

Development Kit For the PIC[®] MCU

Exercise Book

PIC16F1937

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

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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 PIC16F1937 kit. Ensure every item is present.

Software

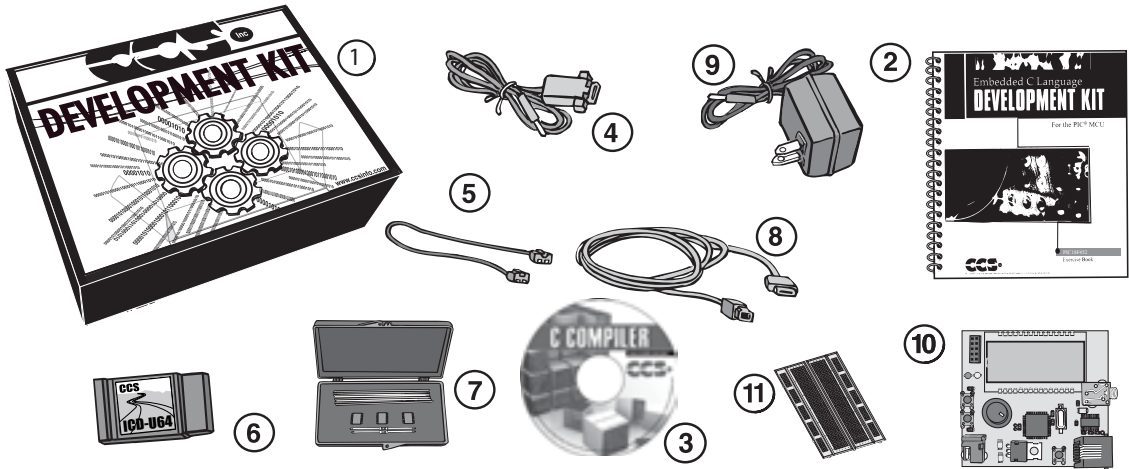
- Insert the CD into the computer and wait for the installation program to start. If your computer is not set up to auto-run CDs, then select **My Computer** and double click on the CD drive.
- Click on **Install** and use the default settings for all subsequent prompts by clicking NEXT, OK, CONTINUE...as required.
- Identify a directory to be used for the programs in this booklet. The installation program will create 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

- Connect the PC to the ICD(6) using the USB cable.⁽¹⁾ Connect the prototyping board (10) to the ICD using the modular cable. Plug in the AC adaptor (9) to the power socket and plug it into the prototyping board (10). 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⁽²⁾ on the ICD-U 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.

⁽¹⁾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.

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



- ① Storage box
- 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 unit for programming and debugging
- ⑦ Parts box includes:
 - 93LC56 serial EEPROM chip
 - DS1631 digital thermometer chip
 - NJU6355 real-time clock chip with attached 32kHz crystal
 - Two 1K resistors
 - Jumpers to connect the Prototyping board to the breadboard
- ⑧ USB (or Serial) PC to ICD cable
- ⑨ AC Adaptor (9VDC)
- ⑩ Prototyping board with a PIC16F1937 processor chip
(See inside front and back covers for details on the board layout and schematic)
- ⑪ Breadboard for prototyping circuits

USING THE INTEGRATED DEVELOPMENT ENVIRONMENT (IDE)

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.
- Click on the **set_timer0** function and press F1. 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.

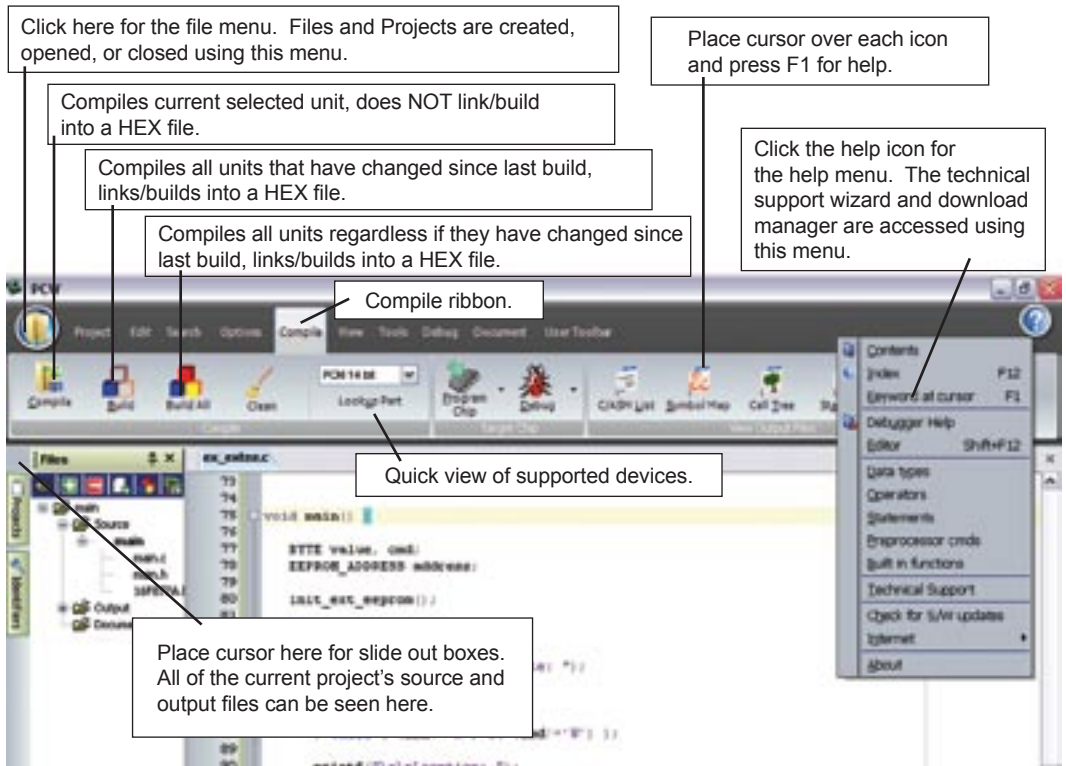
Compiler

- 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 PIC16F1937 chip, a 14-bit opcode part. Make sure **PCM 14 bit** is selected in the drop-down box under the **Compile** tab.
- The main program being compiled is always shown in the bottom of the IDE. If this is not the file you want to compile, click on the tab of the file you want to compile, right click in the 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**.

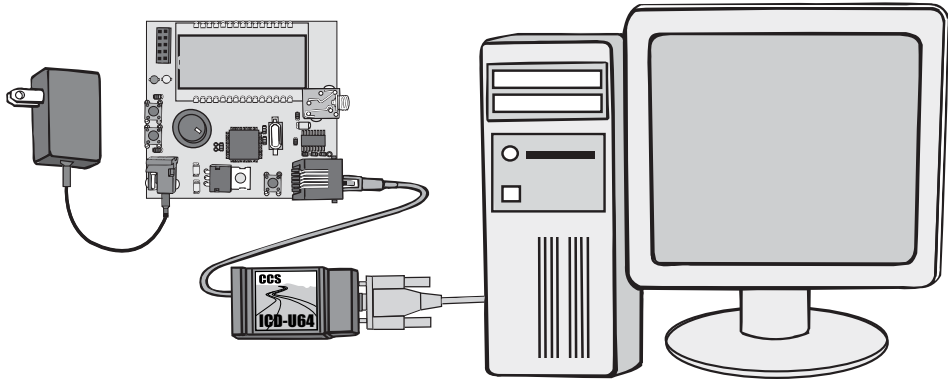
```
#include <16F1937.h>
#device ICD = TRUE
#fuses HS, PLL_SW, NOLVP, NOWDT
#use DELAY(CLOCK = 10000000)



#define GREEN_LED PIN_D0

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

NOTES

- The first four lines of this program define the basic hardware environment. The chip being used is the PIC16F1937, running at 10MHz with the ICD debugger.
- The #define is used to enhance readability by referring to GREEN_LED in the program instead of PIN_D0.
- 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.
- If you are using the ICD-U and the debugger cannot communicate with the ICD unit, go to the **Debug Configure** tab and make sure ICD-USB from the list box is selected.
- Click the green go icon: 
- Expect the debugger window status block to turn yellow, indicating the program is running.
- The green LED on the Prototyping board should be flashing. One second on and one second off.
- The program can be stopped by clicking on the stop icon: 

FURTHER STUDY

- A Modify the program to light the green LED for 5 seconds, the yellow for 1 second and the red for 5 seconds.*
- 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.

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HANDLING INPUT

- ❑ Type in and save the following program as **EX4.c**, compile and run:

```
#include <16F1937.h>
#device ICD = TRUE
#fuses HS, PLL_SW, NOLVP, NOWDT
#use DELAY(CLOCK = 10000000)

#define GREEN_LED      PIN_D0
#define YELLOW_LED     PIN_D1
#define RED_LED        PIN_D2

#define TOP_BUTTON     PIN_C4
#define BOTTOM_BUTTON  PIN_C3
//
void light_one_led(int led {
    output_high(GREEN_LED);
    output_high(YELLOW_LED);
    output_high(RED_LED);

    switch(led) {
        case 0:
            output_low(GREEN_LED);
            break;
        case 1:
            output_low(YELLOW_LED);
            break;
        case 2:
            output_low(RED_LED);
            break;
    }
}

void wait_for_one_press(void) {
    while(input(TOP_BUTTON));
    while(!input(TOP_BUTTON));
}

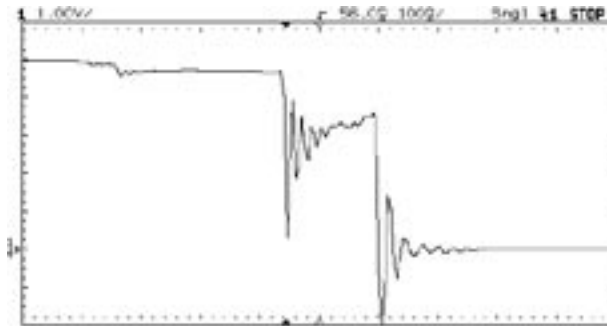
void main(void) {
    while(TRUE) {
        light_one_led(0);
        wait_for_one_press();
        light_one_led(1);
        wait_for_one_press();
        light_one_led(2);
        wait_for_one_press();
    }
}
```

- ❑ As can be seen from the program, pressing the top push button will cycle through the LEDs: green, yellow, then red.
- ❑ Add the following new type below the // lines:
typedef enum {GREEN, YELLOW, RED} colors;

- ❑ Change the parameter of `light_one_led()` to colors instead of int.
- ❑ Change the 0, 1, 2 in the call `light_one_led()` to GREEN, YELLOW, RED.

NOTES

- The Prototyping board has two momentary push-buttons that may be used as inputs to the program. The input pin is connected to a 4.7K 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 top button is held down, the LEDs alternate as fast as possible. When the top button is not pressed, the LED state freezes. This creates a random color program.*

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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 code in the file. Click **Edit>Paste to file** and name it **prototype.h**.
- ❑ It is also helpful to create a library of utility functions to use as needed for future programs. Note that just because a function is part of a program, it 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) and save as a new 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(GREEN_LED);
    output_high(YELLOW_LED);
    output_high(RED_LED);

    if(bit_test(n, 2)) {
        output_low(GREEN_LED);
    }
    if(bit_test(n, 1)) {
        output_low(YELLOW_LED);
    }
    if(bit_test(n, 0)) {
        output_low(RED_LED);
    }
}
```

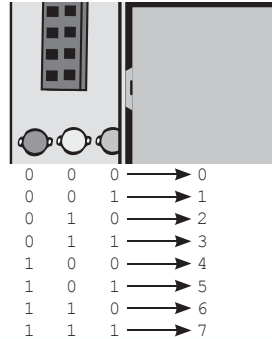
- ❑ Close all files. Type in and save the following program as **EX5.c**.

```
#include "prototype.h"
#include "utility.c"

void main(void) {
    int count = 0;

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

- ❑ **Compile and Run** the program. Check that with each press of the top push button the LEDs increment in the binary number pattern 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 every second without using the push buttons.*
- B** *Instead of the built-in function BIT_TEST, modify the program to use 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 is 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 top push button and notice the debugger now stops since the function terminates.
- Click the **Watches** 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 top push 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 were 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 top push button. The debugger should now stop on the breakpoint. Repeat this a couple of times to see how the breakpoint works. Note that the ICD with PIC16 chips only allow one breakpoint at a time.
- 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 debugger. Sometimes breakpoints skip 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 type in and save the following program as **EX6.c**.

```

#include "prototype.h"
#include "utility.c"

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

    a = 11;
    b = 5;
    c = a + b;
    c = b - a;

    while(TRUE);
}

```

- Compile** the program and step-over until `c=a+b` is executed. Add a **Watch** for `c`, 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 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” box of the evaluation tab is checked. Check it and click **Eval** again. Step over the addition line and click the **Watches** 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 PIC16F1937 chip has 14 pins that may be used to read an analog voltage. These 14 pins can be configured to certain combinations of analog input and digital pins, but not all combinations are possible.
- ❑ Type in the following program to read a single analog pin and save as **EX7.c**.

```
#include "prototype.h"
#include "utility.c"

#define CUTOFF          128
#define NEUTRAL_ZONE   25

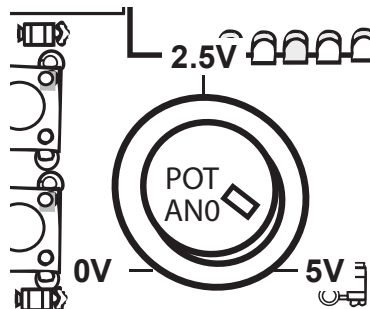
void main(void) {
    int reading;

    setup_adc_ports(sAN0);
    setup_adc(ADC_CLOCK_INTERNAL);
    set_adc_channel(0);

    while(TRUE) {
        reading = read_adc();

        if(reading < (CUTOFF - (NEUTRAL_ZONE / 2))) {
            light_one_led(GREEN);
        } else if(reading > (CUTOFF + (NEUTRAL_ZONE / 2))) {
            light_one_led(RED);
        } else {
            light_one_led(YELLOW);
        }
    }
}
```

- ❑ **Compile and Run** the program. Verify that the Prototyping board knob (A0) is turned so the green LED is on when it is low, the red LED when high and the yellow 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 port, 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 change #device to:*
- ```
#device ICD=TRUE, ADC = 16
```
- This will change the range to 0-65535. Change the constant in the program to reflect the new range. When the above example is complete, remove the ADC=16 so it will default to ADC=8*
- B** *Write a timer program that will light the green LED for x seconds after pressing the top button. x should be 0-25, depending on the setting of the analog knob.*

- The following program modifies **EX7.c** to display the average voltage reading over 10 seconds on the LEDs. Make the changes and save as **EX8.c**.

```
#include "prototype.h"
#include "utility.c"

#define CUTOFF 128
#define NEUTRAL_ZONE 25

void main(void) {
 int i, count = 0, history_ptr = 0;
 int history[10];
 long reading;

 setup_adc_ports(sAN0);
 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) {
 count = history_ptr;
 history_ptr = 0;
 } 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(GREEN);
 } else if(reading > (CUTOFF + (NEUTRAL_ZONE / 2))) {
 light_one_led(RED);
 } else {
 light_one_led(YELLOW);
 }
 }
}
```



- ❑ **Compile and Run** the program and confirm that the movement of the knob takes a few 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.*
- Odd: If the last reading is the same as the averaged 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

- ❑ When **EX5.c** was executed, it would always begin counting at 0. The program can be modified to continue counting where it left off when restarted. This is done by saving the count value in the PIC16F1937 internal data EEPROM. This memory retains the data even when power is removed.
- ❑ Type in and save the following program as **EX9.c**.

```
#include "prototype.h"
#include "utility.c"

void main(void) {
 int count;

 count = read_eeprom(0);

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

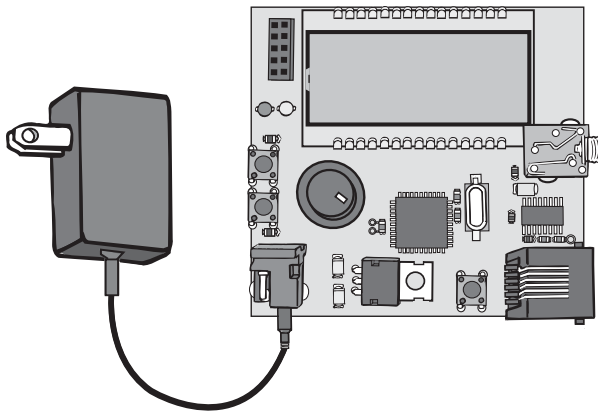
- ❑ **Compile and Run** the program. Verify that when the program is halted, reset, and restarted that the count continues where it left off.

## NOTES

- The first argument to `read/write_eeprom( )` is the address in the EEPROM to write the byte to. The PIC16F1937 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 named **protoalone.h**, and remove the following line:  

```
#device ICD=TRUE
```
- This allows the program to run as a stand-alone, which does not require the ICD to run.
- Modify **EX9.c** to use **protoalone.h**. **Compile** the program, then click **Tools>CCSLOAD** 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 top button 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.

# 10

## USING AN RS-232 PORT

- ❑ 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 PIC16F1937 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 you pick those pins. Add the following line to the end of **protoalone.h**:

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

- ❑ Type in and save the following program as **EX10.c**.

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

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

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

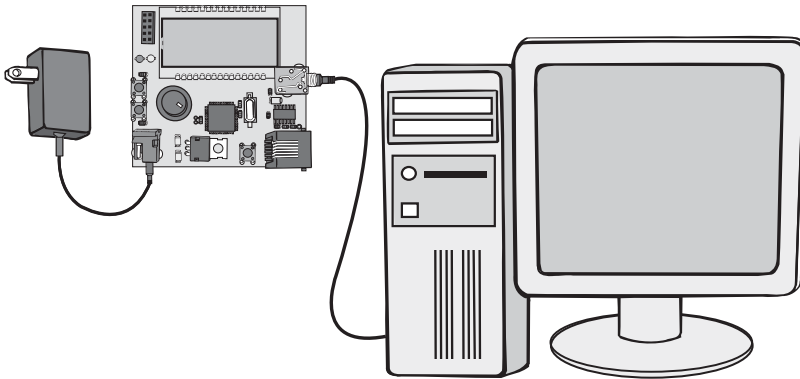
 do {
 printf("\r\nEnter the operator (+-*/): ");
 operation = getc();
 putc(operation);
 } while(!isamong(operation, "+-*/"));

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

 switch(operation) {
 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\r\n", result);
 }
}
```

- Compile and Load** the program into the Prototyping board.
- Connect the Prototyping board to the PC as shown below.



- At the PC, close the debugger window and start the program **Tools>Serial Port Monitor**. Set the correct COMM port and BAUD rate 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

- Type in and save the following program as **EX11.c**:

```
#include "protoalone.h"
#include "utility.c"

#define MAX 3

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

struct animal animals[MAX] =
 {{ 'A', "Ants", 0}, { 'B', "Birds", 0}, { 'C', "Cats", 0}};

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

void main(void) {
 char code;
 int index;

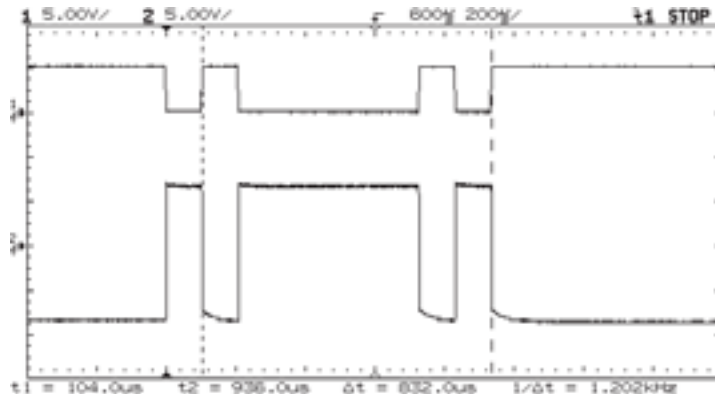
 while(TRUE) {
 printf("\r\nEnter the code: ");
 code = getc();
 putc(code);

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

- Compile and Load** the program onto the Prototyping board.
- Power up the board and use the serial port monitor to test.

## NOTES

- 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 PIC16F1937 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 schematic on back cover for details) The following diagram shows a single character A (01000001) as sent at 9600 baud. The top is from the PIC16F1937, the bottom is from the MAX232, the 8 data bits are between the dotted lines. Each bit is 104 $\mu$ s.





## FURTHER STUDY

- 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.*
- 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.c** by changing **protoalone.h** to **prototype.h**.
- Compile** and **Load** the program into the Prototyping board.
- Under the **Debug Configure** tab, change **Userstream Enable** to true and **Echo on Monitor** to false and click **Apply**.
- 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**.
- Add the following line to the program before the while loop and **Compile** and **Run** the program, entering the requested data:
 

```
setup_timer_0 (RTCC_INTERNAL);
```
- 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 **TMR0** register. Write this value down.
- Clear the breakpoints and set a breakpoint on the final **printf()**.
- Click GO.
- Check the **TMR0** 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 0.4µs. Multiply your number of ticks by 0.4 to find the time in µs. 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 PIC16F1937 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 PIC16F1937 has five 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.
- ❑ Type in and save the following program as **EX13.c**:

```
#include "prototype.h"

void main(void) {
 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);
}
```

- ❑ **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, 0.4us. 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(void) {
 long time, a, b, c;

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

 a = b * c;
 time = get_timer1();
 time -= ???;
 printf("Time: %lu microseconds\r\n", ((2 * (time + 2)) / 5));
}
```

# NOTES

- Since “time” represents the number of 0.4 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 PIC16F1937 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 26214.4μs. 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 0.8μs and the range of the timer is now 52428.8μs.
- The following is a summary of the timers on the PIC16F1937 chip:

|                |                                                                                                                                                             |
|----------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------|
| #0             | Input is Instruction Clock or external pin<br>Range is 0-255<br>Input can be divided by 1,2,4,8,16,32,64,128,256<br>Can generate interrupt on each overflow |
| #1             | Input is Instruction Clock or external pin<br>Range is 0-65535<br>Input can be divided by 1,2,4,8<br>Can generate interrupt on each overflow                |
| #2<br>#4<br>#6 | Input is Instruction Clock only<br>Range can be programmed from 0-1 to 0-255<br>Input can be divided by 1,4,16<br>Can generate interrupt on 1-16 overflows  |

## FURTHER STUDY

- Modify the program to time the actual time for a delay\_us(200) to see how accurate the compiler is.*
- 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 PIC16F1937 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. Type in and save the following program as **EX14.c**:

```
#include "prototype.h"

int16 overflow_count;

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

void main(void) {
 int32 time;

 setup_timer_1(T1_INTERNAL | T1_DIV_BY_1);
 enable_interrupts(int_timer1);

 while(TRUE) {
 enable_interrupts(global);
 while(input(TOP_BUTTON));
 set_timer1(0);
 overflow_count = 0;
 while(!input(TOP_BUTTON));
 disable_interrupts(global);

 time = get_timer1();
 time += ((int32)overflow_count << 16);
 time -= 15;
 printf("Time: %lu.%06lu seconds\r\n",
 (2 * time) / 5000000, (((2 * time) / 5) % 1000000));
 }
}
```

- ❑ **Compile and Run** the program. Press the top button, release, and note that the time it was held down is shown to 6 decimal places in the monitor pane.

## NOTES

- 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.FFFFFFF**

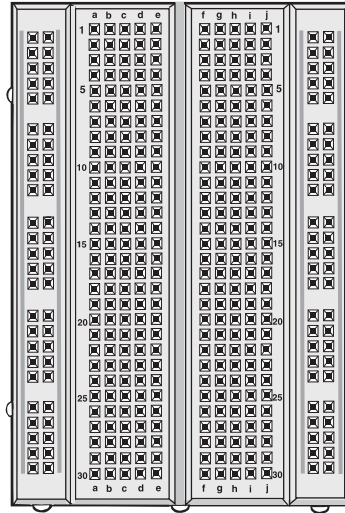
*Where MM is minutes, SS is seconds and FFFFFFF is fractions of a second.*

- 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 BREADBOARD

- 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.



- This exercise will use an external serial EEPROM chip. Type in and save the following program as **EX15.c**

```
#include "protoalone.h"
#include "utility.c"

#define EEPROM_SELECT PIN_A1
#define EEPROM_CLK PIN_A3
#define EEPROM_DI PIN_B1
#define EEPROM_DO PIN_B2

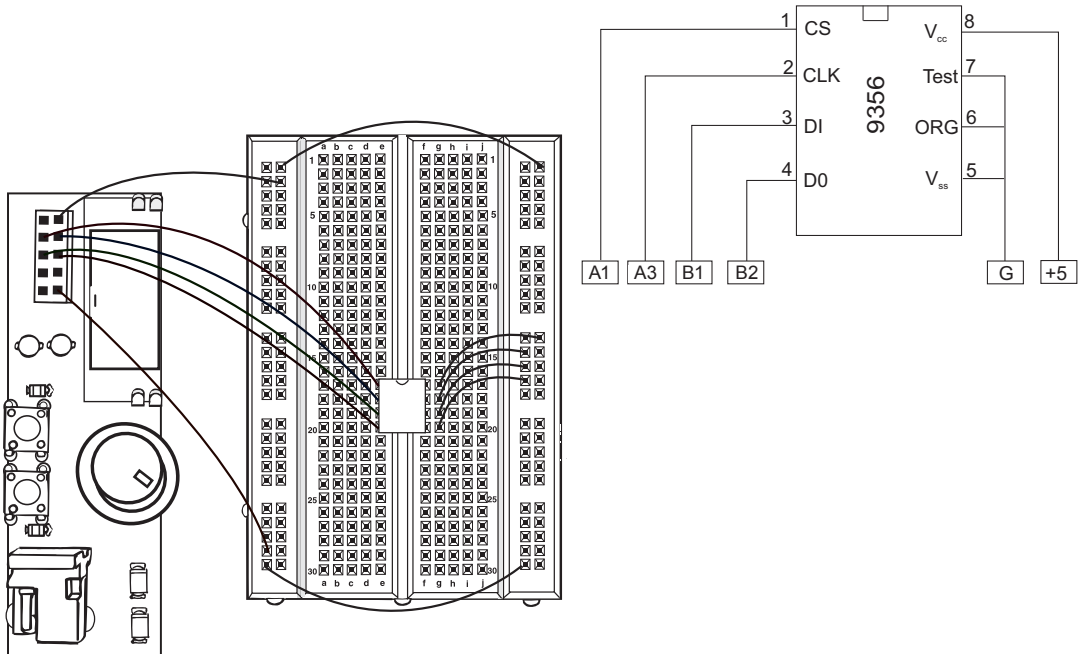
#include <9356.c>

void main(void) {
 int count;

 init_ext_eeprom();
 count = read_ext_eeprom(0);

 while(TRUE) {
 show_binary_on_leds(count);
 wait_for_one_press();
 count++;
 write_ext_eeprom(0, count);
 }
}
```

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



- ❑ **Compile and Run** the program. Test the program like **EX9**.

## FURTHER STUDY

- A** To show your understanding of the breadboard, rewire this same circuit to use 4 less jumper wires.
- B** The functions to communicate with the 9356 chip are in the 9356.c file. 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 code so both data in and data out use the same pin on the PIC16F1937.

# 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>

#define EEPROM_SELECT PIN_A1
#define EEPROM_CLK PIN_A3
#define EEPROM_DI PIN_B1
#define EEPROM_DO PIN_B2

#include <9356.c>

void main(void) {
 int cmd, address;

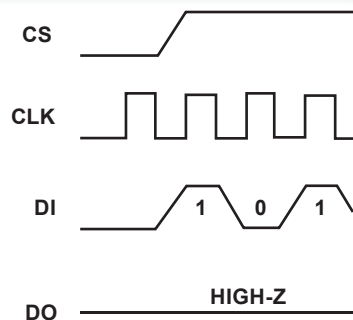
 init_ext_eeprom();

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

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

 if(cmd == 'R') {
 printf("\n\rValue: 0x%X", read_ext_eeprom(address));
 } else {
 printf("\n\rEnter Data: ");
 write_ext_eeprom(address, get_int());
 }
 }
}
```

- The 9356 device being used has 4 I/O connections as shown in this timing diagram. A diagram like this is typically found in the device datasheet. 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.





- 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 `Tcss`. Table 1-2 shows `Tcss` needs to be at least 50ns. Not a problem in the code.

## FURTHER STUDY

- Add a new command program to erase the entire EEPROM. Add a function `erase_ext_eeprom()` that uses the chip's ERAL command.*
- 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 and is called I<sup>2</sup>C. This exercise uses a temperature sensor that communicates via I<sup>2</sup>C. Type in and save the following program as **EX17.c**:

```
#include "prototype.h"

#define DAL_SCL PIN_A3
#define DAL_SDA PIN_A1

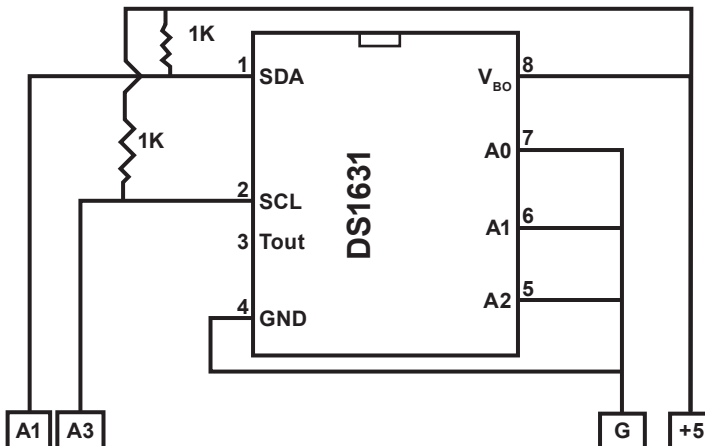
#include <DS1631.c>

void main(void) {
 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:



- ❑ **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 PIC16F1937. This byte is followed by any number of data bytes and a stop condition. Some devices allow the data direction bit to change 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();
```

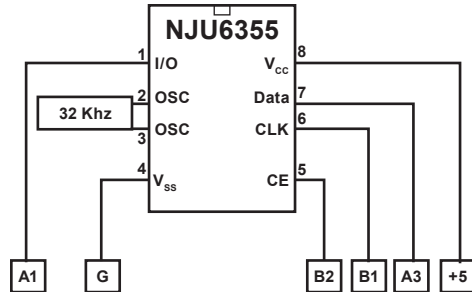
## FURTHER STUDY

- A** *Make a version of this program that lights the green LED if the temperature is at or below 75, the yellow LED if it is 76-79, and the red LED when it is 80 and up.*
- 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.*

# 18

## REAL-TIME INTERFACING

- Connect 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 PIC16F1937 is an SPI interface. Internally the date/time is kept in the chip in BCD.



- Type in and save the following program as **EX18.c**:

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

#define RTC_DATA PIN_A3
#define RTC_CLK PIN_B1
#define RTC_CE PIN_B2
#define RTC_IO PIN_A1

#include <NJU6355.c>

void set_time(void) {
 int hour, min;

 printf("\n\rHour: ");
 hour = get_int();
 printf("\n\rMinute: ");
 min = get_int();

 rtc_set_datetime(0, 0, 0, 0, hour, min);
}

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

 rtc_init();

 while(TRUE) {
 rtc_get_time(hour, min, sec);

 if(sec != last_sec) {
 printf("\n\r%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 red LED.*
- B Update the program to do both date and time. See the NJU6355.c file for help on the parameters to **rtc\_set\_datetime()**.*

# INTRODUCTION TO THE SEGMENT LCD AND LCD DRIVER

- ❑ The PIC16F1937 includes a Liquid Crystal Display (LCD) Driver Module that controls the outputs to a number of segment and common pins and displays characters or numbers on a Segment LCD using timing signals generated by the module.
- ❑ The LCD Driver Module has a number of registers that control the operation of the Segment LCD by specifying the modes, clock signals, contrast, and other functions as described in the table below:

| Register | Register Functions                                  |
|----------|-----------------------------------------------------|
| LCDCON   | Configures operation of the LCD modes.              |
| LCDCST   | Configures contrast level of the LCD segments.      |
| LCSPS    | Configures waveform type and LCD clock prescaler.   |
| LCDREF   | Configures voltage references and LCD voltage pins. |
| LCDRL    | Configures internal reference ladder.               |
| LCDSEn   | Configures port pins used for the LCD segments.     |
| LCDDATAx | Controls operation of the individual LCD segments.  |

- ❑ The LCD Driver Module controls a number of segment and common pins which are driven by clock signals generated by the module to control the segments on the LCD. The segment pins of the module are connected to the segment pins on the LCD and the common pins are the grounds connected to the segments on the LCD. Using an LCD setup with multiple common pins allows for more segments on the LCD to be controlled with fewer segment pins connecting them to the module.
- ❑ Depending on the setup of the common pins on the LCD, this will determine the multiplexing mode to be used to control the LCD. The multiplex mode helps the driver module determine how to generate the clock signals on the segment and common pins to control multiple segments on the LCD using only one set of pins. The table below shows how many segment pins the PIC16F1937 can control depending on the multiplex mode:

| Multiplex Mode | Number of Segments Controlled |
|----------------|-------------------------------|
| Static         | 24                            |
| 1 / 2          | 48                            |
| 1 / 3          | 72                            |
| 1 / 4          | 96                            |

- ❑ Depending on which multiplex mode is selected, the bias mode will also need to be selected. The bias mode determines the voltage levels to be used to determine the on and off states for the segments on the LCD.
- ❑ The prototyping board in the MiniPICD1937 Development Kit includes an external 4.5 Digit 7-Segment LCD. It functions in 1/3 multiplex mode which means it uses 3 common pins and 12 segment pins to control the segment on the LCD.

- ❑ Create an `lcd.c` file and type in the following code, which will be used to display numbers on the Segment LCD:

```
#define DIGIT4 COM0+3, COM0+5, COM1+5, COM2+3, COM1+0, COM0+0, COM1+3, COM2+0
#define DIGIT3 COM0+16, COM0+17, COM1+17, COM2+16, COM1+10, COM0+10, COM1+16, COM2+10
#define DIGIT2 COM0+19, COM0+20, COM1+20, COM2+19, COM1+18, COM0+18, COM1+19, COM2+18
#define DIGIT1 COM0+22, COM0+23, COM1+23, COM2+22, COM1+21, COM0+21, COM1+22, COM2+21

// Digit 5 "-" LB CON
//
#define SPECIAL COM2+5, COM2+17, COM2+20, COM2+23

// Character Maps
//
// 0 1 2 3 4 5 6 7 8
9 //
BYTE const digits[10] = {0xFC, 0x60, 0xDA, 0xF2, 0x66, 0xB6, 0xBE, 0xE0,
0xFE, 0xE6};

#define BLANK 0x00

BYTE lcd_position;

void lcd_display(char c) {
 BYTE segment;

 if(c == '\f') {
 lcd_position = 0;
 } else {
 if((c >= '0') && (c <= '9')) {
 segment = digits[c - '0'];
 } else {
 segment = BLANK;
 }
 }

 switch	lcd_position) {
 case 1:
 lcd_symbol(segment, DIGIT4);
 break;
 case 2:
 lcd_symbol(segment, DIGIT3);
 break;
 case 3:
 lcd_symbol(segment, DIGIT2);
 break;
 case 4:
 lcd_symbol(segment, DIGIT1);
 break;
 }
 lcd_position++;
}
```

- ❑ Type in and save the following program as **EX19.c**:

```
#include "protoalone.h"
#include "lcd.c"

void main(void) {
 long count = 0;

 setup_lcd(LCD_MUX13 | LCD_REF_ENABLED | LCD_B_HIGH_POWER, 0,
0xFF0429);
 lcd_contrast(7);

 while(TRUE) {
 printf(lcd_display, "\\f%4lu", count);

 if(count++ == 10000) {
 count = 0;
 }

 delay_ms(50);
 }
}
```

- ❑ **Compile and Run** the program and verify that it counts from 0-9999 before resetting to 0.



- ❑ The following program will use the DS1631 temperature sensor and the Segment LCD to create a digital thermometer.
- ❑ Add the following functions to the lcd.c file:

```

void lcd_sign(signed long reading) {
 char digit5 = 0x00;

 if((reading < -999) || (reading > 999)) {
 digit5 |= 0x80;
 }
 if(reading < 0) {
 digit5 |= 0x40;
 }
 if((reading < -1999) || (reading > 1999)) {
 digit5 |= 0x10;
 }

 lcd_symbol(digit5, SPECIAL);
}

void lcd_digit(char c) {
 BYTE segment;
 printf("%X, ", c);
 if(c == '\f') {
 lcd_position = -2;
 } else {
 if((c >= '0') && (c <= '9')) {
 segment = digits[c - '0'];
 } else {
 segment = BLANK;
 }

 switch(lcd_position) {
 case 1:
 lcd_symbol(segment, DIGIT4);
 break;
 case 2:
 lcd_symbol(segment, DIGIT3);
 break;
 case 3:
 lcd_symbol(segment, DIGIT2);
 break;
 }
 }
 lcd_position++;
}

void lcd_degree(char temp) {
 char degree = 0x00;

 if(temp == 'F') {
 degree = 0x8E;
 }

 lcd_symbol(degree, DIGIT1);
}

```

- Type in and save the following program as **EX20.c**:

```
#include "protoalone.h"
#include "lcd.c"

#define DAL_SCL PIN_A3
#define DAL_SDA PIN_A1

#include <DS1631.c>

void main(void) {
 long temperature;

 init_temp();

 setup_lcd(LCD_MUX13 | LCD_REF_ENABLED | LCD_B_HIGH_POWER, 0,
0xFF0429);
 lcd_contrast(7);

 while(TRUE) {
 temperature = read_full_temp();
 temperature /= 100.0;

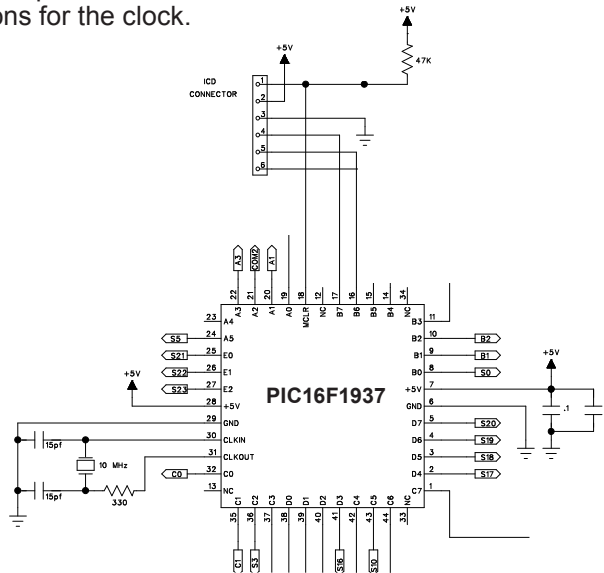
 printf(lcd_sign, "%c", temperature);
 printf(lcd_digit, "\\f%5ld", temperature);
 printf(lcd_degree, "%c", 'F');
 }
}
```

- Connect the DS1631 as in Exercise #17.
- Compile and Run** the program.
- Verify that the program displays the current temperature reading in °F and that the temperature will update while holding your finger on the DS1631.

# MIGRATING TO YOUR OWN HARDWARE

The following diagram is a somewhat minimal circuit for a PIC16F1937

- ❑ Notice this chip has two +5V and ground connections. Some chips have only one of each. A 0.1 $\mu$ f 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 PIC16F1937 data sheet will show a number of other options for the clock.



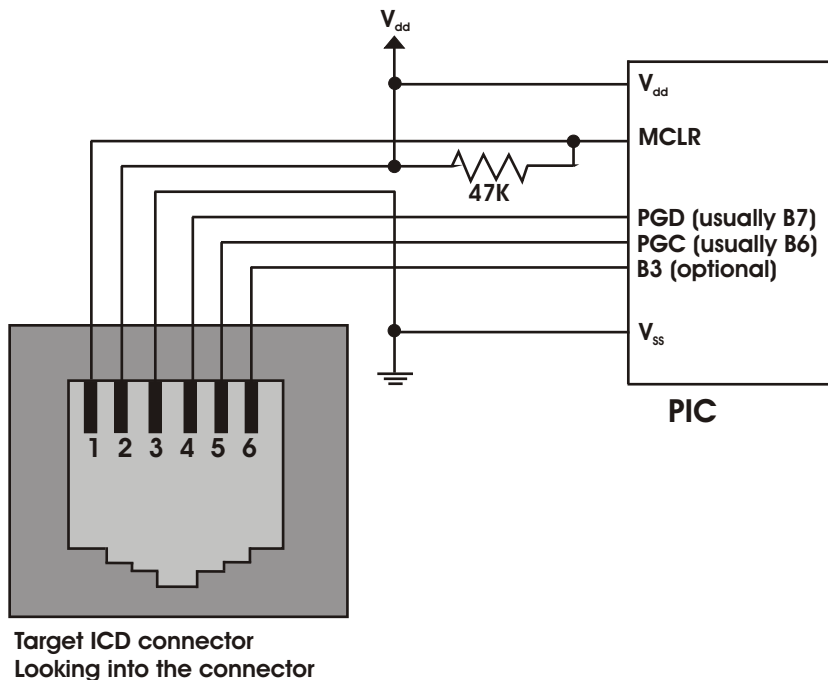
## Troubleshooting

- ❑ 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 10MHz 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-S is powered by this pin (5V) and the ICD-U 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 PIC16F1937 or 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 | PICmicro® MCU C: An introduction to Programming the Microchip PIC® in CCS by Nigel Gardner                                                                                                                                                                                  | The C Programming Language by Brian W. Kernighan and Dennis M. Ritchie (2nd ed.)                                                                                                                                                            |
|----------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 3        | 1.1 The structure of C Programs<br>1.2 Components of a C Program<br>1.3 main()<br>1.5 #include<br>1.8 constants<br>1.11 Macros<br>1.13 Hardware Compatibility<br>5.5 While loop<br>9.1 Inputs and Outputs                                                                   | 1.1 Getting Started<br>1.4 Symbolic Constants<br>3.1 Statements and Blockx<br>3.5 Loops<br>1.11 The C Preprocessor                                                                                                                          |
| 4        | 1.7 Variables<br>1.10 Functions<br>2.1 Data Types<br>2.2 Variable Declaration<br>2.3 Variable Assignment<br>2.4 Enumeration<br>3.1 Functions<br>3.4 Using Function Arguments<br>4.2 Relational Operators<br>5.7 Nesting Program Control Statements<br>5.10 Switch Statement | 1.2 Variables and Arithmetic Expr<br>2.1 Variable Names<br>2.2 Data Types and Sizes<br>2.3 Constants<br>2.4 Declarations<br>2.6 Relational and Logical Operators<br>3.4 Switch<br>1.7 Functions<br>1.8 Arguments<br>4.1 Basics of Functions |
| 5        | 4.3 Logical Operators<br>4.4 Bitwise Operators<br>4.5 Increment and Decrement<br>5.1 if Statements<br>5.2 if-else Statements<br>9.3 Advanced BIT Manipulation                                                                                                               | 3.2 if-Else<br>2.8 Increment and Decrement Ops<br>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<br>6.1 One-Dimensional Arrays                               | 1.3 The For Statement<br>1.6 Arrays<br>2.10 Assignments Operators and Exp                                              |
| 10 | 1.6 printf Function<br>9.6 Data Comms/RS-232                             | 1.5 Character Input and Output<br>2.6 Loops-Do-While<br>7.1 Standard Input and Output<br>7.2 Formatted Output - printf |
| 11 | 6.2 Strings<br>6.4 Initializing Arrays<br>8.1 Introduction to Structures | 7.9 Character Arrays<br>6.1 Basics of Structures<br>6.3 Arrays of Structures                                           |
| 13 | 9.4 Timers                                                               |                                                                                                                        |
| 14 | 2.6 Type Conversion<br>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 PICmicro <sup>®</sup><br>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<br>Page                                       | <a href="http://www.ccsinfo.com">www.ccsinfo.com</a><br>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><br>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 simulator 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.*

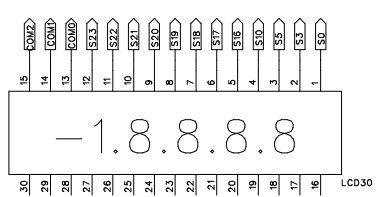
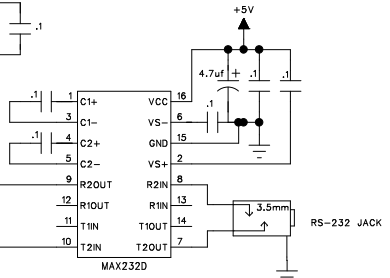
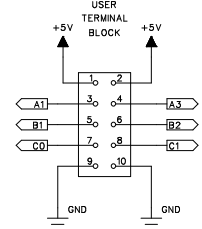
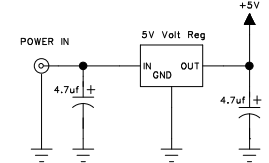
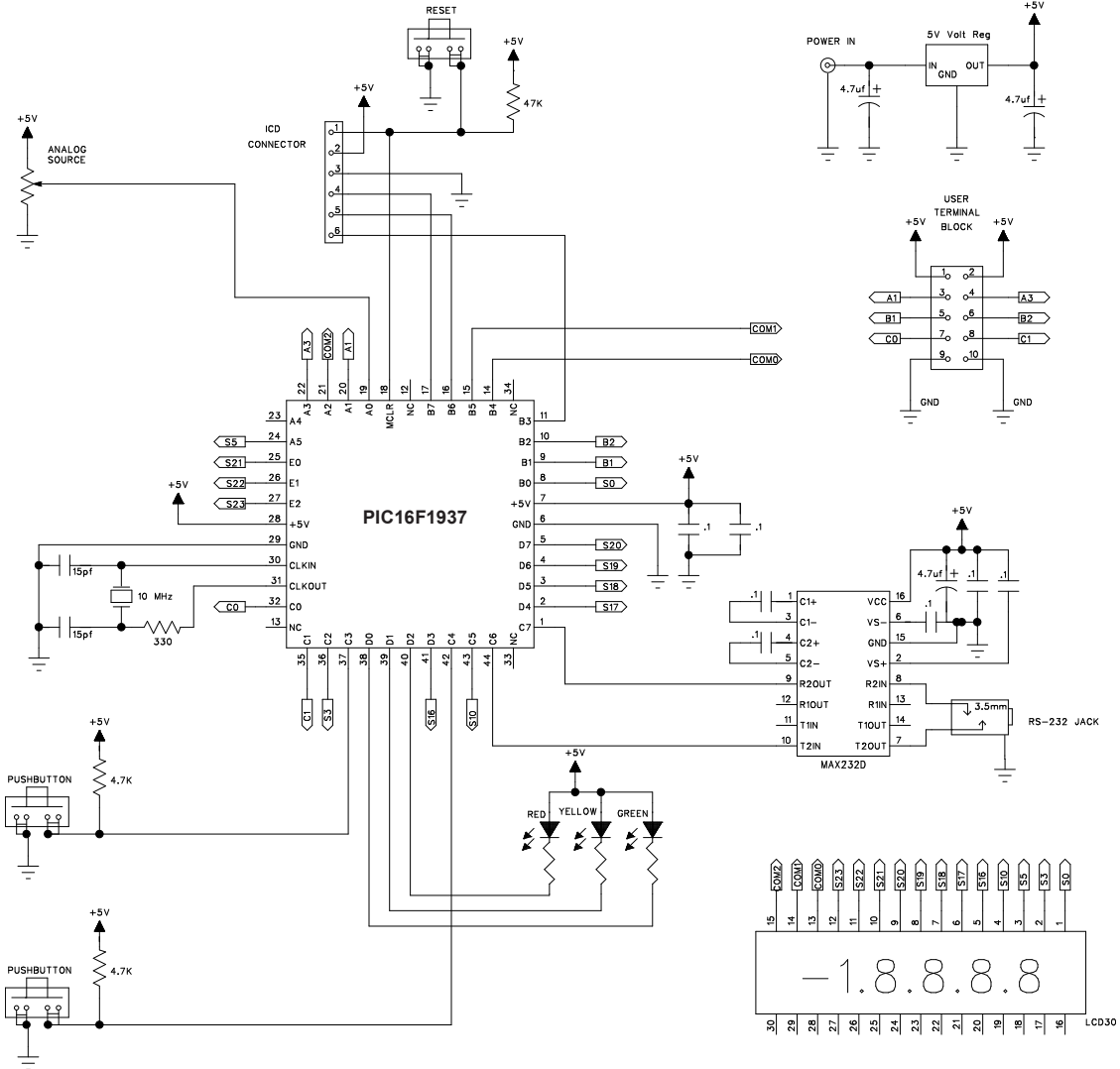
Step 2: *Select Hex File for target board.*

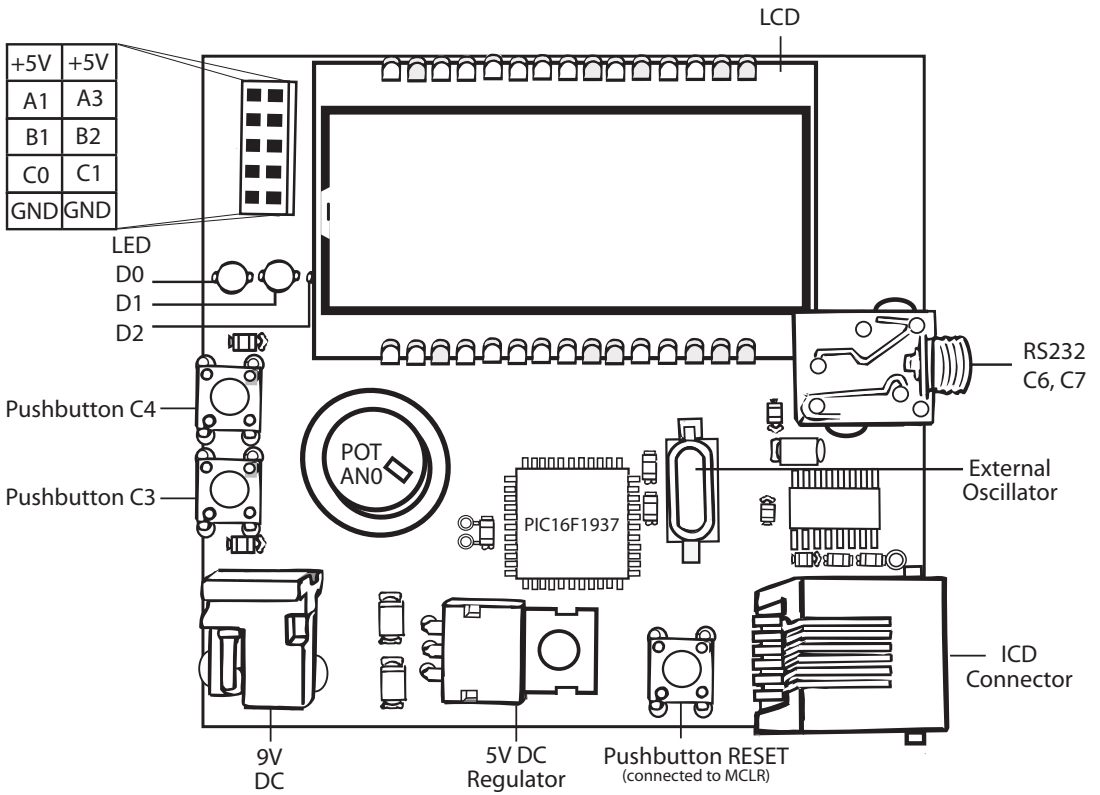
Step 3: *Select Test Target. Status bar will show current progress of the operation.*

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.







|     |     |
|-----|-----|
| +5V | +5V |
| A1  | A3  |
| B1  | B2  |
| C0  | C1  |
| GND | GND |

LED  
D0  
D1  
D2

Pushbutton C4

Pushbutton C3

9V  
DC

5V DC  
Regulator

Pushbutton RESET  
(connected to MCLR)

LCD

RS232  
C6, C7

External  
Oscillator

ICD  
Connector