

# Development Kit For the PIC<sup>®</sup> MCU

## Exercise Book

# ACE Kit

March 2010



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Custom Computer Services, Inc.  
Brookfield, Wisconsin, USA  
262-522-6500

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Custom Computer Services, Inc. proudly supports the Microchip brand with highly optimized C compilers and embedded software development tools.

# 1

# UNPACKING AND INSTALLATION

## Inventory

- Use of this kit requires a PC with Windows 95, 98, ME, NT, 2000 or XP. The PC must have a spare 9-Pin Serial or USB port, a CD-ROM drive and 75 MB of disk space.
- The diagram on the following page shows each component in the ACE kit. Ensure every item is present.

## Software

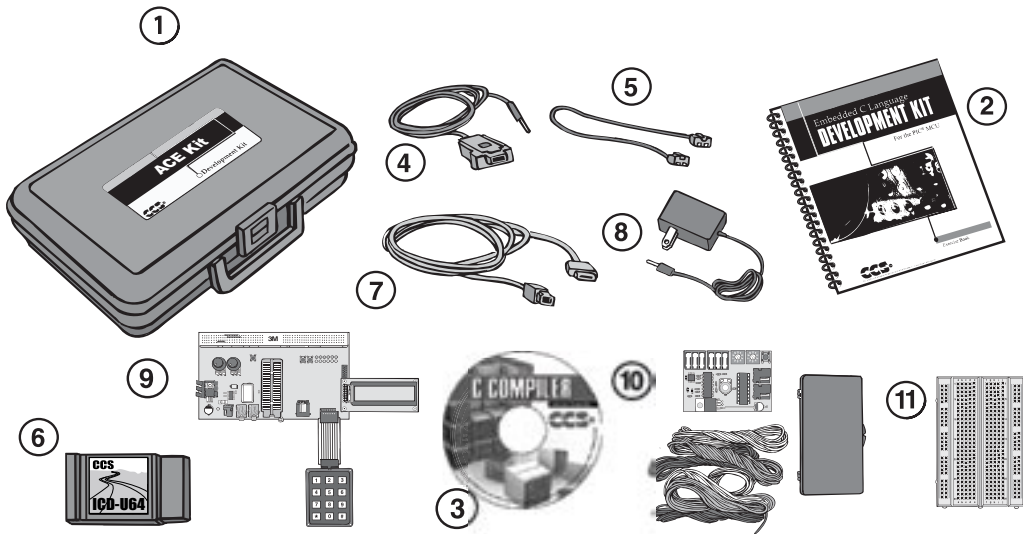
- Insert the CD into the computer and wait for the installation program to start. If your computer is not set up to auto-run CDs, then select **My Computer** and double-click on the CD drive.
- Click on **Install** and use the default settings for all subsequent prompts by clicking NEXT, OK, CONTINUE...as required.
- Identify a directory to be used for the programs in this booklet. The install program will have created an empty directory `c:\program files\picc\projects` that may be used for this purpose.
- Select the compiler icon on the desktop. In the PCW IDE, click **Help>About** and verify a version number is shown for the IDE and PCM to ensure the software was installed properly. Exit the software.

## Hardware

- Place the PIC16F877A into the socket and lower the handle to lock it into place. If the oscillator is not already installed, install it into the clock header making sure that pin 1 of the header lines up with pin 1 of the oscillator.
- Connect the PC to the ICD(6) using the USB cable.(7) Connect the prototyping board (9) to the ICD using the modular cable(5). Plug in the DC adaptor (8) to the power socket and plug it into the prototyping board (9). The first time the ICD-U is connected to the PC, Windows will detect new hardware. Install the USB driver from the CD or website using the new hardware wizard. The driver needs to be installed properly before the device can be used.
- The LED should be red<sup>(2)</sup> on the ICD to indicate the unit is connected properly.
- Run the Programmer Control Software by clicking on the CCSLOAD icon on the desktop. Use CCSLOAD Help File for assistance.
- The software will auto-detect the programmer and target board and the LED should be illuminated green. If any errors are detected, go to Diagnostic tab. If all tests pass, the hardware is installed properly.
- Disconnect the hardware until you are ready for Chapter 3. Always disconnect the power to the Prototyping board before connecting/disconnecting the ICD or changing the jumper wires to the Prototyping board.

<sup>(1)</sup>ICS-S40 can also be used in place of ICD-U. Connect it to an available serial port on the PC using the 9 pin serial cable. There is no driver required for S40.

<sup>(2)</sup>ICD-U40 units will be dimly illuminated green and may blink while connecting.



- ① Carrying case
- ② Exercise booklet
- ③ CD-ROM of C compiler (optional)
- ④ Serial PC to Prototyping board cable
- ⑤ Modular ICD to Prototyping board cable
- ⑥ ICD or Mach X unit for programming and debugging (optional)
- ⑦ USB or Serial PC to ICD cable
- ⑧ AC Adaptor (12VDC)
- ⑨ Prototyping board with a 40 pin ZIF socket
- ⑩ Experiments Kit:
  - 24LC16B/P
  - PIC16F877A Reprogrammable chip
  - NJU6355ED  
(real-time clock chip with 32kHz crystal)
  - 74HC595N
  - 93LC56 Serial EEPROM chip
- DS1631 digital thermometer chip
- DS1868 dual digital potentiometer chip
- DS1982 iButton chip
- PCF8570PN I<sup>2</sup>C chip
- Three 1.0K 1/4 W Resistor
- 4.7K 1/4 W Resistor
- Two 15 pf Capacitor
- 22 pf Capacitor
- 3.57 mHz crystal
- 4 mHz Oscillator
- 10 mHz Oscillator
- Two 14 pin headers
- Jumper Wire
- USB Add-on
- 2-digit 7-segment LED
- ⑪ Breadboard

## Editor

- Open the PCW IDE. If any files are open, click **File>Close All**
- Click **File>Open>Source File**. Select the file: **c:\program files\picc\examples\ex\_stwt.c**
- Scroll down to the bottom of this file. Notice the editor shows comments, preprocessor directives and C keywords in different colors.
- Move the cursor over the **Set\_timer0** and click. Press the F1 key. Notice a Help file description for set\_timer0 appears. The cursor may be placed on any keyword or built-in function and F1 will find help for the item.
- Review the editor special functions by clicking on **Edit**. The IDE allows various standard cut, paste and copy functions.
- Review the editor option settings by clicking on **Options>Editor Properties**. The IDE allows selection of the tab size, editor colors, fonts, and many more. Click on **Options>Toolbar** to select which icons appear on the toolbars.

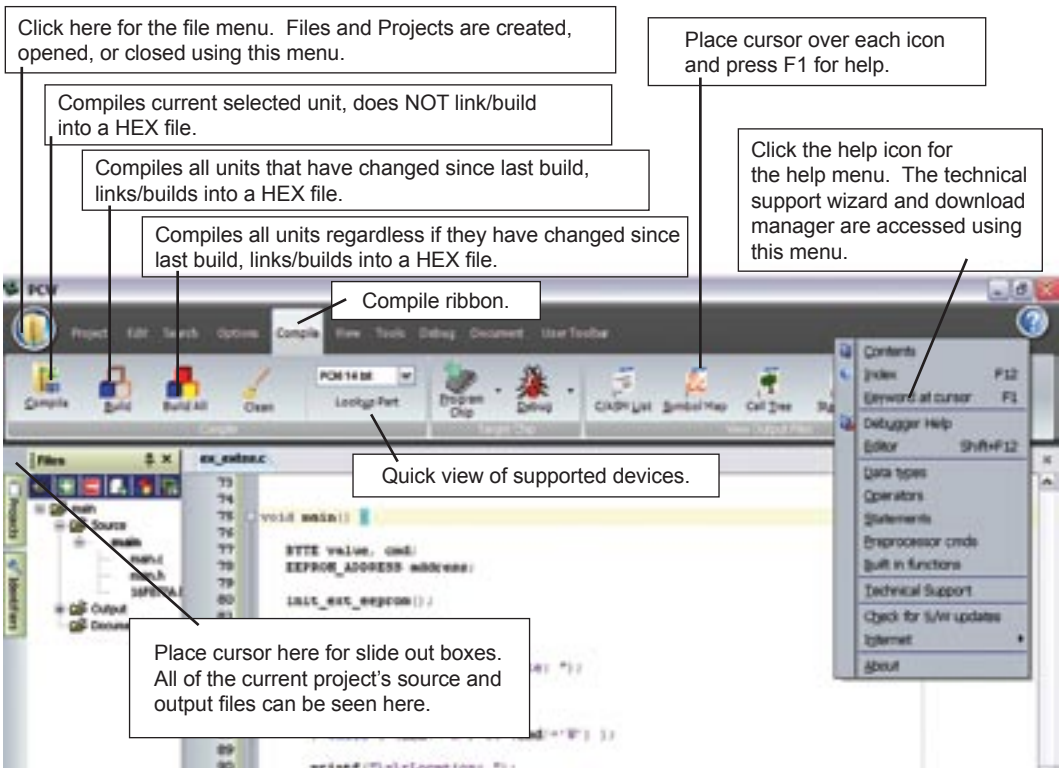
## Compiler

- Use the drop-down box under Compile to select the compiler. CCS offers different compilers for each family of Microchip parts. All the exercises in this booklet are for the PIC16F877A chip, a 14-bit opcode part. Make sure **PCM 14 bit** is selected in the white box under the **Compiler** tab.
- The main program compiled is always shown in the bottom of the IDE. If this is not the file you want to compile, then click on the tab of the file you want to compile. Right click into editor and select **Make file project**.
- Click **Options>Project Options>Include Files...** and review the list of directories the compiler uses to search for included files. The install program should have put two directories in this list: devices and drivers.
- Normally the file formats need not be changed and global defines are not used in these exercises. To review these settings, click **Options>Project Options>Output Files** and **Options>Project Options>Global Defines**.
- Click the compile icon to compile. Notice the compilation box shows the files created and the amount of ROM and RAM used by this program. Press any key to remove the compilation box.

## Viewer

- ❑ Click **Compile>Symbol Map**. This file shows how the RAM in the microcontroller is used. Identifiers that start with @ are compiler generated variables. Notice some locations are used by more than one item. This is because those variables are not active at the same time.
- ❑ Click **Compile>C/ASM List**. This file shows the original C code and the assembly code generated for the C. Scroll down to the line:

```
int_count=INTS_PER_SECOND;
```
- ❑ Notice there are two assembly instructions generated. The first loads 4C into the W register. INTS\_PER\_SECOND is #defined in the file to 76. 4C hex is 76 decimal. The second instruction moves W into memory. Switch to the Symbol Map to find the memory location where int\_count is located.
- ❑ Click **View>Data Sheet**, then **View**. This brings up the Microchip data sheet for the microprocessor being used in the current project.



# 3

## COMPILING AND RUNNING A PROGRAM

- Open the PCW IDE. If any files are open, click **File>Close All**
- Click **File>New>Source File** and enter the filename **EX3.C**
- Type in the following program and **Compile**.

```
#include <16f877A.h>
#device ICD=TRUE
#fuses HS,NOLVP,NOWDT,PUT
#use delay (clock=20000000)

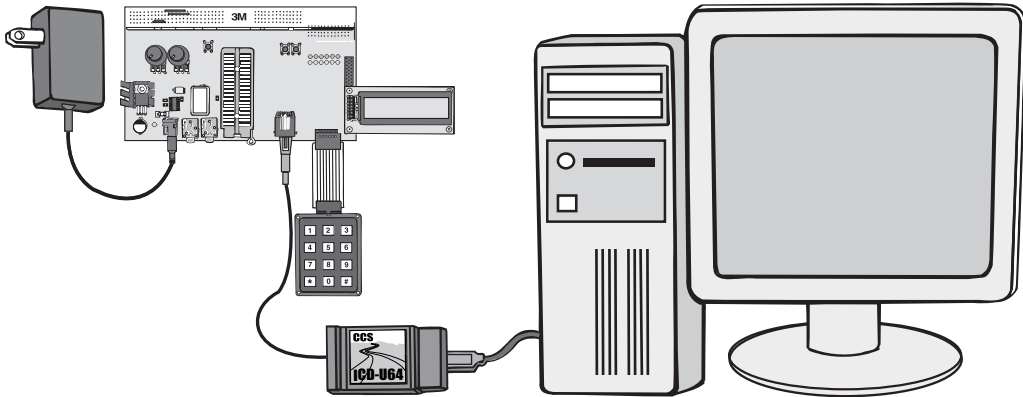
#define FIRST_LED PIN_A5



void main () {
    while (TRUE) {
        output_low (FIRST_LED);
        delay_ms (1000);
        output_high (FIRST_LED);
        delay_ms (1000);
    }
}
```

- Run a jumper wire from PIN 20 to PIN 42 on the terminal strip.

### NOTES

- The first four lines of this program define the basic hardware environment. The chip being used is the PIC16F877A, running at 20MHz with the ICD debugger.
- The #define is used to enhance readability by referring to GREEN\_LED in the program instead of PIN\_A5.
- The “while (TRUE)” is a simple way to create a loop that never stops.
- Note that the “output\_low” turns the LED on because the other end of the LED is +5V. This is done because the chip can tolerate more current when a pin is low than when it is high.
- The “delay\_ms(1000)” is a one second delay (1000 milliseconds).



- Connect the ICD to the Prototyping board using the modular cable, and connect the ICD to the PC. Power up the Prototyping board.
- Click **Debug>Enable Debugger** and wait for the program to load.
- Click the green go icon: 
- Expect the debugger window status block to turn yellow indicating the program is running.
- The first LED on the Prototyping board should be flashing between green and red. One second green and one second red.
- The program can be stopped by clicking on the stop icon: 

## FURTHER STUDY

**A** *Modify the program to light the first LED for 5 seconds, then the second for 1 second and the third for 5 seconds.*

*Be sure to place a jumper from the LED to the desired output port.*

*Example: pin B4(51) to LED2(43)*

*pin B5(52) to LED3(44)*

**B** *Add to the program a #define macro called "delay\_seconds" so the delay\_ms(1000) can be replaced with : delay\_seconds(1); and delay\_ms(5000) can be: delay\_seconds(5);.*

**Note:** *Name these new programs EX3A.c and EX3B.c and follow the same naming convention throughout this booklet.*

*For the remaining of the exercises all needed jumper wires will be listed under a heading titled "Jumpers."*

# 4

## HANDLING INPUT

- ❑ Type in the following program, named **EX4.C, Compile and Run:**

```
#include <16f877A.h>
#device ICD=TRUE
#fuses HS,NOLVP,NOWDT,PUT
#use delay(clock=20000000)

#define FIRST_LED PIN_A5
#define SECOND_LED PIN_B4
#define THIRD_LED PIN_B5
#define PUSH_BUTTON PIN_A4
//
void light_one_led(int led) {
    output_high(FIRST_LED);
    output_high(SECOND_LED);
    output_high(THIRD_LED);
    switch(led) {
        case 0 : output_low(FIRST_LED); break;
        case 1 : output_low(SECOND_LED); break;
        case 2 : output_low(THIRD_LED); break;
    }
}

wait_for_one_press() {
    while(input(PUSH_BUTTON)) ;
    while(!input(PUSH_BUTTON)) ;
}

void main() {
    while(TRUE) {
        light_one_led(0);
        wait_for_one_press();
        light_one_led(1);
        wait_for_one_press();
        light_one_led(2);
        wait_for_one_press();
    }
}
```

- ❑ Jumpers: pinA5(20) to LED1(42)  
pinB4(51) to LED2(43)  
pinB5(52) to LED3(44)  
pinA4(19) to switch1(40)
- ❑ As can be seen from the program, the first LED should come on. Press the button and the second LED should light and then the third LED when pressed again. Add the following new type below the // lines:

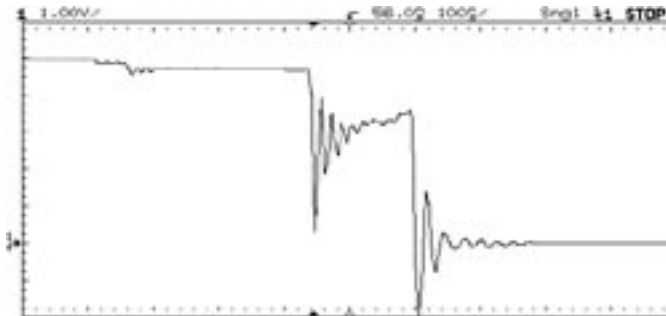
```
typedef enum {FIRST,SECOND,THIRD} LEDS;
```



- ❑ Change the parameter to `light_one_led` to `leds` instead of `int`.
- ❑ Change the 0, 1, 2 in the call to `FIRST`, `SECOND`, `THIRD`.

## NOTES

- The Prototyping board has one momentary pushbutton that may be used as an input to the program. The input pin is connected to a 10K pull-up resistor to +5V. The button, when pressed, shorts the input pin to ground. The pin is normally high while in this configuration, but it is low while the button is pressed.
- This program shows how to use simple C functions. The function `wait_for_one_press()` will first get stuck in a loop while the input pin is high (not pressed). It then waits in another loop while the pin is low. The function returns as soon as the pin goes high again. Note that the loops, since they do not do anything while waiting, do not look like much—they are a simple `;` (do nothing).
- When the button is pressed once, it is common for several very quick connect disconnect cycles to occur. This can cause the LEDs to advance more than once for each press. A simple debounce algorithm can fix the problem. Add the following line between the two while loops: `delay_ms(100)`; The following scope picture of a button press depicts the problem:



## FURTHER STUDY

- A *Modify the program so that while the button is held down the LEDs alternate as fast as possible. When the button is not pressed the LED state freezes. This creates a random color program.*

# 5

## PROGRAM STRUCTURE

- ❑ It is good practice to put all the hardware definitions for a given design into a common file that can be reused by all programs for that board. Open EX4.C and highlight the first nine lines of the file. Click **Edit>Paste to file** and give it the name **prototype.h**.
- ❑ It is also helpful to collect a library of utility functions to use as needed for future programs. Note that just because a function is part of a program does not mean it takes up memory. The compiler deletes functions that are not used. Highlight the `wait_for_one_press()` function, `light_one_led` function and the typedef line (if added from Chapter 4 Notes section) and save that to a file named `utility.c`. Open **utility.c** and add the following new function to the file:

```
void show_binary_on_leds(int n) {
    output_high(FIRST_LED);
    output_high(SECOND_LED);
    output_high(THIRD_LED);
    if( bit_test(n,0) )
        output_low(FIRST_LED);
    if( bit_test(n,1) )
        output_low(SECOND_LED);
    if( bit_test(n,2) )
        output_low(THIRD_LED);
}
```

- ❑ Close all files and start a new file named **EX5.C** as follows:

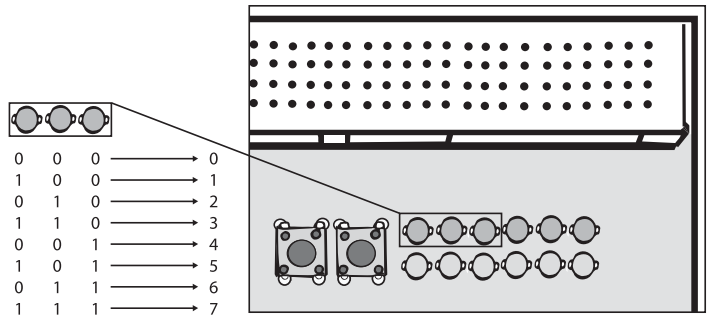
```
#include <prototype.h>
#include <utility.c>

main() {
    int count = 0;

    while(TRUE) {
        show_binary_on_leds(count);
        wait_for_one_press();
        count++;
    }
}
```

- ❑ Jumpers: pinA5(20) to LED1(42)  
pinB4(51) to LED2(43)  
pinB5(52) to LED3(44)  
pinA4(19) to switch1(40)

- Compile and Run the program. Check that with each button press, the LEDs increment in a binary number 0-7 as shown here.



## NOTES

- In C, a function must either appear in the input stream before it is used OR it must have a prototype. A prototype is the part of the function definition before the “{“. In a program where main calls function A and function A calls function B, the order in the file must be B, A, MAIN. As an alternative, have Ap, Bp, MAIN, A, B where Ap and Bp are prototypes. Frequently, prototypes are put into a header file with a .h extension.
- The scope, initialization, and life of C variables depend on where and how they are declared. The following is a non-inclusive summary of the common variable scopes. Note that if a variable has an initialization (like **int a=1;**) the assignment happens each time the variable comes to life.







Where it is defined	Can be accessed	Life of the variable
Inside a function	Only in that function	While function is alive
Inside a function with STATIC	Only in that function	During the entire run of the program
Outside all functions	In any function defined afterwards in the file	During the entire run of the program
After “{“ inside a function	Only between the “{“ and corresponding “}”	Only up to the corresponding “}”

## FURTHER STUDY

- A** Modify the program to increment the binary number 1 every second (the button is not used).
- B** Instead of the built-in function `BIT_TEST` use the standard C operators (such as `&` and `==`) to test the bits.

# 6

## DEBUGGING

- Open **EX5.C** and start the debugger **Debug>Enable Debugger**.
- Click the reset icon to ensure the target is ready.
- Click the step-over icon  twice. This is the step over command. Each click causes a line of C code to be executed. The highlighted line has not been executed, but the line about to be executed.
- Step over the `show_binary_on_leds(count);` line and notice that one click executed the entire function. This is the way step over works. Click step over on `wait_for_one_press();`. Press the prototype button and notice the debugger now stops since the function terminates.
- Click the **Watch** tab, then the add icon  to add a watch. Enter **count or choose count the variables from list**, then click **Add Watch**. Notice the value shown. Continue to step over through the loop a few more times (press the button as required) and notice the count watch increments.
- Step over until the call to `show_binary_on_leds(count);` is highlighted. This time, instead of step over, use the standard step icon  several times and notice the debugger is now stepping into the function.
- Click the GO icon  to allow the program to run. Press the prototype button a couple of times to verify that the program is running normally. Click the stop icon  to halt execution. Notice the C source line that the program stopped on. This is the line where the program is waiting for a button press.
- In the editor, click on `show_binary_on_leds(count);` to move the editor cursor to that line. Then click the Breaks tab and click the add icon  to set a breakpoint. The debugger will now stop every time that line is reached in the code. Click the GO icon and then press the prototype button. The debugger should now stop on the breakpoint. Repeat this a couple of times to see how the breakpoint works.
- Click **Compile>C/ASM list**. Scroll down to the highlighted line. Notice that one assembly instruction was already executed for the next line. This is another side effect of the ICD-S debugger. Sometimes breakpoints slip by one ASM instruction.
- Click the step over icon a few times and note that when the list file is the selected window, the debugger has executed one assembly instruction per click instead of one entire C line.
- Close all files and start a new file **EX6.C** as follows:

```

#include <prototype.h>
#include <utility.c>

void main() {
    int a,b,c;

    a=11;
    b=5;
    c=a+b;
    c=b-a;
    while(TRUE);
}

```

- Compile the program and step-over until the `c=a+b` is executed. Add a watch for `c` and the expected value is 16.
- Step-over the subtraction and notice the value of `c`. The `int` data type by default is not signed, so `c` cannot be the expected `-6`. The modular arithmetic works like a car odometer when the car is in reverse only in binary. For example, 00000001 minus 1 is 00000000, subtract another 1 and you get 11111111.
- Reset and again step up to the `c=a+b`. Click the **Eval** tab. This pane allows a one time expression evaluation. Type in `a+b` and click **Eval** to see the debugger and calculate the result. The complete expression may also be put in the watch pane as well. Now enter `b=10` and click **Eval**. This expression will actually change the value of `B` if the “keep side effects” check box of the evaluation tab is checked. Check it and click **Eval** again. Step over the addition line and click the **Watch** tab to observe the `c` value was calculated with the new value of `b`.

## FURTHER STUDY

- A** *Modify the program to include the following C operators to see how they work:*  
`* / % & ^`  
 Then, with `b=2` try these operators: `>> <<`  
 Finally, try the unary complement operator with: `c=~a;`
- B** *Design a program to test the results of the relational operators:*  
`< > == !=`  
 by exercising them with `b` as 10, 11, and 12.  
 Then, try the logical operators `||` and `&&` with the four combinations of `a=0,1`  
 and `b=0,1`.  
 Finally, try the unary not operator with: `c=!a;` when `a` is 0 and 1.

## 7

# ANALOG TO DIGITAL CONVERSION

- ❑ The PIC16F877A chip has eight pins that may be used to read an analog voltage. These eight pins can be configured to certain combinations of analog input and digital pins, but not all combinations are possible. The following is a simple program (**EX7.c**) to read one analog pin.

```
#include <prototype.h>
#include <utility.c>

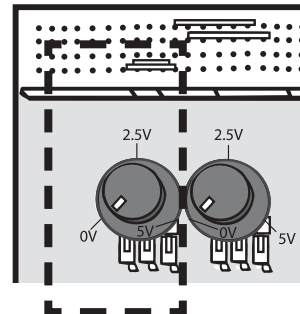
#define cutoff 128          // 2.5 Volts
#define neutral_zone 25    // 0.5 Volts

void main() {
    int reading;

    setup_adc_ports( RA0_ANALOG );
    setup_adc( ADC_CLOCK_INTERNAL );
    set_adc_channel( 0 );

    while(TRUE) {
        reading = read_adc();
        if(reading < (cutoff-neutral_zone/2))
            light_one_led(FIRST);
        else if (reading > (cutoff+neutral_zone/2))
            light_one_led(THIRD);
        else
            light_one_led(SECOND);
    }
}
```

- ❑ Jumpers: pinA5(20) to LED1(42)  
pinB4(51) to LED2(43)  
pinB5(52) to LED3(44)  
pinA4(19) to switch1(40)  
Analog 9 (9) to A0(15)
- ❑ Compile and Run the program. Verify that the Prototyping board knob Analog 9 (9) jumpered to pin A0(15) is turned so the first LED is on when it is low, the third LED when high and the second LED for a small region in the center.



- By default, the analog to digital converter is 8 bits. Thus, a range of 0 to 5 volts analog is represented by the numbers 0-255. The A/D reading can be converted to volts by the formula:  
$$\text{Volts} = \text{reading} * (5.0/255)$$
- The `setup_adc_ports` function call determines what pins are set to be analog inputs. The `setup_adc` function call determines how fast the conversion is done. The internal clock option uses an internal RC clock. Although the timing is not exact, it is long enough for an accurate conversion. The time can be based off the instruction clock for more precise timing.
- The `set_adc_channel` function sets the A/D converter to channel 0 (AN0 or A0). This switches an internal mux in the part, but does not start an A/D conversion. Even though a conversion has not started, there is a small capacitor in the chip that must charge up after the port switch and before the voltage is read. This is fast with a low impedance input, but for a higher impedance input, a small delay should be put in after the channel is changed.
- The call to `read_adc` starts a conversion, waits for it to complete and returns the result. The conversion time is around 20us.

## FURTHER STUDY

- A** *Modify the program to use a long variable for reading. Open `prototype.h` and after:*  
`#device ICD=TRUE`  
*add the following*  
`ADC=10`  
*This will change the range to 0-1023. Change the constant in the program to reflect the new range.*  
*When the above example is complete, remove the `ADC=10` so it will default to `ADC=8`*
- B** *Write a timer program that will light the first LED for x seconds when pressing the button. x should be 0-25, depending on the setting of the analog knob.*

# ARRAYS AND ANALOG FILTERING

- The following **EX8.c** program illustrates how to change the **EX7.c** program such that the value used to light the LED is the average voltage over the previous 10 seconds.

```
#include <prototype.h>
#include <utility.c>

#define cutoff 128           // 2.5 volts
#define neutral_zone 25     // 0.5 Volts

void main() {
    int history[10];
    int history_ptr = 0;
    long reading;
    int count=0;
    int i;
    setup_adc_ports( RA0_ANALOG );
    setup_adc( ADC_CLOCK_INTERNAL );
    set_adc_channel( 0 );

    while (TRUE) {
        reading=0;
        delay_ms(1000);
        history[history_ptr++] = read_adc();
        if (history_ptr==10) {
            history_ptr=0;
            count = 10;
        } else
            if (count<10)
                count=history_ptr;
        for (i=0; i<count;i++)
            reading += history[i];
        reading /= count;
        if (reading<(cutoff-neutral_zone/2))
            light_one_led(FIRST);
        else if (reading>(cutoff+neutral_zone/2))
            light_one_led(THIRD);
        else
            light_one_led(SECOND);
    }
}
```

- Jumpers: pinA5(20) to LED1(42)  
pinB4(51) to LED2(43)  
pinB5(52) to LED3(44)  
Analog 9(9) to A0(15)



- Run the new program and confirm that the movement of the knob takes 10 seconds to appear on the LEDs. Furthermore, confirm that a quick movement of the knob from high to low makes no difference in the LEDs.

## NOTES

- This program uses several of the C shortcut operators. For example, the `reading += history[i]` is the same as `reading = reading + history[i]` and `history[history_ptr++] = read_adc();` is the same as `history[history_ptr] = read_adc();`  
`history_ptr = history_ptr+1;`
- A C array declared `history[10]` means the valid subscripts are `history[0]` through `history[9]`.
- The reading variable needs to be a long (16 bits) because the largest value  $255 \times 10$  is larger than 8 bit int.
- The history variable can be placed in the watch list and then when the program is halted, the debugger will show all the points in history being used to make up the filtered reading.

## FURTHER STUDY

- A** *Modify the program to keep all LEDs off until 10 samples are obtained.*
- B** *Modify the program to handle the LEDs differently on even and odd cycles as follows:*
  - Even: Show the actual last reading on the LED (not filtered).*
  - Odd: If the last reading is the same as the filtered reading, show this on the LEDs. Otherwise, turn all LEDs off.**The LED flashes after a change, and when the reading is stable, the LED will be solid*

# STAND-ALONE PROGRAMS AND EEPROM

- ❑ Execution of the **EX5.c** program always begins counting at 0. This can be modified by creating **EX9.c** that continues counting where it left off when restarted. This is done by saving the count value in the PIC16F877A internal data EEPROM. This memory retains the data even when the power is removed.
- ❑ Create the **EX9.c** as follows:

```
#include <prototype.h>
#include <utility.c>

void main() {
    int count;

    count = read_eeprom(0);
    while(TRUE) {
        show_binary_on_leds(count);
        wait_for_one_press();
        count++;
        write_eeprom(0,count);
    }
}
```

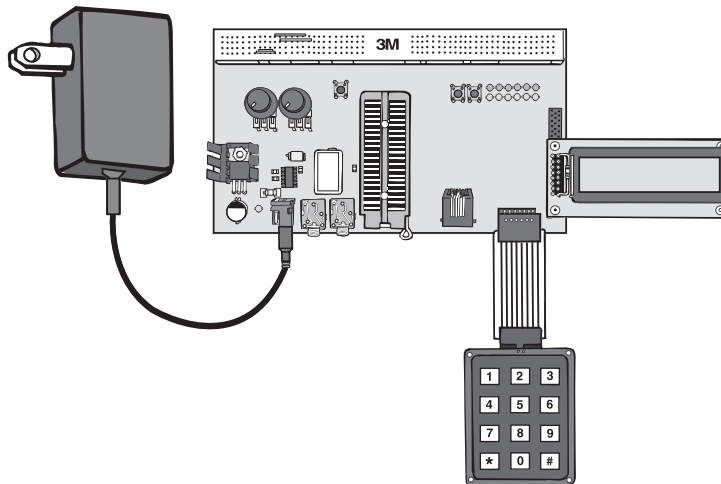
- ❑ Jumpers: pinA5(20) to LED1(42)  
pinB4(51) to LED2(43)  
pinB5(52) to LED3(44)  
pinA4(19) to switch1(40)
- ❑ Compile and Run the program. Verify when the program is halted, reset, and restarted that the count continues where left off.

## NOTES

- The first argument to read/write\_eeprom is the address in the EEPROM to write the byte to. The PIC16F877A part ranges from 0 to 255, allowing 256 bytes to be saved. The second argument in write\_eeprom is the value to write.
- There is a limit to how many times a given location in the data EEPROM can be written to. For example, the PIC16F877 chip allows 100,000 times and the A version of this chip may allow 10 times that amount. For this reason, a program should be designed not to write any more often than is necessary. For example, if the volume setting for a TV is being saved, one might wait until there are no changes for 5 seconds before saving a new value to EEPROM. Some system designs can give early warning on power down and the program can only save to EEPROM at power down.

- Close the debug window.
- Copy the `prototype.h` file to a new file `protoalone.h`. Remove from this file the line:
 

```
#device ICD=TRUE
```
- This makes a program that uses the new include file a stand alone program which does not need the ICD to run.
- Modify `EX9.c` to use `protoalone.h`. Compile the program, then click **Tools>ICD** to load the program onto the Prototyping board.
- Disconnect the power from the Prototyping board, then disconnect the ICD from the Prototyping board.
- Power up only the Prototyping board and verify the program runs correctly.
- Press the reset button on the Prototyping board and release. The LEDs should go off while in reset, then the program will restart.



## FURTHER STUDY

- A** *Modify EX7.c so that the cut-off point is a variable and that variable is kept in EEPROM location 100. Establish a new cut-off point whenever the pushbutton is pressed to wherever the knob is set. Be careful to only write the EEPROM once per press.*
- B** *Modify the EX9.c program so that 10 EEPROM locations are used and each time the button is pressed only one of the 10 locations is written to and the location changes with each press. This will extend the life of this unit by 10 times, if it were a real product.*  
**Hint: The count value could be the sum of all 10 locations %8.**

- ❑ RS-232 is a popular serial communications standard used on most PCs and many embedded systems. Two wires are used (in addition to ground), one for outgoing data and one for incoming data. The PIC16F877A chip has built-in hardware to buffer the serial data if pins C6 and C7 are used. The compiler will allow any pins to be used and will take advantage of the built-in hardware if choosing these pins. Add the following line to the end of the `protoalone.h` file

```
#use rs232 (baud=9600, xmit=PIN_C6, rcv=PIN_C7)
```

- ❑ Create the **EX10.c** as follows:

```
#include <protoalone.h>
#include <utility.c>
#include <stdlib.h>
#include <input.c>

void main() {
    long a,b,result;
    char opr;

    setup_timer_0(RTCC_INTERNAL);
    while(TRUE) {
        printf("\r\nEnter the first number: ");
        a=get_long();

        do {
            printf("\r\nEnter the operator (+-*/): ");
            opr=getc();
        } while(!isamong(opr,"+-*/"));

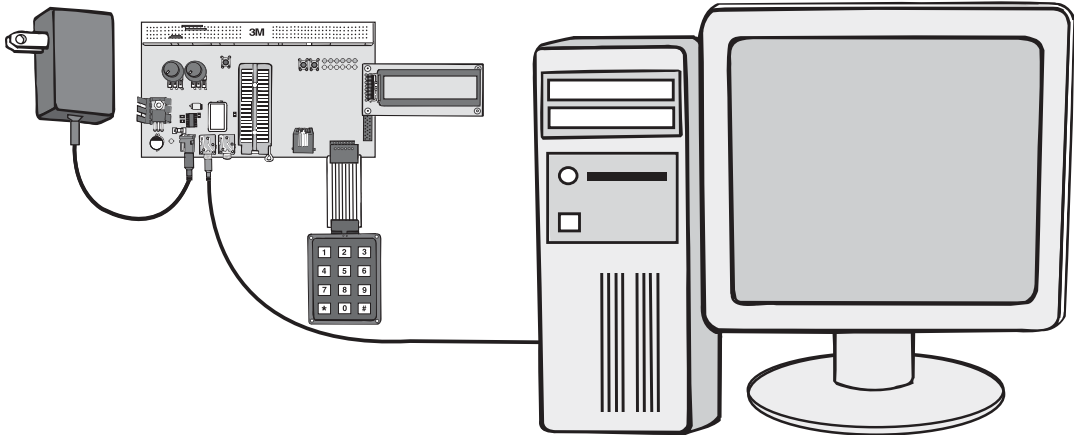
        printf("\r\nEnter the second number: ");
        b=get_long();

        switch(opr) {
            case '+' : result= a+b;    break;
            case '-' : result= a-b;    break;
            case '*' : result= a*b;    break;
            case '/' : result= a/b;    break;
        }

        printf("\r\nThe result is %lu ",result);
    }
}
```

- ❑ Compile and load the program into the Prototyping board.

- Connect the Prototyping board to the PC as shown below.
- Jumpers: PinC6(7) to RS232 TX (12)  
PinC7(8) to RS232 RX (11)



- At the PC, close the debugger window and start the program **Tools>Serial Port Monitor**. Set the correct COMM port if necessary.
- Power up the Prototyping board and a prompt at the PC should appear. Enter a number followed by the enter key, an operator (like +) and another number followed by enter. Verify the result is shown correctly.

## NOTES

- The basic functions for RS-232 are `putc()` and `getc()`. `printf` calls `putc()` multiple times to output a whole string and format numbers if requested. `get_long()` is a function in `input.c` to read a long number by calling `getc()` many times. See `input.c` for other functions such as `get_int()` and `get_string()`.
- The `%` in the `printf` indicates another parameter is included in the `printf` call and it should be formatted as requested. `%lu` indicates to format as an unsigned long.
- `getc()` will cause the program to stop and wait for a character to come in before it returns.

## FURTHER STUDY

- A** Modify to add the operators: `% | & ^`
- B** Modify to use `float` instead of `long`. You will need to do `get_float()` instead of `get_long()` and use the format specifier `%9.4f` to get 4 digits after the decimal place.

## 11

# MORE RS-232 AND USING STRUCTURES

- Create the **EX11.c** as follows:

```
#include <protoalone.h>
#include <utility.c>

struct animal { char code;
                char name[8];
                int count; };

#define MAX 3

struct animal animals[MAX] = {{ 'A', "Ant", 0},
                               { 'B', "Bird", 0},
                               { 'C', "Cat", 0}};

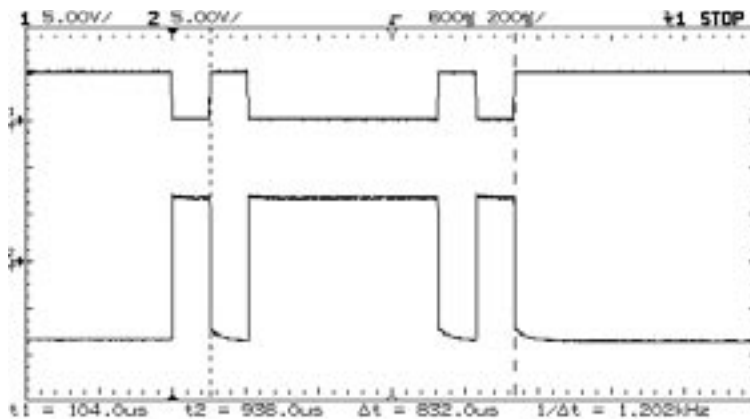
int find(char code, int & index) {
    for(index=0; index<MAX; index++)
        if(animals[index].code==code)
            return(TRUE);
    return(FALSE);
}

void main() {
    int index;
    char code;

    while(TRUE) {
        printf("\r\nEnter the code: ");
        code=getc();
        if(find(code, index)) {
            animals[index].count++;
            printf("\r\nYou now have %u %s's\r\n",
                animals[index].count,
                animals[index].name);
        } else
            printf("\r\nCode not valid\r\n");
    }
}
```

- Compile and load the program into the Prototyping board.
- Jumpers: pinC6(7) to RS232 TX(12)  
PinC7(8) to RS232 RX (11)
- Power up the board and use the serial port monitor to test.

- The `int & index` is our first example with an output parameter to a function. The `&` indicates the value is returned to the caller (actually the callers copy of the variable is used).
- At a hardware level, RS-232 sends a series of bits. The `baud=` option specifies how many bits are sent per second. The bit stream, as specified above, is a start bit (always 0), 8 data bits (lsb first) and a stop bit (always 1). The line then remains at the 1 level. The number of bits may be changed with a `bits=` option and a parity bit can be added before the stop bit with a `parity=` option. A 0 is represented as a positive voltage (+3 to +12V) and a 1 is represented as a negative voltage (-3 to -12V). Since the PIC16F877A outputs only 0V and 5V a level converter is required to interface to standard RS-232 devices such as a PC. A popular chip that does this is the MAX232. See the schematic in the back cover for details. The following diagram shows a single character A (01000001) as sent at 9600 baud. The top is from the PIC16F877A, the bottom is from the MAX232, the 8 data bits are between the dotted lines. Each bit is 104us.





## FURTHER STUDY

- A** Modify the program to keep the counts in a separate (from the structure) array. Then add the `CONST` keyword before animals to put this data in ROM instead of RAM. Compare the memory usage for both programs.
- B** If there is room, modify to add new entries when the code is not found. Set `MAX` to 6 and add a new variable to keep track of the number of entries.

- RS-232 printf statements can be a good tool to help debug a program. It does, however, require an extra hardware setup to use. If the ICD is being used as a debug tool, the compiler can direct `putc()` and `getc()` through the debugger interface to the debugger screen. Add the following line to the end of the **prototype.h** file:
 

```
#use rs232 (DEBUGGER)
```
- Modify **EX10.c** to create **EX12-1.c** by changing `protoalone.h` to **prototype.h**.
- Compile and load the program into the Prototyping board.
- Click GO, then click the **Monitor** tab.
- A prompt should appear. Enter some data to confirm that the program is working.
- Stop and reset the program.
- In PCW click **Project>Open all files** as an easy way to get all the project files open in IDE.
- Click the **stdlib.h** tab, and set a breakpoint in the `atoi()` function on the line:
 

```
result = 10*result + (c - '0');
```
- This function is called from `get_long()` to convert a string to a number. This line is executed for each character in the string.
- Click the debugger **Break Log** tab, check the LOG box, set the breakpoint as 1 and expression as **result**. Result is the value of the number being converted.
- Click GO, then click the **Monitor** tab and enter **1234 enter**.
- Click the **Log** tab and notice that each time the breakpoint was hit the value of the **result** variable was logged. In this case the breakpoint did not cause a full stop of the program, it just logged the value of the requested expression and kept on going.
- Stop the program.
- Delete the breakpoint by selecting the breakpoint and click on the  icon.
- Uncheck the LOG box under the log tab.
- Set a breakpoint on the last `printf()` in the program.
- Enter watches for **a**, **b** and **result**.
- Click GO and enter two numbers and +.
- When the break is reached click on the snapshot icon: .
- Check **Time** and **Watches**, uncheck everything else.
- If a printer is connected to the PC select **Printer**, otherwise select **Unique file**.
- Click on the **Now** button.
- Notice the requested data (time and watches) are either printed or written to a file as requested.
- Click on the snapshot icon again and this time select **Append to file**, put in a filename of EX12.TXT and check **After each single step**.



- Check **Last C line executed** in addition to the **Time** and **Watch** selected already and close the snapshot window.
- Reset and then Step Over until the final printf() is executed. Enter the data when requested.
- Use **File>Open>Any File** to find the file **EX12.TXT** (by default in the Debugger Profiles directory) after setting the file type to all files.
- Notice the log of what happened with each step over command.
- Uncheck the **After each single step** in the snapshot window.
- Clear the breakpoints and set a breakpoint on the **switch**.
- Click Reset then Go and enter the requested data using the + operator.
- When the break is reached click on the **Peripherals** tab and select Timer 0.
- Shown will be the registers associated with timer 0. Although this program does not use timer 0 the timer is always running so there is a value in the **TMRO** register. Write this value down.
- Clear the breakpoints and set a breakpoint on the final **printf()**.
- Click GO.
- Check the **TMRO** register again. If the new value is higher than the previous value then subtract the previous value from the current value. Otherwise, add 256 to the current value and then subtract the previous value (because the timer flipped over).
- The number we now have is the number of clock ticks it took to execute the switch and addition. A clock tick by default is 0.2ms. Multiply your number of ticks by 0.2 to find the time in ms. Note that the timers (and all peripherals) are frozen as soon as the program stops running.

## FURTHER STUDY

---

- A** *The debugger **Eval** tab can be used to evaluate a C expression. This includes assignments. Set a break before the switch statement and use the Eval window to change the operator being used. For example, type a + but change it to a - before the switch.*
- B** *Set a break on the switch statement and when reached, change to the C/ASM view and single step through the switch statement. Look up the instructions executed in the PIC16F877A data sheet to see how the switch statement is implemented. This implementation is dependent on the case items being close to each other. Change \* to ~ and then see how the implementation changes.*

# 13

## TIMERS

- The PIC16F877A has three built-in timers. Each timer has a different set of features. The following example will use Timer #1 to measure the time it takes to execute some C code.
- Create the file **EX13.c** as follows:

```
#include <prototype.h>

void main() {
    long time;

    setup_timer_1(T1_INTERNAL | T1_DIV_BY_1);
    set_timer1(0);

    time = get_timer1();
    printf("Time in ticks is %lu\r\n",time);
}
```

- Jumpers: PinC6(7) to RS232 TX(12)  
PinC7(8) to RS232 RX (11)
- Compile and Run the program. Check the monitor tab to see the result.
- This number is the number of timer ticks that it took to set and read the timer. The T1\_INTERNAL indicates the instruction clock is the source for the timer. The instruction clock is the oscillator divided by 4, or in our case, 0.2ms. This time represents the overhead of our timer code and may now be used in a more useful example.
- Modify the program as follows and replace the ??? with the number of ticks determined in the above program.

```
#include <prototype.h>

void main() {
    long time;
    long a,b,c;

    setup_timer_1(T1_INTERNAL | T1_DIV_BY_1);
    set_timer1(0);
    a=b*c;
    time = get_timer1();
    time -= ???; // subtract overhead
    printf("Time is %lu microseconds.\r\n",
           (time+2)/5);
}
```

# NOTES

- Since “time” represents the number of 0.2 microsecond ticks that it takes to do “a=b\*c”, then time/5 is the number of microseconds it takes to do that one line of C code. Use (time + 2)/5 to round instead of truncating.
- All the timers on the PIC16F877A count up and when the maximum value is reached, the timer restarts at 0. The set\_timer1(0) resets the timer to 0. Timer 1 is 16 bits and the range is 0 to 65535. This means it will overflow every 13107.2us. This is the largest time the program will be able to measure.
- If using T1\_EXTERNAL instead of INTERNAL, then the timer would increment every time pin C0 cycled. This makes it more of a counter.
- If using T1\_DIV\_BY\_2 instead of BY\_1, then the timer would increment once for every 2 instruction clocks. This makes the timer tick 0.4us and the range of the timer is now 26214.4us.
- The following is a summary of the timers on the PIC16F877A chip:

#0	Input is Instruction Clock or external pin Range is 0-255 Input can be divided by 1,2,4,8,16,32,64,128,256 Can generate interrupt on each overflow
#1	Input is Instruction Clock or external pin Range is 0-65535 Input can be divided by 1,2,4,8 Can generate interrupt on each overflow
#2	Input is Instruction Clock only Range can be programmed from 0-1 to 0-255 Input can be divided by 1,4,16 Can generate interrupt on 1-16 overflows

## FURTHER STUDY

- A** Time the actual time for a delay\_us(200) to see how accurate the compiler is.
- B** Make a program to time the addition operator for 8 bit, 16 bit, 32 bit and floating point. Instead of int, the compiler allows the use of int8, int16 and int32 to specify the number of bits in an integer variable.

# 14

## INTERRUPTS

- ❑ An interrupt is a specific event that causes the normal program execution to be suspended wherever it is and an interrupt function is executed. Normal program execution continues when the interrupt function returns. The PIC16F877A has a number of interrupt sources such as a timer overflow, an incoming RS-232 character or a change on a pin.
- ❑ In this exercise, the timer 1 overflow interrupt will be used to extend the timer 1 timer from 16 bits to 32 bits by counting the number of times the timer overflows. Create the file **EX14.c** as follows:

```
#include <prototype.h>

int16 overflow_count;

#int_timer1
void timer1_isr() {
    overflow_count++;
}

void main() {
    int32 time;

    setup_timer_1(T1_INTERNAL | T1_DIV_BY_1);
    enable_interrupts(int_timer1);
    while(TRUE) {
        enable_interrupts(global);

        while(input(PUSH_BUTTON)); // Wait for press
        set_timer1(0);
        overflow_count=0;

        while(!input(PUSH_BUTTON)); //Wait for release
        disable_interrupts(global);
        time = get_timer1();
        time = time + ((int32)overflow_count<<16);
        time -= 15; // subtract overhead
        printf("Time is %lu.%06lu seconds.\r\n",
            time/5000000, (time/5)%1000000);
    }
}
```

- ❑ Jumpers: PinC6(7) to RS232 TX(12)  
PinC7(8) to RS232 RX (11)  
PinA4(19) to switch1(40)
- ❑ Compile and Run the program. Press the button, release, and note the time it was held down is shown to six decimal places in the Monitor pane.

- The interrupt function is designated by preceding it with `#INT_TIMER1`. A number of interrupt functions can be specified by preceding each with the proper directive like `#INT_EXT` for the external interrupt pin (B0) or `#INT_RDA` for an incoming RS-232 character.
- An interrupt must be specifically enabled (via `enable_interrupts` (specific interrupt)) and interrupts must be globally enabled (via `enable_interrupts(GLOBAL)`). The `GLOBAL` enable/disable controls whether any interrupts are serviced.
- Notice interrupts are disabled before the timer is read and combined with the overflow count. This is done to prevent the following situation:
  - The timer value is read and it is 65535
  - The overflow interrupt happens and the counter is incremented to 1
  - The program continues and reads the counter as 1
  - The time is assumed to be 65536+65535 when in fact the correct time is 65535
- If interrupts are disabled and an interrupt event happens, then the interrupt function will be called when interrupts are enabled. If multiple interrupt events of the same type happen while interrupts are disabled, then the interrupt function is called only once when interrupts are enabled.
- The `%06lu` format specifier is the same as `%6lu` except leading zeros are printed.

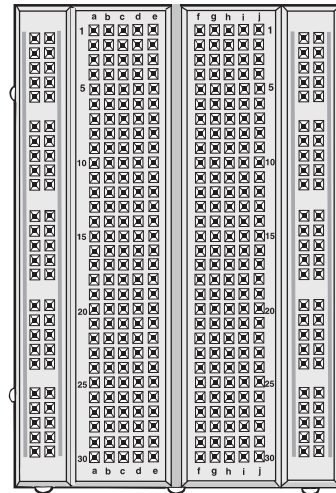
## FURTHER STUDY

- A** *Make a version of this program that prints in the format*  
**MM:SS.FFFFFF**  
*Where MM is minutes, SS is seconds and FFFFFFFF is fractions of a second.*
- B** *Add a second interrupt using timer 0 to interrupt every 13.1ms. In the interrupt routine, count interrupts and when 76 interrupts have happened, do a `putc('.')`. This should display a period every second while interrupts are enabled.*

# 15

## USING THE EXPERIMENTER'S SET

- ❑ The breadboard may be used to prototype circuits with components not on the Prototyping board. The black terminal block is used to connect jumpers from the Prototyping board to the breadboard. The breadboard has two columns on either side where all the holes in the column are connected. These are usually used for +5V and Ground. The inside of the breadboard is split down the center and the holes on either side are connected within the row. The gray shading on the right diagram shows how the holes are electrically connected.



- ❑ This exercise will use an external serial EEPROM chip. Create the file **EX15.c**, a variation of **EX9.C** as follows:

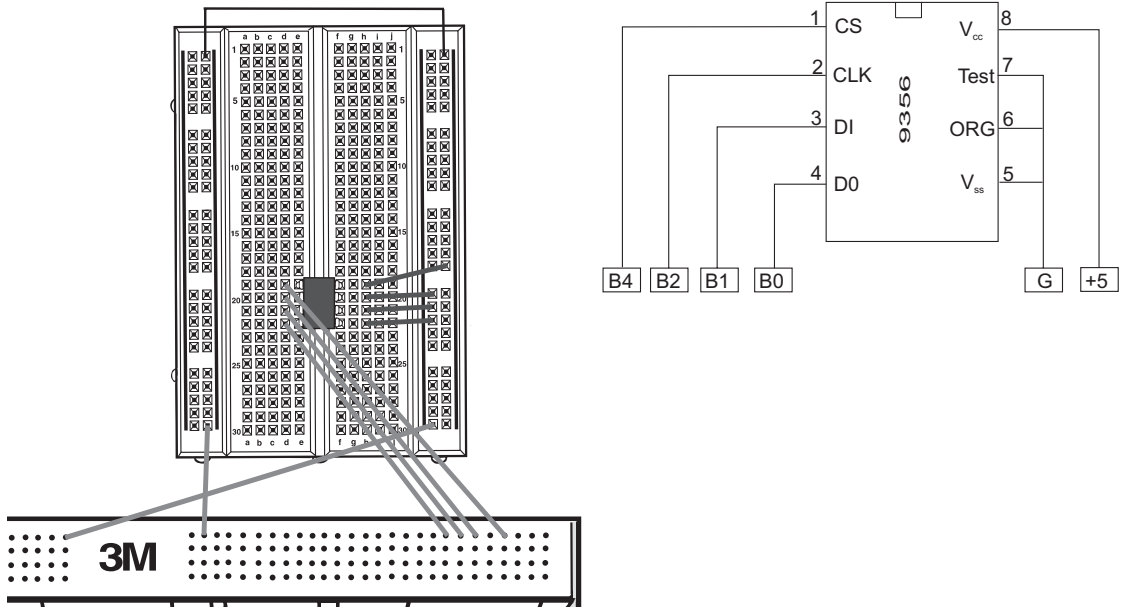
```
#include <protoalone.h>
#include <utility.c>
#include <9356.c>

void main() {
    int count;

    init_ext_eeprom();
    count = read_ext_eeprom(0);
    while(TRUE) {
        printf("\r\nCount=%u", count);
        wait_for_one_press();
        count++;
        write_ext_eeprom(0, count);
    }
}
```

- ❑ Jumpers: PinC6(7) to RS232 TX(12)  
PinC7(8) to RS232 RX (11)  
PinA4(19) to switch1(40)  
PinA5(20) to LED1(42)  
PinB4(51) to LED2(43)  
PinB5(52) to LED3(44)

- ❑ Wire up the circuit as shown in the following diagram. The diagram on the left shows how to route the wires. The schematic view below is how the remaining exercises in this booklet will show the wiring.



- ❑ Compile and Run the program. Verify when the program is halted, reset, and restarted that the count continues where left off. The output will be shown on serial terminal.

## FURTHER STUDY

- A** To show your understanding of the breadboard, rewire this same circuit to use 3 less jumper wires.
- B** The functions to communicate with the 9356 chip are in 9356.c. Since the data in and data out pins are not used at the same time they can be the same pin. Modify the circuit and the 9356.c code so both data in and data out use the same pin on the PIC16F877A.

# 16

## CLOCKING DATA IN AND OUT

- ❑ Using the circuit from Exercise 15 enter, compile and test the following program to more easily test the serial EEPROM:

```
#include <protoalone.h>
#include <stdlib.h>
#include <input.c>
#include <9356.c>

void main() {
    int cmd, address;

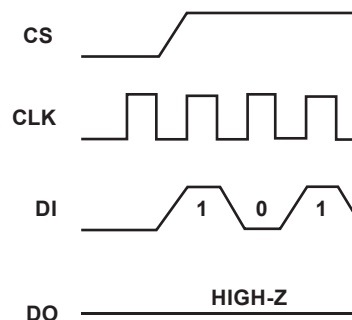
    init_ext_eeprom();

    while(TRUE) {
        printf("\n\n\rEnter address: ");
        address = get_int();

        do {
            printf("\n\rRead or Write (R, W): ");
            cmd = toupper(getc());
        } while((cmd != 'R') && (cmd != 'W'));

        if(cmd == 'R')
            printf("\n\rValue is %u",
                read_ext_eeprom(address));
        else if(cmd == 'W'){
            printf("\n\rEnter data: ");
            write_ext_eeprom(address, get_int());
        }
    }
}
```

- ❑ Jumpers: PinC6(7) to RS232 TX(12)  
PinC7(8) to RS232 RX (11)
- ❑ The 9356 device being used has four I/O connections as shown in this timing diagram. A diagram like this is typically found in the device data sheet. The transmission starts with CS going high on this chip. Then the chip expects the DI to change while the CLK line is low; and it is safe to be read while the CLK is high. Note that the clock pulse before CS goes high is not required. Open the 93LC56 data sheet using **Tools>Internet>Data sheets for Device Drivers.**





- Table 1-4 in the data sheet outlines the command format. All commands start with a 1 and followed by a 2 or 3 bit command. Depending on the command there may then be 8 address bits and 8 data bits. Commands in total are either 12 or 20 bits.
- The following code makes the CS high, then clocks 20 bits of data out in accordance with the previous timing diagram. The data is kept in a three byte array called cmd.

```
output_high (CS) ;
for (i=1;i<=20;++i) {
    output_bit(DI, shift_left(cmd,3,0) ;
    output_high(CLK) ;
    output_low(CLK) ;
}
```
- The `shift_left` function shifts all the bits in `cmd` one position to the left. The 3 tells the function how many bytes are in `cmd` and the 0 is the bit value to shift into the lowest position. The bit shifted out of the highest position is returned from the function, and in this case then passed to `output_bit`. `output_bit()` is like `output_high/low` except that the high/low is determined at run time by the second parameter.
- Open the `9356.c` file in the drivers directory. Reviewing the code in `write_ext_eeprom()` you will see the code to issue a write command. When the shift is left, the first byte transmitted is `cmd[2]`. Since there are 24 bits in `cmd` and we only need 20, there is an initial shift of 4 bits to line up before transmission.
- Figure 1-1 in the data sheet shows the required times between events. For example, the time from CS going high to CLK going high is labeled as  $T_{css}$ . Table 1-2 shows  $T_{css}$  needs to be at least 50ns. Not a problem in the code.

## FURTHER STUDY

- A** Add a new command to the EX16 program to erase the entire EEPROM. Add a function `erase_ext_eeprom()` that uses the chip's ERAL command.
- B** The `write_ext_eeprom` function in `9365.c` has a 11ms delay at the end to wait for the write to complete. Make a new version of this function that, instead of a fixed delay, uses the busy check feature described in the data sheet.

## 17

# USING AN I<sup>2</sup>C TEMPERATURE SENSOR

- The previous exercise used 3-4 wires to communicate serially to a chip. That method is generally referred to as SPI (Serial Port Interface). A popular 2 wire communications bus that allows multiple devices to use the same two wires was developed by Phillips Semiconductor and is called I<sup>2</sup>C. This exercise uses a temperature sensor that communicates via I<sup>2</sup>C. Enter the following simple program to use the temperature sensor.

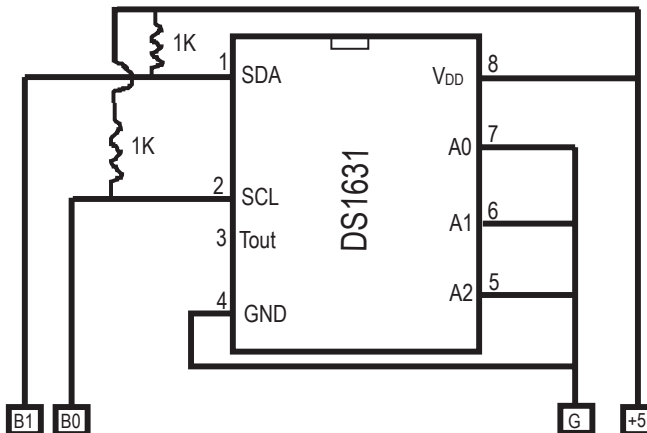
```
#include <prototype.h>
#include <ds1631.c>

void main() {
    float value;

    init_temp();

    while(TRUE) {
        value = read_full_temp();
        value /= 100.0;
        printf("%3.2f\n\r", value);
        delay_ms(1000);
    }
}
```

- Because multiple devices can use the same two wires, no device ever drives the wires high. Pull-up resistors on the wires allow them to float high and devices may ground the wire to make them low. The two wires are designated SDA and SCL. Using the DS1631 chip, wire up the following circuit:



- Jumpers: PinC6(7) to RS232 TX(12)  
PinC7(8) to RS232 RX (11)

- ❑ Compile and Run the program. The monitor window should display the temperature every second. Hold your finger on the chip to raise the temperature reading.

## NOTES

- Since multiple devices are using the same two wires, each device on the bus has a 7 bit address. For the DS1631, four of the address bits are fixed and the other three may be set via the A0, A1, and A2 pins. In our case we set them all to 0. This means up to eight of these chips could be on the same two wire bus.
- Data is transferred over the bus by first sending a unique pattern on the pins called a start condition. This is followed by the 7 bit address, and a bit to designate if data is to transfer to or from the master. The master in our case is the PIC16F877A. This byte is followed by any number of data types and a stop condition. Some devices allow the data direction bit without a stop condition. The DS1631 requires a read command to be sent to it and then the data direction changes and two bytes are read from it. The following is an extract of the code from DS1631.C

```
i2c_start() ;  
i2c_write(0x90) ; // Address and direction  
i2c_write(0xaa) ; // DS1631 command to read  
i2c_start() ;  
i2c_write(0x91) ; // Address and direction  
datah=i2c_read();  
datal_i2c_read(0) ;  
i2c_stop();
```

## FURTHER STUDY

- A** Make a version of this program that lights the first LED if the temperature is at or below 75, the second LED if it is 76-79 and the third LED when it is 80 and up. Be sure to add jumper wires to the LEDs as was done in Exercise 4.
- B** Each byte on the bus is acknowledged. I2C\_WRITE returns a 0 if the byte was accepted. Make a new version of read\_temp() that checks the result of the first I2C\_write() and displays an error if the byte was not accepted. Then change the address from 1001000x to 1001010x and note that the new error is displayed. Now change the hardware circuit to use the new address.

- ❑ Create the file EX18.C as follows:

```
#include "protoalone.h"
#include <input.c>
#define EEPROM_SDA PIN C4
#define EEPROM_SCL PIN C3
#include <2416.c>

void main() {

    BYTE value, cmd;
    EEPROM_ADDRESS address;

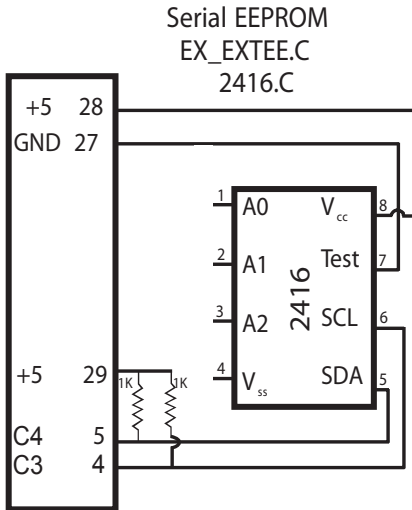
    init_ext_eeprom();

    do {
        do {
            printf("\r\nRead or Write: ");
            cmd=getc();
            cmd=toupper(cmd);
            putc(cmd);
        } while ( (cmd!='R') && (cmd!='W') );
        printf("\n\rLocation: ");

        #if sizeof(EEPROM_ADDRESS)==1
            address = gethex();
        #else
        #if EEPROM_SIZE>0xffff
            address = gethex();
        #else
            address = gethex1();
        #endif
        address = (address<<8)+gethex();
    #endif
        if(cmd=='R')
            printf("\r\nValue: %X\r\n",READ_EXT_EEPROM( address ) );

        if(cmd=='W') {
            printf("\r\nNew value: ");
            value = gethex();
            printf("\n\r");
            WRITE_EXT_EEPROM( address, value );
        }
    } while (TRUE);
}
```

- ❑ Wire the circuit as shown in the diagram below.



- ❑ Jumpers: PinC6(7) to RS232 TX(12)  
PinC7(8) to RS232 RX (11)
- ❑ Compile and Run the program. Verify that the program reads and writes to the external serial EEPROM.

- ❑ Create the file EX19.C as follows:

```
#include <16F877A.h>
#fuses HS,NOWDT,NOPROTECT,NOLVP
#use delay(clock=20000000)
#use rs232(baud=9600, xmit=PIN_C6, rcv=PIN_C7)

#include <input.c>
#include <pcf8570.c>

void main() {

    BYTE value,cmd;
    BYTE address;

    do {
        do {
            printf("\r\nRead or Write: ");
            cmd=getc();
            cmd=toupper(cmd);
            putc(cmd);
        } while ( (cmd!='R') && (cmd!='W') );

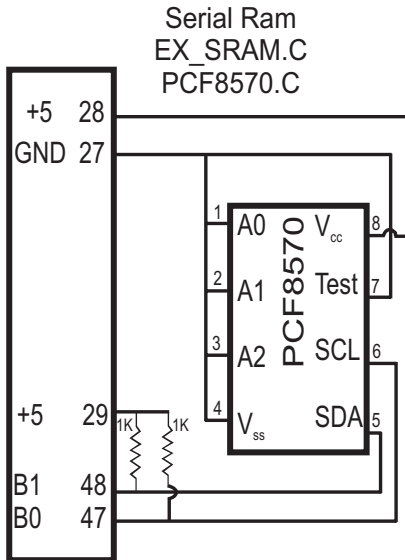
        printf("\n\rLocation: ");

        address = gethex();

        if(cmd=='R')
            printf("\r\nValue: %X\r\n",READ_EXT_SRAM( address ) );

        if(cmd=='W') {
            printf("\r\nNew value: ");
            value = gethex();
            printf("\n\r");
            WRITE_EXT_SRAM( address, value );
        }
    } while (TRUE);
}
```

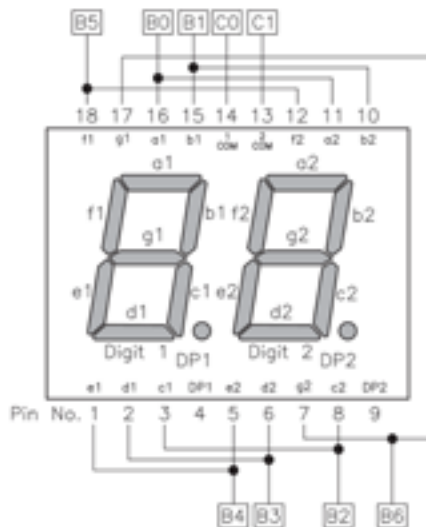
- ❑ Wire the circuit as shown in the diagram below.



- ❑ Jumpers: PinC6(7) to RS232 TX(12)  
PinC7(8) to RS232 RX (11)
- ❑ Compile and Run the program. Verify that the program reads and writes to the external serial SRAM.

# DRIVING A 7-SEGMENT LED DISPLAY

- 7-Segment LED units are used as an easy way to display numbers. Each of the 7-segments is an individual LED that can be turned on just as the LEDs on the Prototyping board. In order to save on I/O pins, it is common to multiplex the LED segments. In this case, there are two digits. Each segment is connected to the corresponding segment on the other digit. Only one digit is energized with the correct segments set. After a short period of time, that digit goes off and the other digit is lit with its segments on. By alternating very quickly, it will appear that both digits are on all the time and nine I/O pins are used instead of 16. Connect up the following circuit to accomplish this goal:



## NOTES

- Each segment is identified with a designator like a1. Segment a is the top LED and 1 is the first digit. To light this digit, power up pins 16 and 14. To light the same segment on digit 2 (a2) then power up pin 16 and 13.
- This example does not use the decimal points (DP1 and DP2).
- Unlike the onboard LEDs, there is no built-in current limiting resistor on these units. Many applications will require a series resistor on each of the segments. In this case, we use a high current LED and know that the PIC16F877A drive capability will ensure the LED segments are not damaged.



- ❑ The following program will count from 1 to 99. Enter and run the program:

```
#include <protoalone.h>

byte CONST LED_MAP[10] =
{0x3f,0x06,0x5b,0x4f,0x66,0x6d,0x7d,0x07,0x7f,0x67};

void display_number( int n ) {
    output_b(LED_MAP[n/10]);
    output_low(PIN_C0);
    delay_ms(2);
    output_high(PIN_C0);
    output_b(LED_MAP[n%10]);
    output_low(PIN_C1);
    delay_ms(2);
    output_high(PIN_C1);
}

void main() {
    int count=1,i;

    while(TRUE) {
        for(i=0;i<=200;i++)
            display_number(count);
        count = (count==99) ? 1 : count+1;
    }
}
```

## NOTES

- Unlike the previous programs, this program writes to all I/O pins on one port at the same time using **output\_b()**.
- The **LED\_MAP** array specifies for each number which segments need to be on. The first entry (zero) needs segments a, b, c, d, e, f on. This is B0-B5 or in hex 0x3F.
- The ? : notation was used to make it easy to change the increment value and range with just this one line.

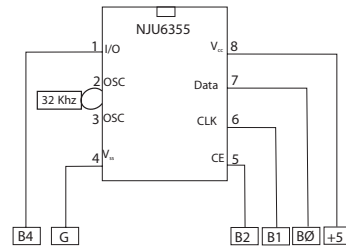
## FURTHER STUDY

- A** Make a version of this program that counts from 00-FF in hex. The hex digits A, b, C, d, E, F can be displayed using seven segments.
- B** Use the DS1631 and this display to make a digital thermometer.

# 21

## REAL-TIME INTERFACING

- ❑ Connect up the circuit to the right using the NJU6355 real-time clock chip. This chip can keep accurate date and time using the small crystal attached to the part. The interface to the PIC16F877A is an SPI interface. Internally the date/time is kept in the chip in BCD.



- ❑ Jumpers: PinC6(7) to RS232 TX(12)  
PinC7(8) to RS232 RX (11)
- ❑ Enter and run the following program to demonstrate the real-time clock:

```
#include <protoalone.h>
#include <nju6355.c>
#include <stdlib.h>
#include <input.c>

void set_time() {
    int hour,min;

    printf("\r\nHour: "); hour=get_int();
    printf("\r\nMin: "); min=get_int();
    rtc_set_datetime(0,0,0,0,hour,min);
}

void main() {
    int hour,min,sec,last_sec;

    rtc_init();
    while (TRUE) {
        rtc_get_time( hour, min, sec );
        if(sec!=last_sec) {
            printf("\r\n%02u:%02u:%02u",hour, min, sec);
            last_sec=sec;
        }
        if(kbhit() && (getc()=='S'))
            set_time();
    }
}
```

## NOTES

- The **kbhit()** function returns true if a character comes in the RS-232 port. The **&&** operator evaluates left to right. This means if the **kbhit()** returns false, then the **getc()** is never called. If it were called, the program would hang here (because there was no character). This effect is referred to as a short circuit. Not all languages guarantee this, however, ANSI C does.

## FURTHER STUDY

---

- A Make a version of this program that starts by asking for an alarm hour and minute. When the alarm time is reached light the third LED. Be sure to jumper the LED to an output port as was done in Exercise 4.*
- B Update the program to do both date and time. See the NJU6355.c file for help on the parameters to `rtc_set_datetime()`.*

- ❑ A convenient way to input and display data is to use a keypad and LCD. The following example shows how to input characters from the keypad and print them to the LCD. The '\*' character is special in that it will clear the screen and return the cursor to the top left corner.
- ❑ Create the EX22.C as follows:

```
#include <16F877A.h>
#fuses HS,NOWDT,NOPROTECT,NOLVP
#use delay(clock=2000000)

#include <lcd.c>
#include <kbd.c>

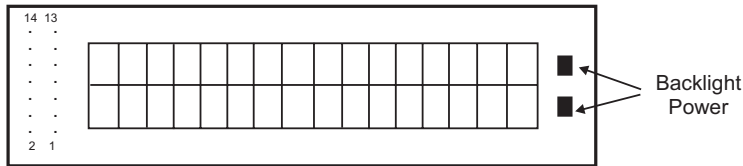
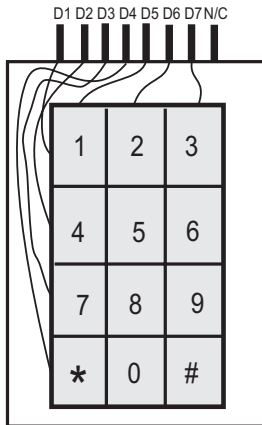
void main() {
    char k;

    lcd_init();
    kbd_init();

    lcd_putc("\fReady...\n");

    while (TRUE) {
        k=kbd_getc();
        if(k!=0)
            if(k=='*')
                lcd_putc('\f');
            else
                lcd_putc(k);
    }
}
```

- ❑ Attach the LCD to the LCD Port D female header on prototyping board, and attach the keypad to the Keypad male header as seen below:



LCD Module

1	Ground	GND
2	+5	+5
3	Contrast	Pot 10
4	RS	H-Data L-Control B1
5	R/W	H-Read L-Write B2
6	Enable	B0
7	Data 0	N/C
8	Data 1	N/C
9	Data 2	N/C
10	Data 3	N/C
11	Data 4	B4
12	Data 5	B5
13	Data 6	B6
14	Data 7	B7

Display Addresses:

80	81	82	83	84	85	86	87	88	89	8A	8B	8C	8D	8E	8F
C0	C1	C2	C3	C4	C5	C6	C7	C8	C9	CA	CB	CC	CD	CE	CF

- ❑ Compile and Run the program. The program will prompt that it is ready for input by displaying “Ready...” on the LCD. Verify that the program is functioning properly by inputting numbers on the keypad and confirming that the input is echoed onto the LCD.

- ❑ Create the file EX23.C as follows:

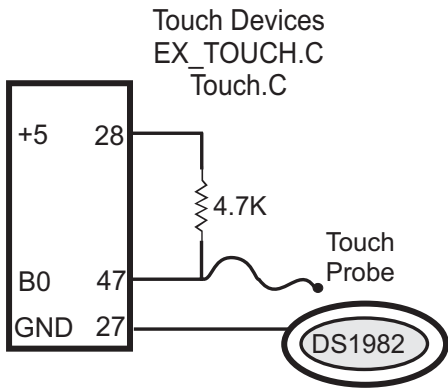
```
#include <16F877A.h>
#fuses HS,NOWDT,NOPROTECT,NOLVP
#use delay(clock=20000000)
#use rs232(baud=9600, xmit=PIN_C6, rcv=PIN_C7)

#include <touch.c>

void main() {
    BYTE buffer[8];
    BYTE i;

    printf("\r\nWaiting for a touch device...\r\n");
    while (TRUE) {
        while(!touch_present()) ;
        delay_ms(200);
        if(touch_present()) {
            touch_write_byte(0x33);
            for(i=0;i<8;++i)
                buffer[i]=touch_read_byte();
            printf("Family: %2X ID: ",buffer[0]);
            for(i=6;i!=0;--i)
                printf("%2X",buffer[i]);
            printf("\r\n");
            delay_ms(1000);
        }
    }
}
```

- ❑ The DS1982 is a one wire EEPROM. The base of the device should be grounded. Touching the top of the DS1982 with the touch probe causes data to be transmitted serially. Wire the circuit as shown in the diagram below.



- ❑ Jumpers: pinC6(7) to RS232 TX (12)  
pinC7(8) to RS232 RX (11).
- ❑ Compile and Run the program. Test that it displays the family code and ID of any device that “touch”es pin B0.

- ❑ Create the file EX23.C as follows:

```
#include <16F877A.h>
#fuses HS,NOWDT,NOPROTECT,NOLVP
#use delay(clock=20000000)
#use rs232(baud=9600, xmit=PIN_C6, rcv=PIN_C7)

#include <input.c>
#include <ds1868.c>

void main() {
    int    value;
    char  pot_num;

    setup_adc_ports (ALL_ANALOG);
    setup_adc (ADC_CLOCK_INTERNAL);
    init_pots ();

    do {
        set_adc_channel (0);
        delay_us (100);
        value = read_adc ();
        printf ("\n\r\n\rInput 1: %2X  ", value);

        if (NUM_POTS > 1) {
            set_adc_channel (1);
            delay_us (100);
            value = read_adc ();
            printf ("Input 2: %2X  \n\r", value);

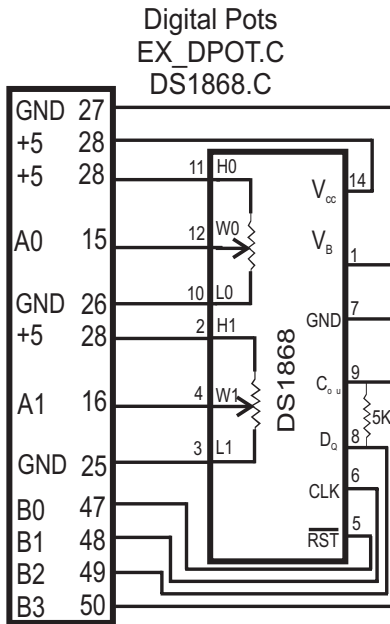
            do {
                printf ("\n\rChange pot 1 or 2?");
                pot_num = getc ();
            } while ((pot_num!='1') && (pot_num!='2'));
            putc (pot_num);
        }
        else
            pot_num = '1';

        printf ("\n\rNew pot pot_value:");
        value = gethex ();

        set_pot ((pot_num-'1'), value);
    } while (TRUE);
}
```



- ❑ The DS1868 is a digital potentiometer that can be used to take the place of the analog potentiometers. The DS1868 accepts its input from digital signals instead of a mechanical shaft. The digital potentiometer is controlled by one byte. This value between 0x00 and 0xFF represents the dividing ratio of the internal resistor network. Thus the output is set proportionally according to the input value. In this example, V<sub>ss</sub> is represented by 0x00 and V<sub>dd</sub> is represented by 0xFF. Wire the circuit as shown in the diagram below.
- ❑ Jumpers: pinC6(7) to RS232 TX (12)



pinC7(8) to RS232 RX (11)

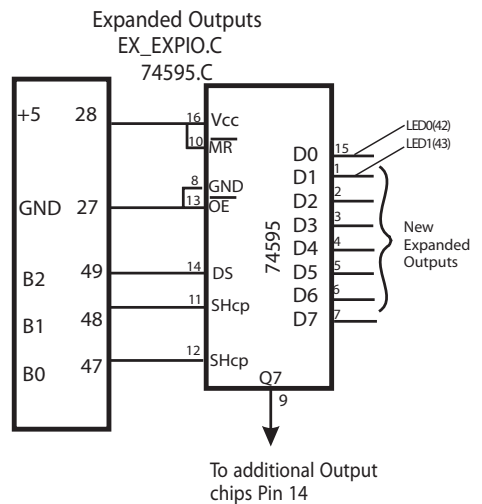
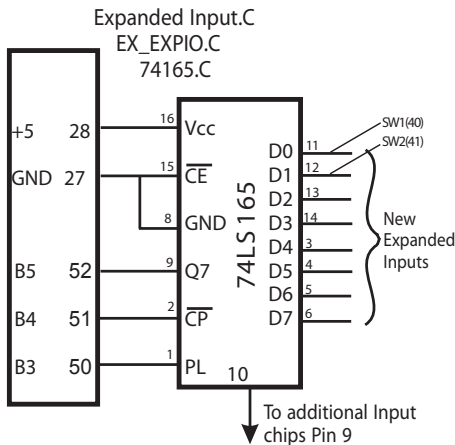
- ❑ Compile and Run the program.
- ❑ The program will prompt for the potentiometer settings. Set the potentiometer and show the results by using an analog to digital converter.

- ❑ The 74595 is a serial to parallel shift register which has eight stages. Each stage has a clock and data input. Data is loaded into the shift register when the clock pin changes from a low to high. The eight shift registers are connected together such that the data line is connected to the first register and that registers latch output is connected to the next stage and so on. After the shift register has all the data in place, one pulse on RCLK causes the eight outputs to change to the new values immediately.
- ❑ The 74165 is a parallel to serial shift register. This part uses eight inputs and with each clock pulse shifts them out bit for bit to the data pin. When the Shift/Load pin on the part is high, the data line output is high impedance. When the pin goes low, the data is latched and shifted out each time the clock goes high.
- ❑ The above two components may be used to expand the number of I/O ports that can be utilized.
- ❑ Type in the following program, named EX25.C.

```
#include <16F877A.h>
#fuses HS,NOWDT,NOLVP,PUT
#use delay(clock=20000000)
#include <74595.c>
#include <74165.c>

void main()
{
    BYTE data;
    while(TRUE)
    {
        read_expanded_inputs(&data);
        data &= 0x03;
        write_expanded_outputs (&data);
    }
}
```

- ❑ Wire up the circuit as shown in the following diagram. The diagram on the left shows the connections for the 74165 to create the expanded inputs. The diagram on the right shows the connections for the 74595 to create the expanded outputs.
- ❑ Compile and Run the program. Verify that the expanded inputs and outputs are functioning correctly by pressing the switches in different patterns and checking the LEDs for correct output. When button 1 is pushed, LED 1 will toggle red. Button 2 will toggle LED 2 to red. However, when both buttons are pushed, LED 3 will toggle green.



# USING THE SIGNAL GENERATOR BOARD FOR PULSES

- ❑ The purpose of the signal generator board is to produce TTL pulses with various durations and duty cycles. The two 10 position switches on the board set the duration of high low level of the pulse. The following table shows the possible values..

<u>Selected number</u>	<u>Delay in ms</u>
0	0
1	0.1
2	1
3	10
4	25
5	50
6	100
7	250
8	500
9	1000

- ❑ Connect the ACE kit and the generator board according following instructions. The signal generator board has six connectors in the left upper side and all pins are described on the board.
  - Connect +5V and GND between the ACE kit and generator board.
  - Connect PULSE output on the generator board with PORT B pin 0 on the ACE kit.
  - Connect serial monitor between the serial connector A on the board and the PC serial port.
  - Attach the power source cable and ICD programmer to the ace kit.
  
- ❑ Create the file ex26.c as follows:

```

#include <protoalone.h>

unsigned long count_high = 0;    // counts H
unsigned long count_low = 0;    // counts L
unsigned long count_all = 0;    // counts number of executed ISR
unsigned long count_states = 0; // number of signal transition

int state = 0;                  // actual signal level
int last_state = 0;            //last signal level

#int_timer2
void timer2_isr()
{
    state = input(PIN_B0);

    count_all++;

    if (state) count_high++;
    else count_low++;

    if (last_state != state) count_states++;

    last_state = state;
}

void main() {
    float freq, duty;

    // prescale 1:1, postcaler 1:1, reset on =200
    setup_timer_2(T2_DIV_BY_1,200,1);
    enable_interrupts(int_timer2); // enable TIMER2 IRQ
}

```

```
(cont.)
while(TRUE)
{
    enable_interrupts(global);

    if (count_all >= 50000)    // 2sec measurement
    {
        disable_interrupts(global);

        freq = count_states/4.0;
        duty = (float)count_high/count_low;

        printf("\r\nTRANS: %Lu",count_states);
        printf("  DUTY: %.3g",duty);
        printf("  FREQ: %.3g Hz",freq);

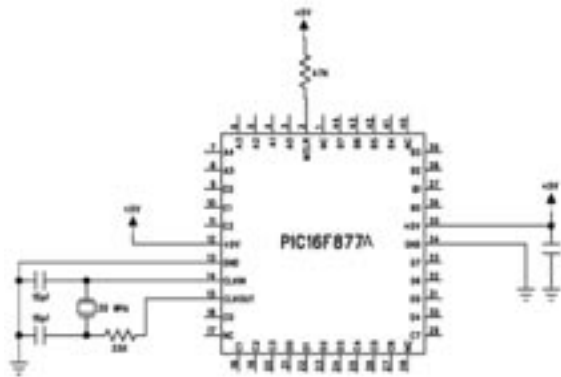
        count_high = 0;
        count_low = 0;
        count_all = 0;
        count_states = 0;

        enable_interrupts(global);
    }
}
```

- The purpose of this program is to measure frequency and duty cycle of the pulses. The output is send using the serial port. The SLOW serial monitor can be used to monitor the output.
- Compile the program and flash it into the chip using ICD.
- Experiment various combinations of the 10 position switches to produce pulses with different duty-cycles and frequencies. Open the SLOW serial monitor and observe the results.

The following diagram is a somewhat minimal circuit for a PIC16F877A

- ❑ Notice this chip has two +5V and ground connections. Some chips have only one of each. A 0.1uf capacitor mounted near the chip is a good idea and one on either side of the chip is even better. This will reduce noise both to and from the chip.
- ❑ The clock circuit here uses a crystal. With many high speed crystals the resistor on clock out prevents the crystal from being driven. The capacitor values used are generally specified in the crystal specification sheets. The PIC16F877A data sheet will show a number of other options for the clock.



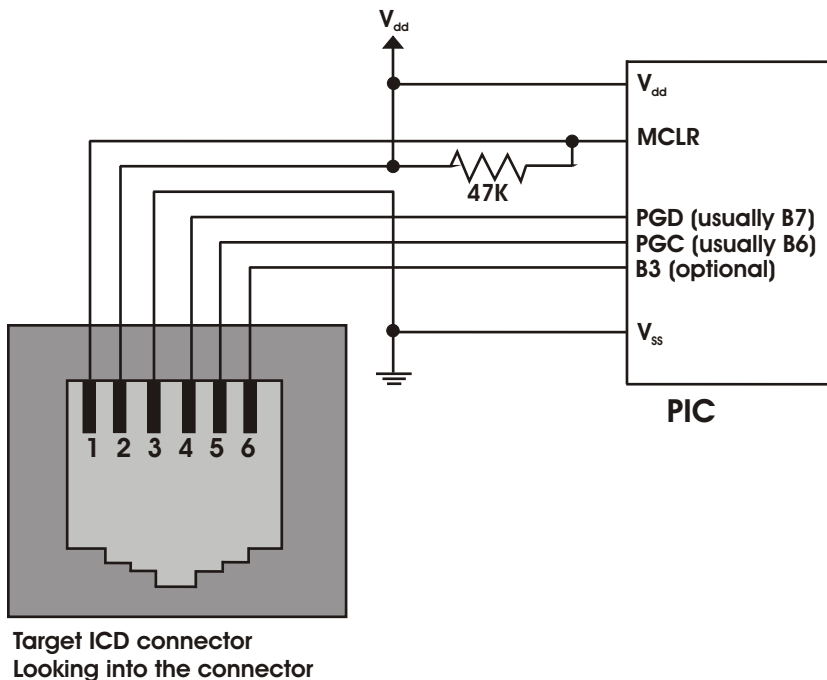
## Troubleshooting

- ❑ The MCLR pin must be in a high state for the chip to run. Note the Prototyping board schematic uses a pushbutton to ground this pin and to reset the chip.
- ❑ Most problems involve the clock. Make sure the configuration fuses are set to the proper oscillator setting. In the above case, for a 20MHz crystal HS (High Speed) is the proper setting. In the above circuit, the size of the resistor may need adjustment depending upon the crystal.
- ❑ If the program does not seem to be running, verify 5 Volts on the MCLR pin and the two power pins.
- ❑ Isolate hardware problems from firmware problems by running a program with the following at the start of main ( ) and check B0 with a logic probe or scope:

```
while(TRUE) {
    output_low (PIN_B0);
    delay_ms (1000);
    output_high (PIN_B0);
    delay_ms (1000);
}
```

## The In-Circuit Programming/Debugging Interface

- ❑ To program and/or debug in circuit, two I/O pins (B6, B7) are reserved. If debugging is not to be done, then these pins may also be used in the target circuit. However, care must be taken to ensure the target circuit has high impedance during programming.
- ❑ The MCLR pin is also used by the programmer and for debugging. Note that during programming, the voltage on this is 13 volts. The 47K resistor to 5V is sufficient isolation for the 13V. However, if anything else is connected to the MCLR pin, be sure the 13V will not damage or interfere.
- ❑ The ICD unit requires  $V_{dd}$  from the target. It is easiest to power up the target normally and then, connect the target board  $V_{dd}$  to the ICD for power. The ICD-S40 is powered by this pin (5V) and the ICD-U40 uses it to pull up the signals (3V-5V).
- ❑ The B3 pin is optional and is not used for programming. However, the Monitor feature of the debugger does use B3. It is possible to program and debug (without monitor) and allocate B3 to the target hardware. In this case do not connect B3 to the ICD connector



- ❑ Note that the ICD to target cable reverses the pins so the MCLR signal is ICD pin 6 and that connects to the target pin 1.



## References

This booklet is not intended to be a tutorial for the C programming language. It does attempt to cover the basic use and operation of the development tools. There are some helpful tips and techniques covered, however, this is far from complete instruction on C programming. For the reader not using this as a part of a class and without prior C experience the following references should help.

Exercise	<b>PICmicro<sup>®</sup> MCU C: An introduction to Programming the Microchip PIC<sup>®</sup> in CCS by Nigel Gardner</b>	<b>The C Programming Language by Brian W. Kernighan and Dennis M. Ritchie (2nd ed.)</b>
3	1.1 The structure of C Programs 1.2 Components of a C Program 1.3 main() 1.5 #include 1.8 constants 1.11 Macros 1.13 Hardware Compatibility 5.5 While loop 9.1 Inputs and Outputs	1.1 Getting Started 1.4 Symbolic Constants 3.1 Statements and Blockx 3.5 Loops 1.11 The C Preprocessor
4	1.7 Variables 1.10 Functions 2.1 Data Types 2.2 Variable Declaration 2.3 Variable Assignment 2.4 Enumeration 3.1 Functions 3.4 Using Function Arguments 4.2 Relational Operators 5.7 Nesting Program Control Statements 5.10 Switch Statement	1.2 Variables and Arithmetic Expr 2.1 Variable Names 2.2 Data Types and Sizes 2.3 Constants 2.4 Declarations 2.6 Relational and Logical Operators 3.4 Switch 1.7 Functions 1.8 Arguments 4.1 Basics of Functions
5	4.3 Logical Operators 4.4 Bitwise Operators 4.5 Increment and Decrement 5.1 if Statements 5.2 if-else Statements 9.3 Advanced BIT Manipulation	3.2 if-Else 2.8 Increment and Decrement Ops 2.90 Bitwise Operators
6	4.1 Arithmetic Operators	2.5 Arithmetic Operators
7	9.5 A/D Conversion	3.3 Else

8	5.4 For Loop 6.1 One-Dimensional Arrays	1.3 The For Statement 1.6 Arrays 2.10 Assignments Operators and Exp
10	1.6 printf Function 9.6 Data Comms/RS-232	1.5 Character Input and Output 2.6 Loops-Do-While 7.1 Standard Input and Output 7.2 Formatted Output - printf
11	6.2 Strings 6.4 Initializing Arrays 8.1 Introduction to Structures	7.9 Character Arrays 6.1 Basics of Structures 6.3 Arrays of Structures
13	9.4 Timers	
14	2.6 Type Conversion 9.11 Interrupts	2.7 Type Conversions
16	9.8 SPI Communications	
17	9.7 I <sup>2</sup> C Communications	
18	5.2 ? Operator	2.11 Conditional Expressions
19	4.6 Precedence of Operators	2.12 Precedence and Order Eval

## On The Web

Comprehensive list of PIC <sup>®</sup> MCU Development tools and information	<a href="http://www.mcuspace.com">www.mcuspace.com</a>
Microchip Home Page	<a href="http://www.microchip.com">www.microchip.com</a>
CCS Compiler/Tools Home Page	<a href="http://www.ccsinfo.com">www.ccsinfo.com</a>
CCS Compiler/Tools Software Update Page	<a href="http://www.ccsinfo.com">www.ccsinfo.com</a> click: Support → Downloads
C Compiler User Message Exchange	<a href="http://www.ccsinfo.com/forum">www.ccsinfo.com/forum</a>
Device Datasheets List	<a href="http://www.ccsinfo.com">www.ccsinfo.com</a> click: Support → Device Datasheets
C Compiler Technical Support	<a href="mailto:support@ccsinfo.com">support@ccsinfo.com</a>

# Other Development Tools

## EMULATORS

The ICD used in this booklet uses two I/O pins on the chip to communicate with a small debug program in the chip. This is a basic debug tool that takes up some of the chip's resources (I/O pins and memory). An emulator replaces the chip with a special connector that connects to a unit that emulates the chip. The debugging works in a similar manner except that the chip has all of its normal resources, the debugger runs faster and there are more debug features. For example an emulator typically will allow any number of breakpoints. Some of the emulators can break on an external event like some signal on the target board changing. Some emulators can break on an external event like some that were executed before a breakpoint was reached. Emulators cost between \$500 and \$3000 depending on the chips they cover and the features.

## DEVICE PROGRAMMERS

The ICD can be used to program FLASH chips as was done in these exercises. A stand alone device programmer may be used to program all the chips. These programmers will use the .HEX file output from the compiler to do the programming. Many standard EEPROM programmers do know how to program the Microchip parts. There are a large number of Microchip only device programmers in the \$100-\$200 price range. Note that some chips can be programmed once (OTP) and some parts need to be erased under a UV light before they can be re-programmed (Windowed). CCS offers the Mach X which is a stand-alone programmer and can be used as an in-circuit debugger.

## PROTOTYPING BOARDS

There are a large number of Prototyping boards available from a number of sources. Some have an ICD interface and others simply have a socket for a chip that is externally programmed. Some boards have some advanced functionality on the board to help design complex software. For example, CCS has a Prototyping board with a full 56K modem on board and a TCP/IP stack chip ready to run internet applications such as an e-mail sending program or a mini web server. Another Prototyping board from CCS has a USB interface chip, making it easy to start developing USB application programs.

## SIMULATORS

A simulator is a program that runs on the PC and pretends to be a microcontroller chip. A simulator offers all the normal debug capability such as single stepping and looking at variables, however there is no interaction with real hardware. This works well if you want to test a math function but not so good if you want to test an interface to another chip. With the availability of low cost tools, such as the ICD in this kit, there is less interest in simulators. Microchip offers a free simulator that can be downloaded from their web site. Some other vendors offer simulators as a part of their development packages.

# CCS Programmer Control Software

The CCSLOAD software will work for all the CCS device programmers and replaces the older ICD.EXE and MACHX.EXE software. The CCSLOAD software is stand-alone and does not require any other software on the PC. CCSLOAD supports ICD-Sxx, ICD-Uxx, Mach X, Load-n-Go, and PRIME8.

## Powerful Command Line Options in Windows and Linux

- Specify operational settings at the execution level
- Set-up software to perform, tasks like save, set target Vdd
- Preset with operational or control settings for user

## Easy to use Production Interface

- Simply point, click and program
- Additions to HEX file organization include associating comments or a graphic image to a file to better ensure proper file selection for programming
- Hands-Free mode auto programs each time a new target is connected to the programmer
- PC audio cues indicate success and fail

## Extensive Diagnostics

- Each target pin connection can be individually tested
- Programming and debugging is tested with known good programs
- Various PC driver tests to identify specific driver installation problems

## Enhanced Security Options

- Erase chips that failed programming
- Verify protected code cannot be read after programming
- File wide CRC checking

## Automatic Serial Numbering Options

- Program memory or Data EEPROM
- Incremented, from a file list or by user prompt
- Binary, ASCII string or UNICODE string

## CCS IDE owners can use the CCSLOAD program with:

- MPLAB@ICD 2/ICD 3
- MPLAB@REAL ICE™
- **All CCS programmers and debuggers**

## How to Get Started:

Step 1: *Connect Programmer to PC and target board. Software will auto-detect the programmer and device.*

Step 2: *Select Hex File for target board.*

Step 3: *Select Test Target. Status bar will show current progress of the operation.*

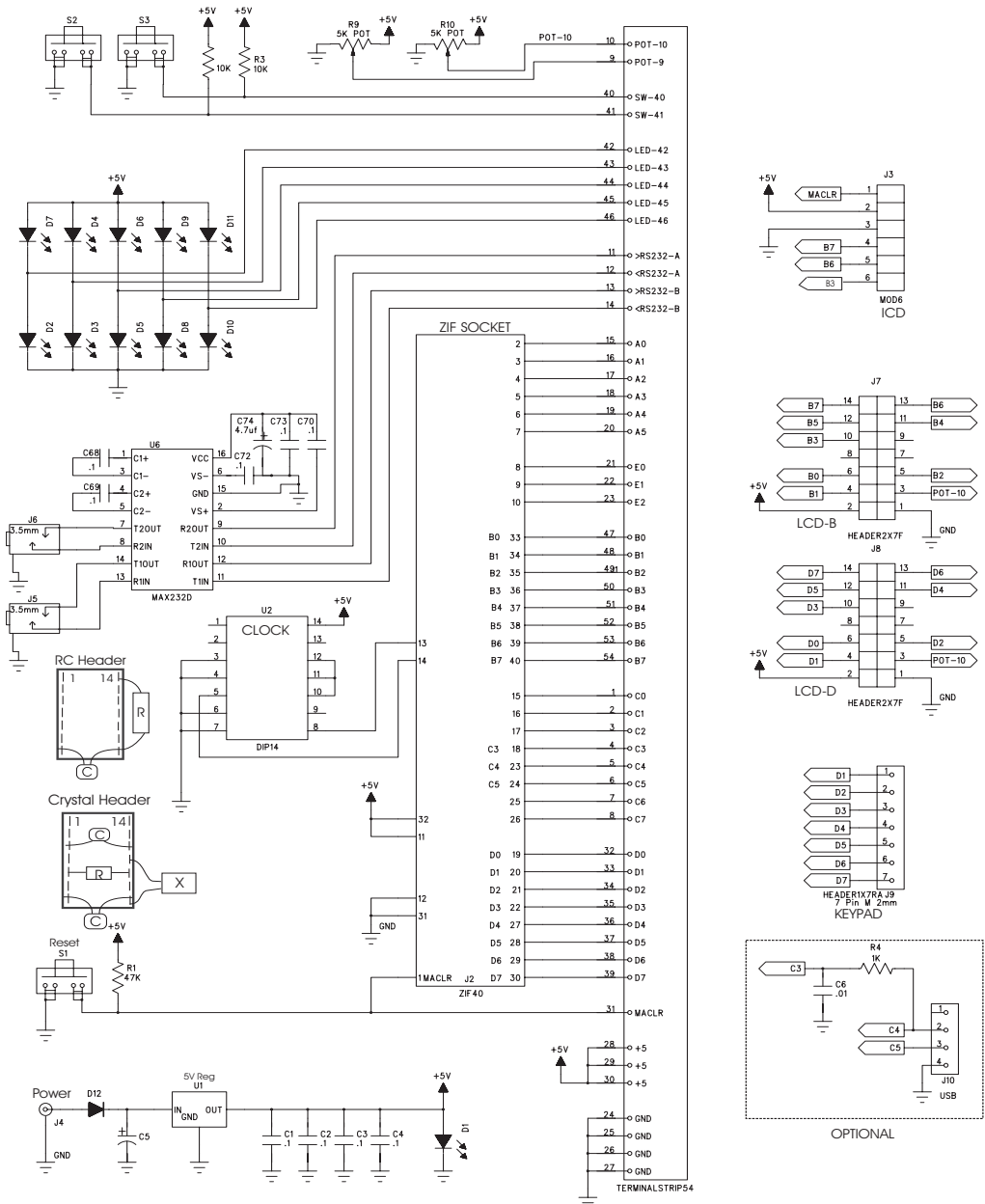
Step 4: *Click "Write to Chip" to program the device.*

Use the Diagnostics tab for troubleshooting or the ccsload.chm help file for additional assistance.



# SCHEMATICS

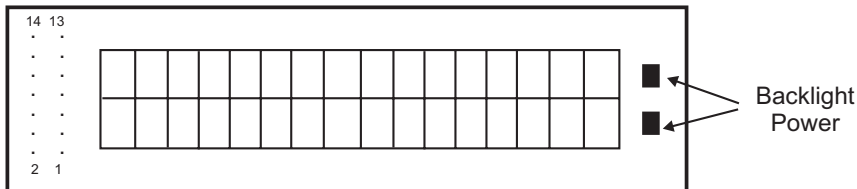
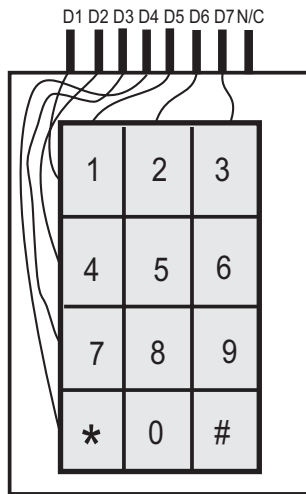
## Software Prototyping Board





# SCHEMATICS

## LCD & Keypad



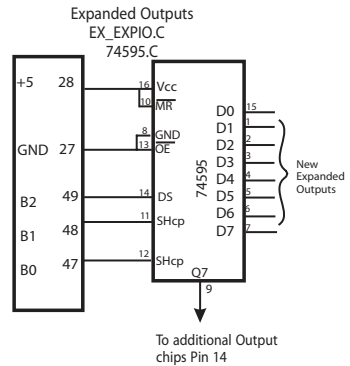
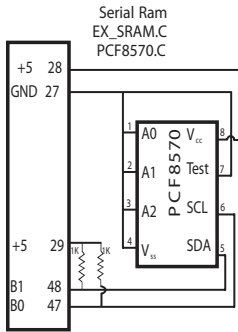
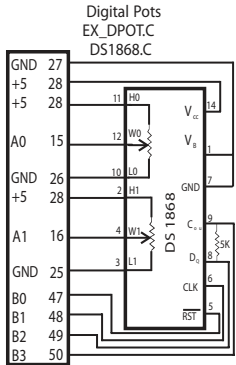
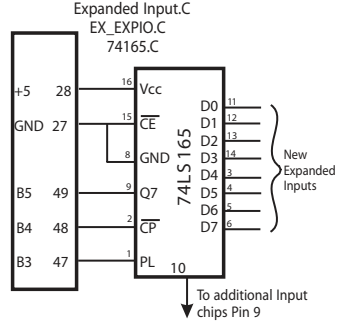
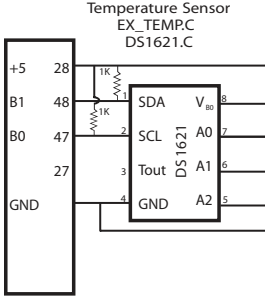
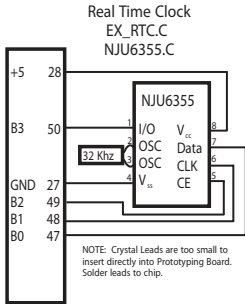
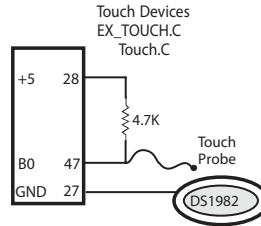
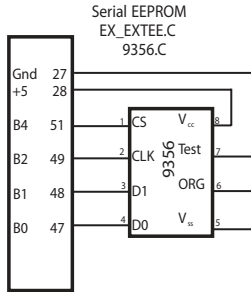
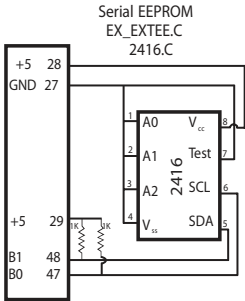
LCD Module

1	Ground	GND
2	+5	+5
3	Contrast	Pot 10
4	RS	H-Data L-Control B1
5	R/W	H-Read L-Write B2
6	Enable	B0
7	Data 0	N/C
8	Data 1	N/C
9	Data 2	N/C
10	Data 3	N/C
11	Data 4	B4
12	Data 5	B5
13	Data 6	B6
14	Data 7	B7

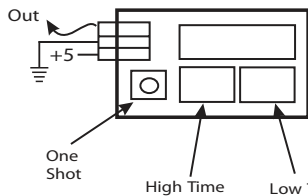
### Display Addresses:

80	81	82	83	84	85	86	87	88	89	8A	8B	8C	8D	8E	8F
C0	C1	C2	C3	C4	C5	C6	C7	C8	C9	CA	CB	CC	CD	CE	CF

# Experimenter's Kit



## Signal Generator Board



- 0 - Hold until one shot pressed
- 1 - 100us 6 - 100ms
- 2 - 1ms 7 - 250ms
- 3 - 10ms 8 - 500ms
- 4 - 25ms 9 - 1000ms
- 5 - 50ms

For example, both switches set to 7 will yield a 2hz 50% duty square wave.



# SCHEMATICS

## USB Add-On

### Parts:

- ❑ USB Connector
- ❑ PIC18F4550 IC Chip\*
- ❑ .47uf 0805 Capacitor

### Parts Installation:

