turn off LED on RB0
      call  DELAY       ;Call delay routine
      goto  LOOP        ;Repeat main loop

DELAY
      decfsz      COUNTERL    ;Decrement COUNTERL
      goto  DELAY       ;If not zero, keep decrementing COUNTERL
      decfsz      COUNTERH    ;Decrement COUNTERH
      goto  DELAY       ;If not zero, decrement COUNTERL again
      return
      END
```

Example 2 – Assembly and C

```
main()
{
short first_pass = TRUE;

      //----- Set up port direction reg's -----
      #asm
            movlw 0           // Set port b to outputs
            tris port_b
            clrf port_b

            movlw 0xff  // Set port a to inputs
            tris port_a
      #endasm

      //----- Wait for powerup, Initilize LCD -----
      delay_ms(200);
      init_lcd();

      //----- Write a startup message -----
      msg_1();

      //----- Write status message -----
      msg_2();
      …
```

Example 3 – C

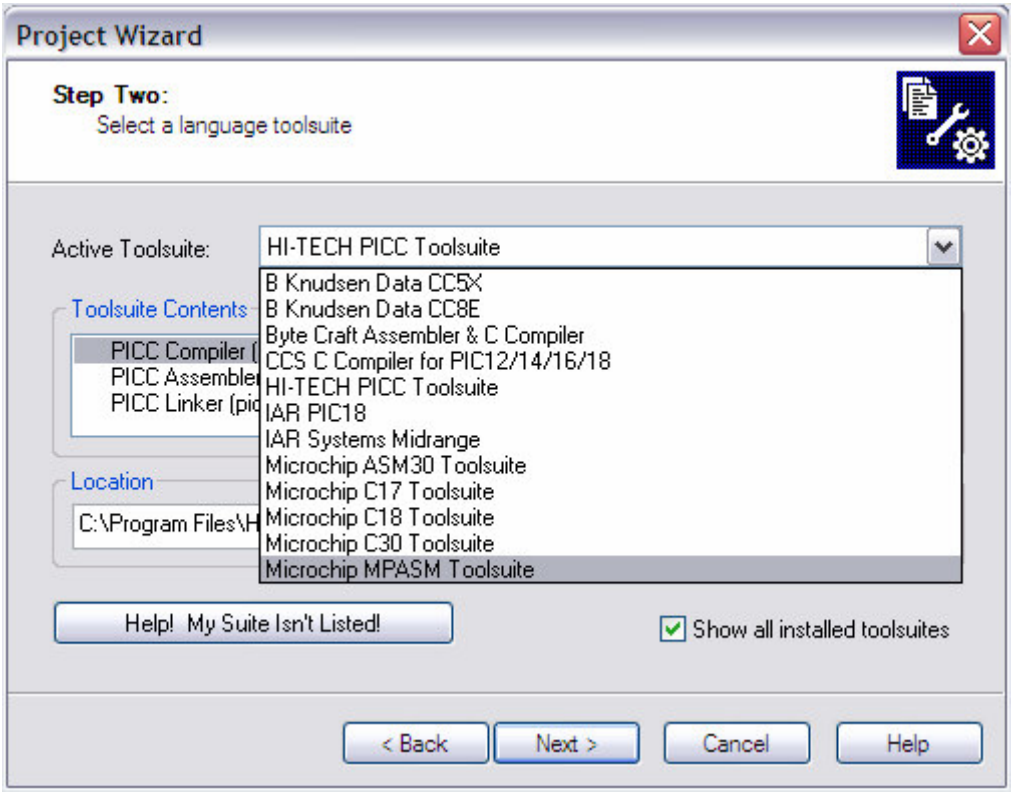
```
void main() {

U8  i           = 0;  // General purpose loop var.
U16 num            ;  // General purpose number var.
U8 row          = 0;  // Current display row.
U16 blinkc      = 0;  // LED blinker counter.
U16 blink_onoff = 1;  // LED state.
U8 bcd_h,bcd_m,bcd_s; // BCD numbers.

   init_ports();
   init();
   enable_interrupts();

   ROW_RESET;

   ////////////////////////////

   for (;;) { // infinite loop

      // FLASH LED @ RA3
      if (++blinkc>500) {  // time to change state ?
         blinkc=0;
      …
```

I suggest writing your code completely in C because it is much faster and easier than writing your code in Assembly or a combination of languages.

NOTE: The version of C that you use to write you software will depend on the C compiler you choose to use in your project.

5. Compiler, Assembler, and Linker

Once you have downloaded and installed MPLab IDE and chosen a programming language you will have to select a compiler. The compiler, assembler, and linker are usually combined in a single package. In MPLab IDE you can choose you compiler by using the Project Wizard or selecting the menu option Project → Select Language Toolsuite. *The following image shows some of the available toolsuites in MPLab IDE:*



Most of the toolsuites are NOT preinstalled and are quite expensive. As a student you will most likely be interested in the free toolsuites that come with MPLab IDE which are Microchip MPASM Toolsuite and CCS C Compiler for PIC12/24/26/18. Other free compilers that can be integrated into MPLab IDE are available on the web.

NOTE: The CCS C Compiler is free but incompatible with many PIC microcontrollers. Check the supported device list at *http://www.ccsinfo.com/devices.php?page=devices*

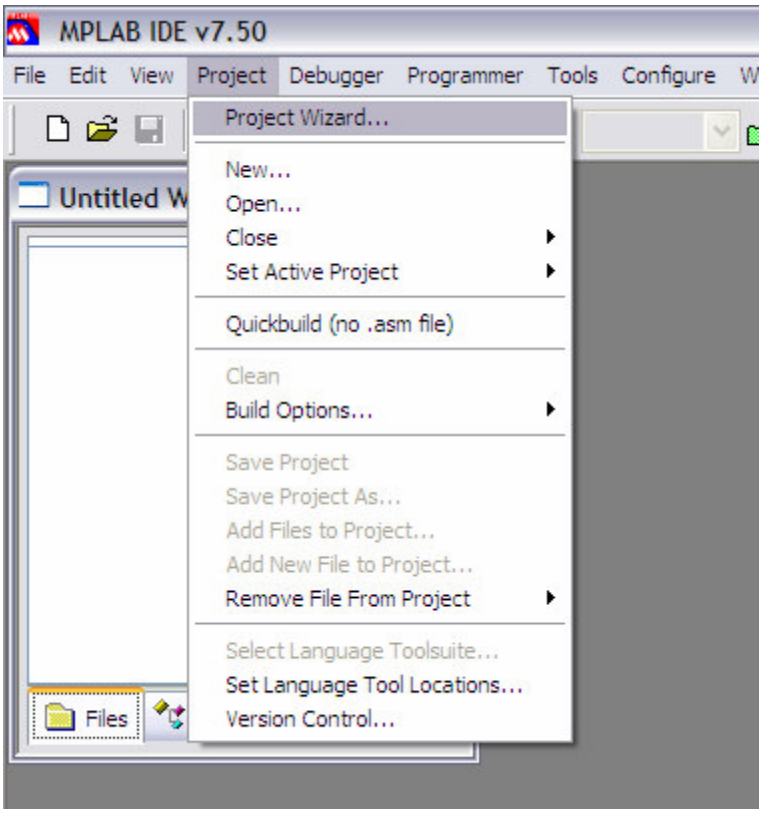
Because of the previous note I searched in the Internet for a free C compiler. I came across the HI-TECH PICC-Lite compiler available at http://htsoft.com/products/PICClite_comparison.php. The compiler can be easily installed and integrated into MPLab IDE.

6. Using MPLab IDE

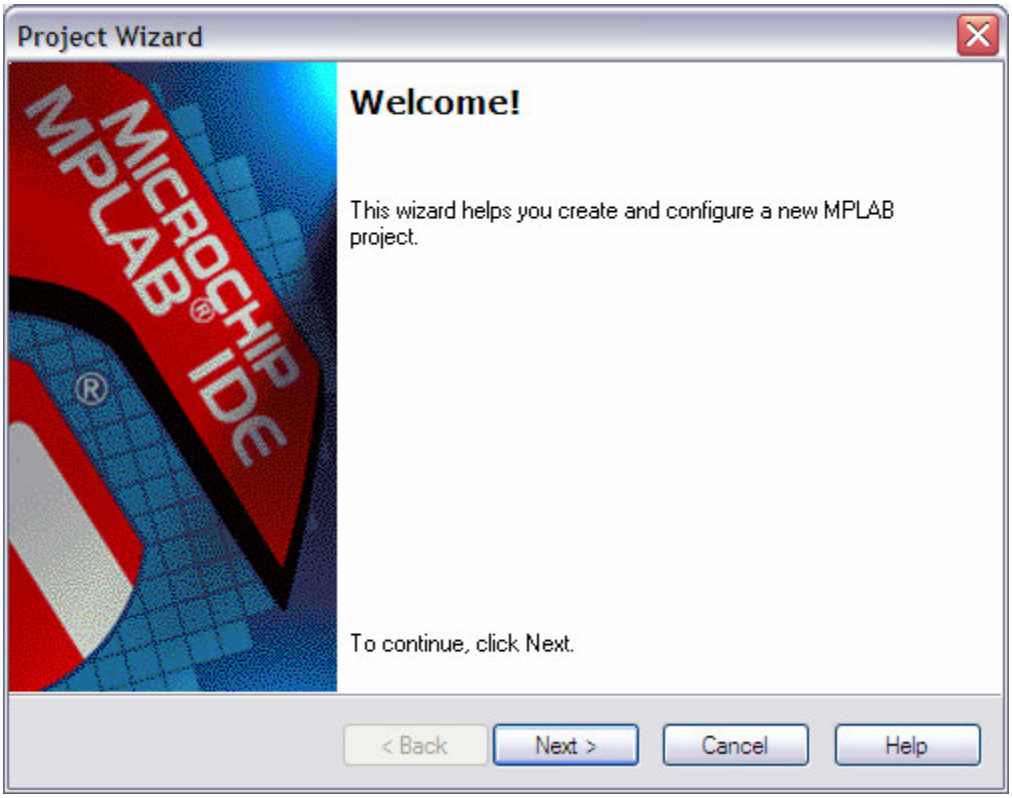
Let's start writing software in MPLab IDE in the C programming language by creating a new project.

Open MPLab IDE and observe the Workspace and Output windows. The Workspace window organizes the files in your project in an easy to see hierarchy.

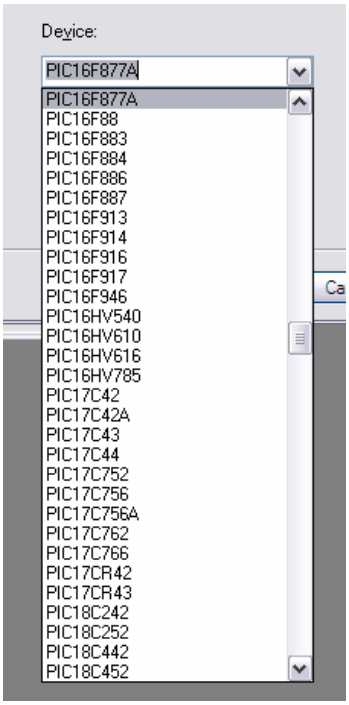
Select Project → Project Wizard *to create a new project as shown in the following image:*



You should see the following welcome message in a dialog window:

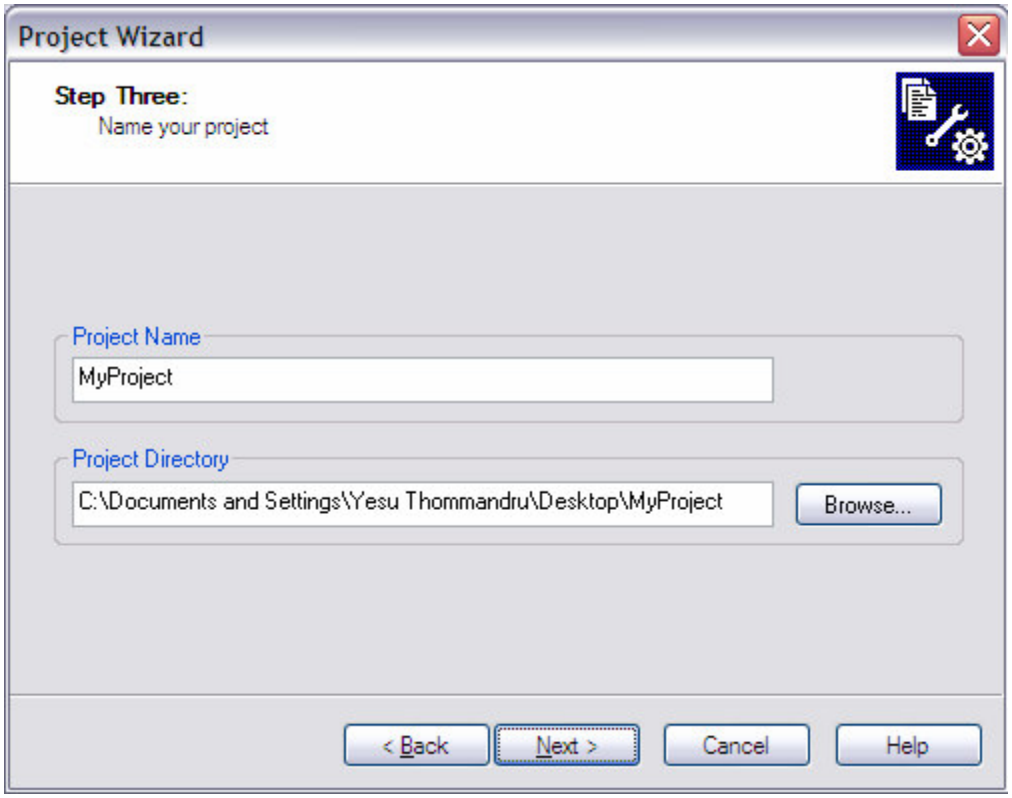


Hit Next > *and you will see enter Step One: Select a device. There will be a single pull down menu with a huge amount of PIC microcontrollers to choose from.*



After selecting your device hit Next > *and you will enter Step Two: Select a language toolsuite (see section 5). Choose your compiler and hit* Next >.

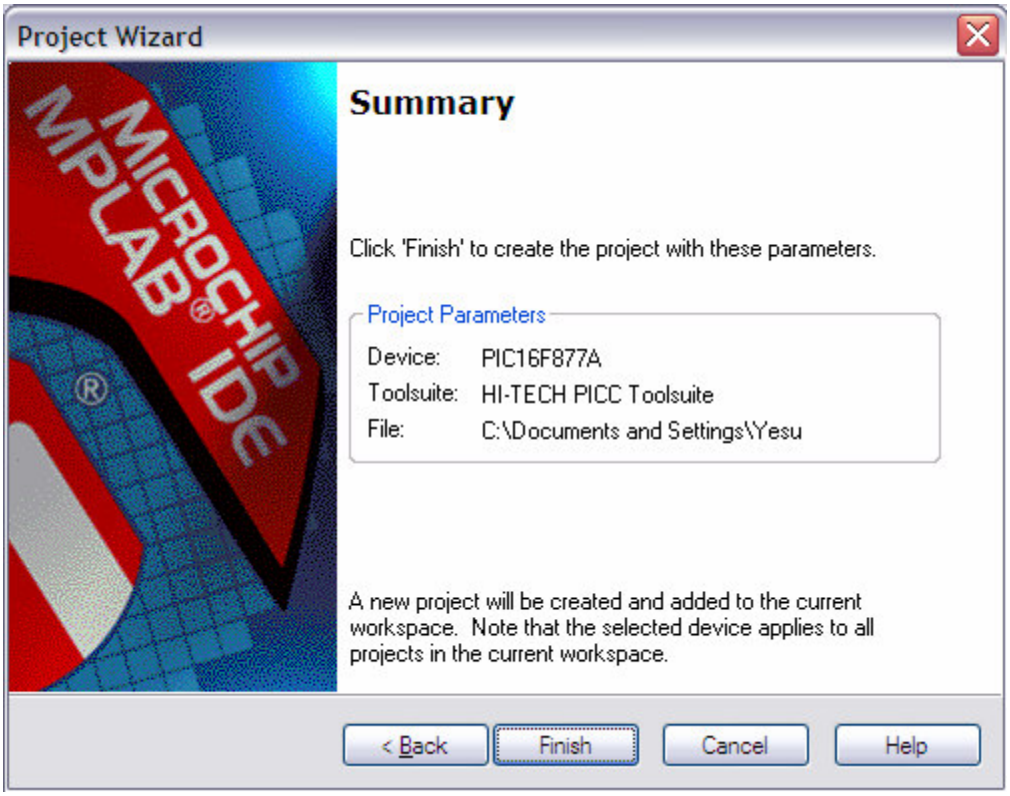
You should be at a window called Step Three: Name your project. Enter your project name, choose a directory, and hit Next >. *In this example we will create a project called MyProject and create a folder on the desktop.*



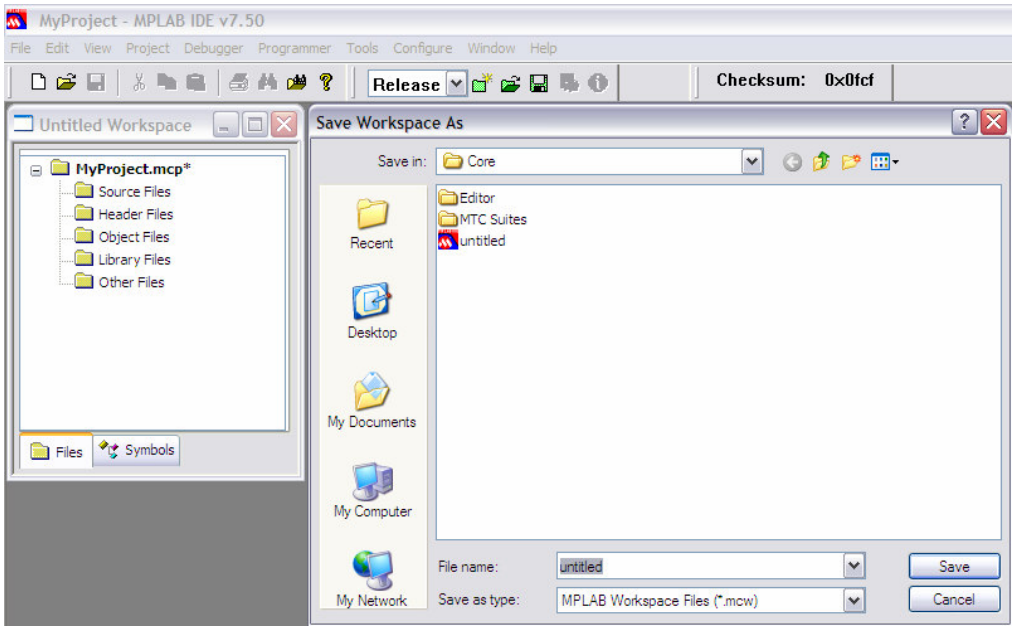
Step Four: Add existing files to your project allows you to add any required files into your project directory. Examples of required files are <pic.h>, <stdlib.h>, and <string.h>. Add any necessary files to your project and hit Next >. *(In this example we'll skip this step)*

TIP: If you're using the HI-TECH PICC-Lite compiler there are several helpful files such as lcd.h, lcd.c, delay.h, delay.c and many others in the folder /HI-TECH Software\PICC-Lite\9.50\samples that can help you in your project.

The last window in the Project Wizard is a summary of the options you have selected. If everything looks ok hit Finish *to create the project.*



After hitting Finish *you will be presented with a dialog window asking you to save your workspace. A workspace is a file that allows a user to gather and organize various sources and resources. Rename and save your workspace in the project directory.*



Your workspace window now contains a hierarchy of folders for your project.

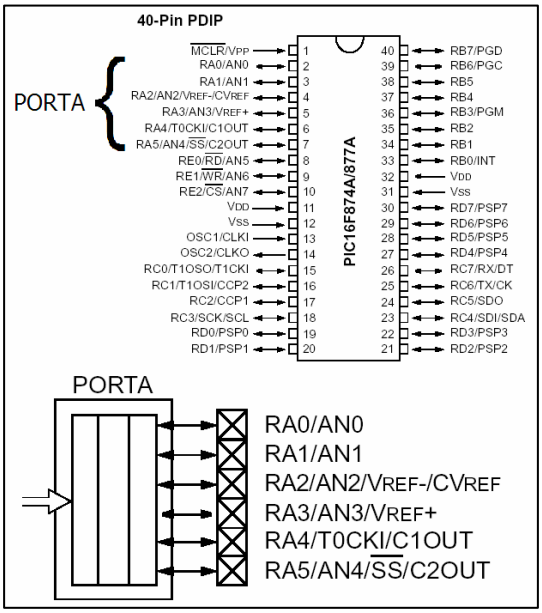
7. Writing Software

We will now write basic software in C using MPLab IDE. The following program flashes an LED on one of the PORTA pins of the PIC microcontroller (look at the PIC's datasheet).

main.c

```
//LED example program written for
//PIC programming tutorial.

//standard include files
#include <stdlib.h>
#include <pic.h>
#include "delay.h"

//main function
void main()
{
	PORTA = 0x00;	//set RA0-RA5 low
	TRISA = 0x00;	//set PORTA to output

	//superloop
	while(1)
	{
		PORTA = !PORTA;
		DelayMs(250);
	}
}
```

For basic C operations and delays the files stdlib.h and delay.h are needed. The file pic.h is required for access to the PIC microcontrollers I/O pins, memory locations, and other components. The following diagram shows how I/O pins on a PIC16f877A correspond to software variables:



PORTA in the file main.c refers to the 6-bit I/O port on the PIC microcontroller. Each pin can be set high or low using simple masking commands: PORTA = 0x01 sets RA0 high. Multiple pins can be set: PORTB = 0xFF. Check the datasheet for the number and size of ports on your PIC.

TRISA is a direction control register corresponding to PORTA. The corresponding TRIS registers have the same bit width as the ports they control. Setting a tris bit to 1 signals that an I/O pin on that port will be used as an input pin. Setting a tris bit to 0 signals that an I/O pin will be used as an output pin.

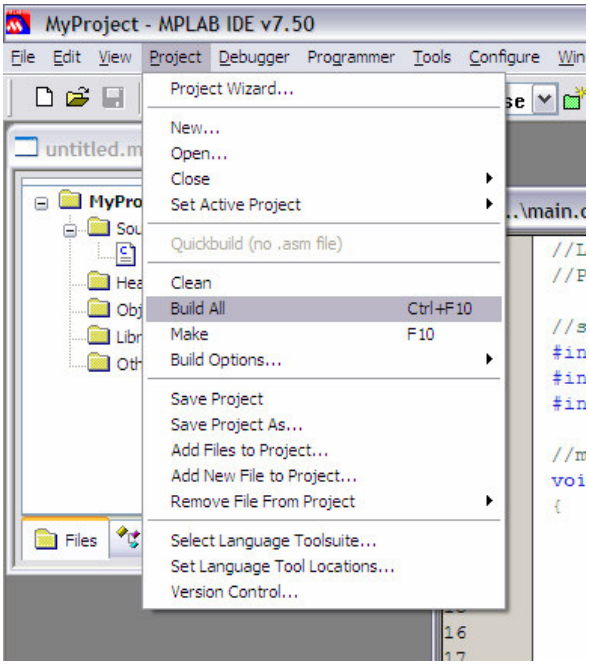
TIP: Usually the first function called when entering the main function is an initialization function that sets all ports and their directions.

The program then enters a superloop and flips PORTA on and off with a delay of 250 milliseconds. The structure, purpose, and complexity of your software depend on the application of use of your PIC microcontroller. For a good source on programming microcontrollers in C visit http://www.best-microcontroller-projects.com/programming-microcontrollers-in-c.html.

NOTE: Standard C functions such as printf() or scanf() are meaningless in embedded programming. In order to test I/O functionality the PIC will have to be breadboarded.

8. The "Burning" Process

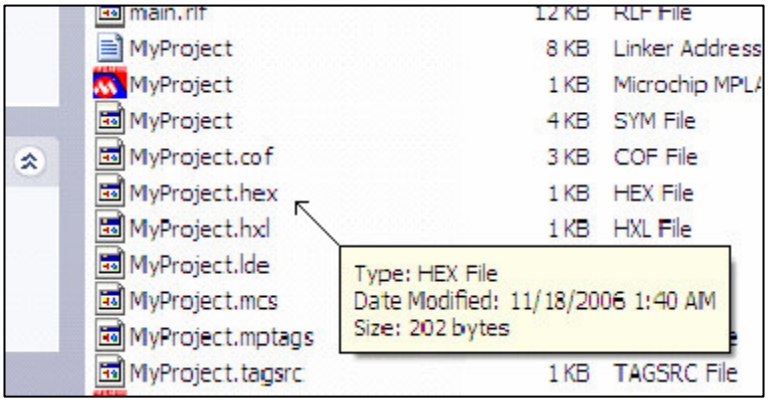
Once you have you software written you can compile your code to check for syntactical errors. The first important step in the "Burning" processing is building your project. Before building your project make sure your configuration bits are set appropriately by selecting Configure → Configuration Bits. *Then select* Project → Build All *or hit* Ctrl + F10 *to build your project.*



The output window will print the results of each step in the build process. You will probably receive some warning or advisory messages. If the build process was successful the output window should print a Memory Usage Map that looks like the following:

```
Memory Usage Map:

Program space:
   CODE             used    21h (    33) of   800h words   (  1.6%)
   CONST            used     0h (     0) of   800h words   (  0.0%)
   ENTRY            used     0h (     0) of   800h words   (  0.0%)
   STRING           used     0h (     0) of   800h words   (  0.0%)

Data space:
   BANK0            used     3h (     3) of    60h bytes   (  3.1%)
   BANK1            used     0h (     0) of    50h bytes   (  0.0%)
   COMBANK          used     0h (     0) of    10h bytes   (  0.0%)

EEPROM space:
   EEDATA           used     0h (     0) of   100h bytes   (  0.0%)

ID Location space:
   IDLOC            used     0h (     0) of     4h bytes   (  0.0%)

Configuration bits:
   CONFIG           used     0h (     0) of     1h word    (  0.0%)

Summary:
   Program space       used    21h (    33) of   800h words   (  1.6%)
   Data space          used     3h (     3) of    B0h bytes   (  1.7%)
   EEPROM space        used     0h (     0) of   100h bytes   (  0.0%)
   ID Location space   used     0h (     0) of     4h bytes   (  0.0%)
   Configuration bits  used     0h (     0) of     1h word    (  0.0%)

Loaded C:\MyProject\MyProject.cof.
BUILD SUCCEEDED: Sat Nov 18 01:34:23 2006
```

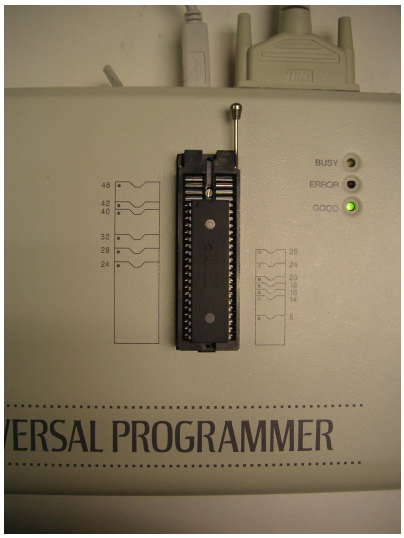
When you build your project a large amount of files are created and stored in your project directory. The most important file created is the hexadecimal file as shown in the following image:



This is the file that will be "burned" into your PIC microcontroller. Copy this HEX file and take it to the computer connected to your available programmer.

NOTE: The senior design lab (Town Engineering room 316) has an easy to use Dataman Universal Programmer used to program PIC microcontrollers.

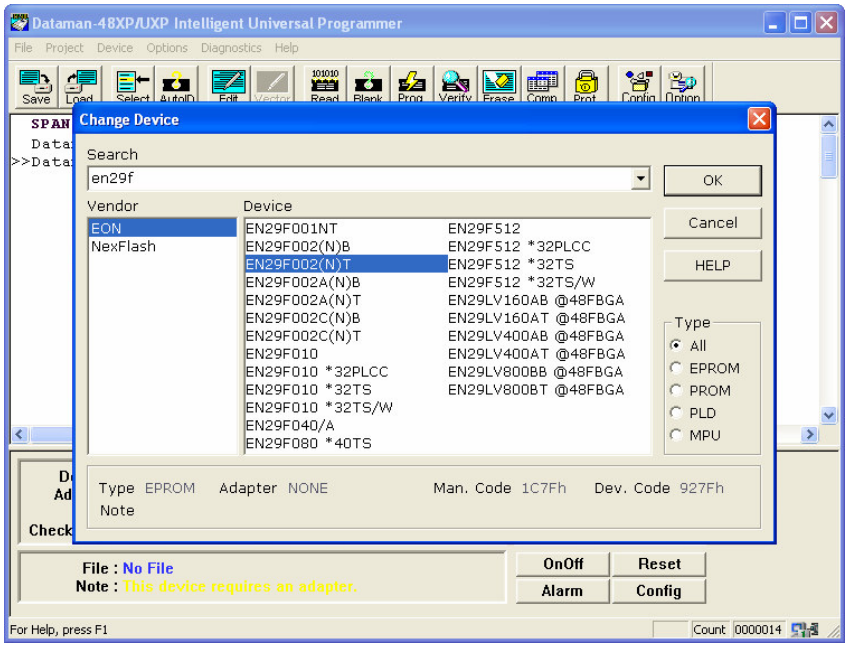
Place your PIC microcontroller in the black ZIF socket and place the silver lever in the down position to clamp onto the I/O pins.



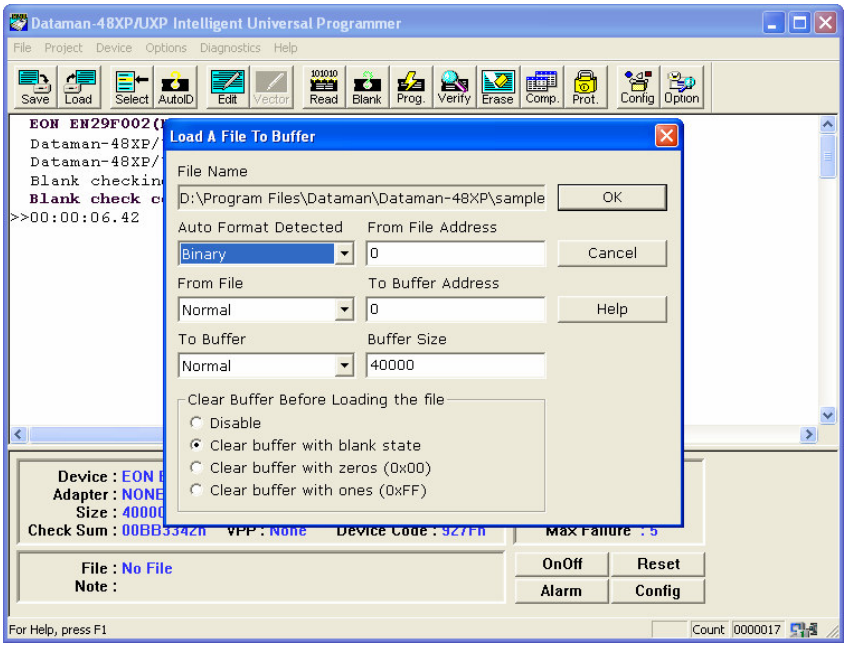
Start the Dataman Programmer software by going to Start → All Programs → Dataman Programmers → Dataman-48XP. *There are basically three steps in the Dataman Programmer "burning" process:*

1. *Select device*
2. *Load HEX file*
3. *Program PIC*

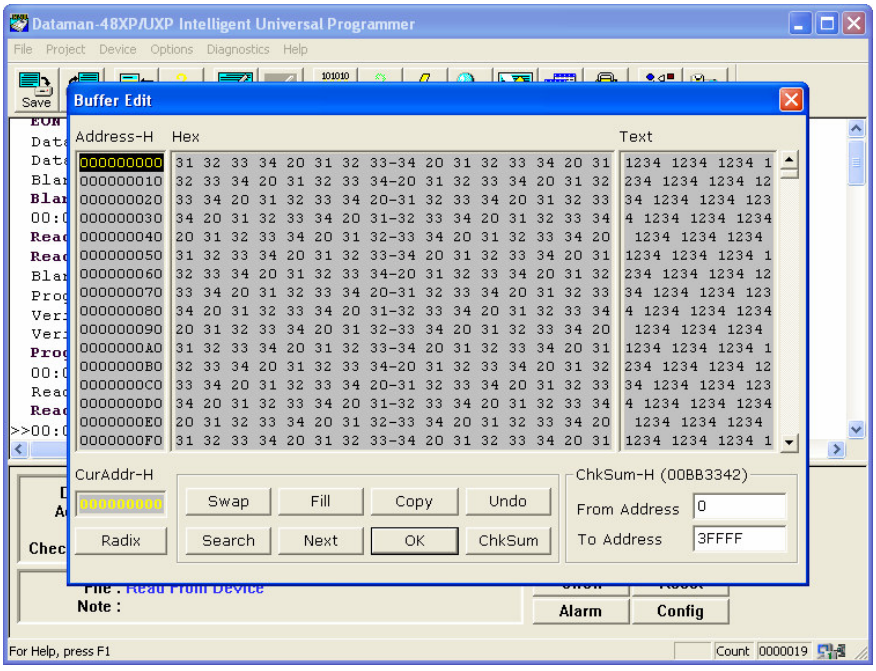
Select the Device → Select Device *from the menu or press* Alt + C *in order to choose your PIC microcontroller. A large list of devices will be displayed in a window. Find you PIC and press* OK.



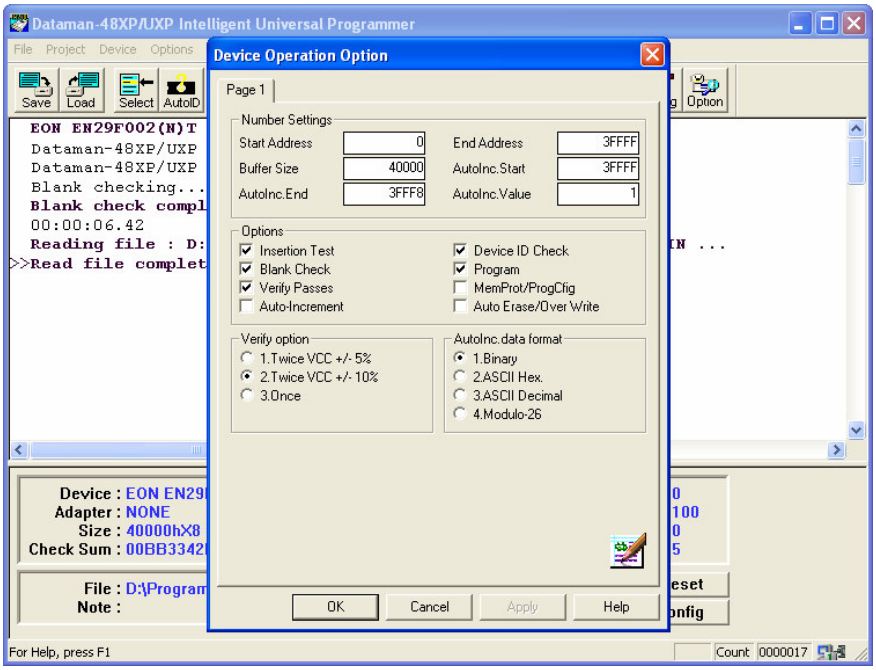
Select File → Load File *or click the* Load *button or press* Alt + L *in order to load the HEX file from your project. The Dataman software should automatically detect the file as an Intel HEX file. Make sure one of the Clear Buffer radio buttons is selected and press* OK.



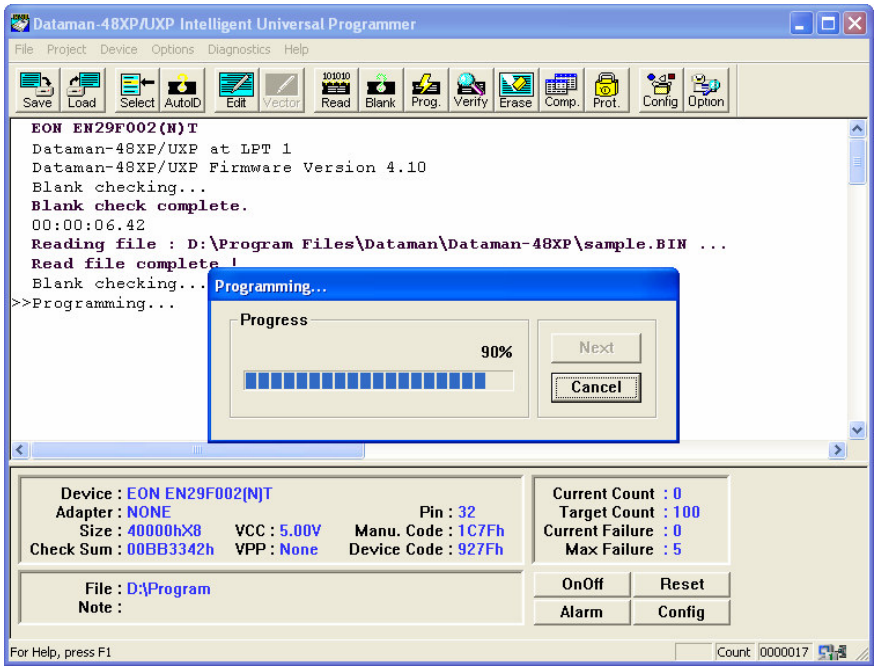
Right now you have loaded your HEX file from your project into the Dataman buffer. The PIC microcontroller isn't programmed yet! The Dataman software allows you to view and edit the buffer as shown in the following image but this step should be unnecessary.



Before programming the PIC microcontroller you can set certain device options in the Dataman software by pressing the Config *button in the menu bar. A window with several sections of checkboxes and radio buttons will appear for your specific device. Read your PIC's datasheet to fully understand these configuration bits. Make your appropriate choices and click* OK.



Now it is time to program your PIC microcontroller. The correct device has been selected, the HEX file has been loaded and configuration bits have been set. Select Device → Program → Auto *or press* Alt + P *to program your PIC microcontroller. You should see a progress bar at the center of your screen:*



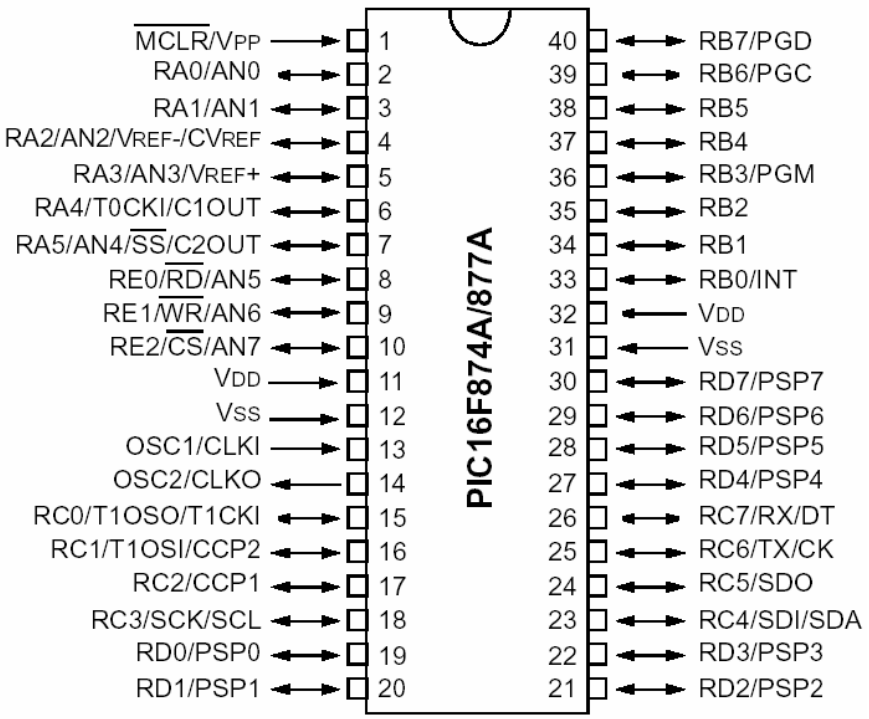
If the "burn" process has been successful a Programming Complete message will be printed to the screen. There are many other functions provided by the software. For more details read the datasheet on the Dataman 48UXP Universal Programmer available at http://dataman.com/Webpages/Programmers/Product48UXPInformation.aspx.

NOTE: When reprogramming a PIC you may receive the error messages: "Poor contact at pin 13" or "Over current detected". These messages most likely mean you have destroyed your PIC.

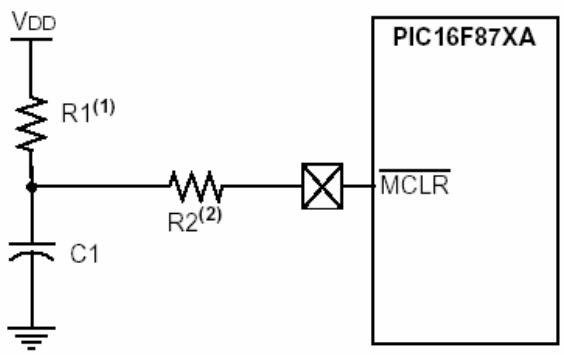
9. Breadboarding a PIC Microcontroller

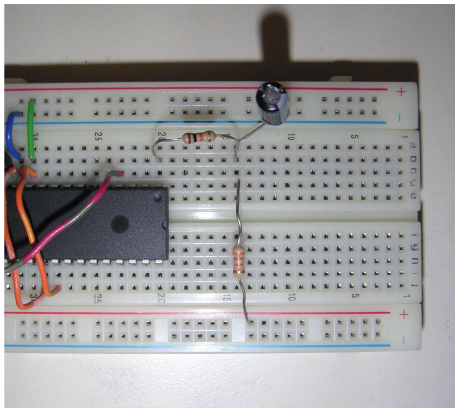
When breadboarding a PIC microcontroller the most important thing to remember (besides how easily they can be destroyed) is the mandatory pin connections required to make your program run. These connections will differ from device to device so please read your datasheet for more specific information.

Using the PIC16F877A as an example we will outline the basic step required to run the flashing LED program written in MyProject previously described. The following is a pin diagram of the PIC16F877A:



With regards to voltage supply, pins 1, 11, 12, 32, and 33 must always be connected. V_{DD} is the positive voltage supply while V_{SS} is ground. The MCLR/V_{PP} pin is a special pin that keeps the PIC is reset mode until a proper voltage supply is detected. This pin must be connected in a special way in line with two resistors and a capacitor:





A representative from Microchip claimed the following values for components in the circuit:

Component	Value
R1	33 KΩ
R2	10 KΩ
C1	0.1 µF

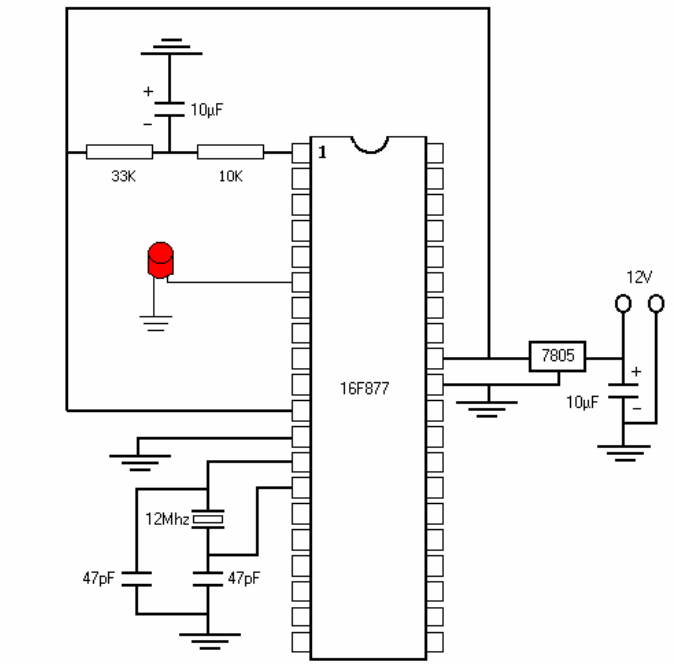
For more accurate values please read chapter 14.0 Special Features of the CPU in your PIC microcontroller's datasheet.

The next important step in breadboarding a PIC microcontroller is the clock oscillation required to step through your program. Because most PIC's do not have internal oscillators and external clocking method is required. Pin 13 OSC1 must be connected in order for your program to run.

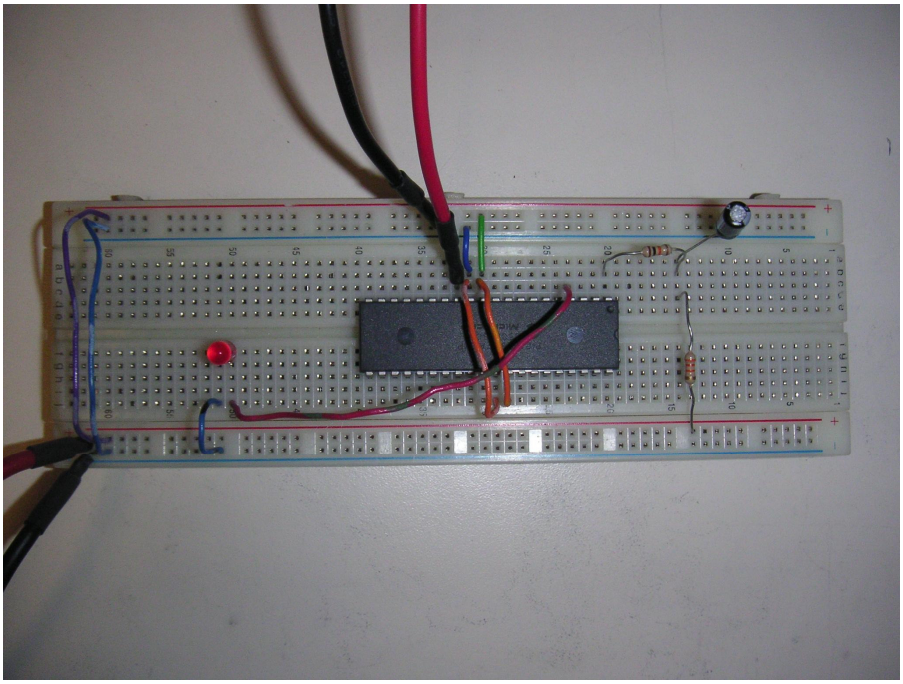
During the testing phase a square wave signal from an Arbitrary Waveform Generator may be used as the source of oscillation. The correct frequency will depend on the PIC you are using as well as your software requirements.

When your components are ready to be soldered onto a PCB a timer IC will be required. A cheap 555 timer can be purchased from Digikey or Mouser. Radio Shack also sells them for $1.49.

The following diagram is the basic circuit schematic for wiring up a PIC microcontroller to run the LED flash program. You can ignore the 7805 chip and supply the PIC with 5V. As you can see the red LED is connected to one of the pin in PORTA. The LED should flash on and off at a speed depending upon your chosen frequency.



You circuit should end up looking something like this:



For more information of breadboarding a PIC microcontroller please read the appropriate PIC datasheet and visit First Project Tutorial with the 16F877 at http://members.home.nl/b.vandam/lonely/pagina000.html.

10. Other Considerations

The software you will develop for your project will obviously be much more complex that the LED flash program written for this document. Microchip's website has a section dedicated to software development along with web seminars and tutorials.

This tutorial is not all inclusive and should only be used as a starting point for a general overview of programming a PIC microcontroller. The most information you can acquire on PIC microcontrollers is the individual datasheets and specs. They provide a wealth of information in a neatly organized document. Also take advantage of Microchip's very helpful technical support team at http://support.microchip.com/.
The following names are contacts at Iowa State University capable of helping with programming PIC microcontrollers:

- *Prof. Ralph Patterson*
- *CSG 2101 Coover*
  - *Steve Kavorik*
  - *Jason Boyd*
  - *Jason Jirak*
- *Dr. Doug Jacobson*
- *SSOL Howe Hall*
  - *Mike Cook*
- *Diane Rover – Associate Dean of Engineering*
- *Dr. Akilesh Tyagi*
- *Prof. Zhao Zhang*

I would also appreciate any feedback on this tutorial. Please feel free to email me with questions and/or suggestions at yesu@iastate.edu. Thank you for taking the time read this short introduction to programming PIC microcontrollers.