

Experiment 4

PICLab project board

In this lab you will build your own microcomputer, Brock's own PICLab microcontroller project board. Based on a capable high-integration microcontroller (Microchip PIC16F8xx series IC), it features all the basic computer parts: CPU, on-board memory, ALU, etc., but also programmable input/output ports, hardware timers, analog-to-digital converters, etc. This makes it an excellent platform to base experimental Physics projects on.

4.1 Introduction

The vast majority of computers in the world do not run Windows, Unix or Linux. They do not execute word processing or multimedia applications. These are the computers that run appliances such as your television, VCR, microwave, and cell phone. These intelligent devices are known as embedded processors, microcontrollers or peripheral interface controllers (PICs). They are used to perform specific repetitive tasks that require low computational resources such as disk space or high throughput video processors, and little or no human intervention.

In contrast to the typical number crunching desktop computer, these devices excel in their ability to communicate with the world around them. To this end, a microcontroller IC not only implements the basic arithmetic and logical functions of a typical microprocessor, but also includes a variety of programmable input/output ports, hardware timers, analog-to-digital converters, and a fast and efficient means of interrupting the execution of the microcontroller program to service a variety of external or internal events.

A very capable example of a microcontroller is the Microchip PIC16F877. This 40-pin IC includes an 8-bit reduced instruction set (RISC) processor with 35 instructions, 8k words of re-writable (flash) program memory, 512 bytes of scratchpad (RAM) memory and system registers, 256 bytes of electrically-re-writable (EEPROM) data memory. There are 33 programmable input/output pins, an 8-channel analog to digital converter (ADC), three event counters/timers, and a universal synchronous/asynchronous receiver/transmitter (USART) capable of communication at up to 1.25Mbits/s. With a 4 MHz clock oscillator, each instruction requires 1 μ s to execute. The device will operate at up to 20 MHz and execute five million instructions per second. This microcontroller can be programmed in circuit with an in-circuit serial programmer (ICSP) or it can reprogram itself by downloading a new program via the serial (COM) port of a PC or terminal.

Brock's *PICLab microcontroller project board* is compatible with the Microchip PIC16F8xx se-

ries of ICs. This family includes two 40-pin versions, PIC16F874/877, and two 28-pin versions, PIC16F873/876. These chips are functionally identical but differ in the number of input/output pins, and the size of the program and data memory.

The PICLab project board includes a variety of peripheral circuits intended to simplify the development of a microcontroller based project. Included are the circuits required to drive a 7 segment LED display, an interface to an LCD display, a keypad, a serial RS232 or USB interface, relays and current drivers for the control of external devices and an in circuit programming interface. There is also a small prototyping area for the inclusion of extra components. The PICLab can be powered from a 9 V DC “wall wart”, a battery, or it can extract power from a computer’s USB port.

A fully assembled PICLab board can operate as *a stand-alone device*. A five button expandable keypad can be used to input data and control the operation of the project board. For the display of output data, a four digit seven-segment LED display can be utilized. Alternately, a more elaborate LCD alphanumeric display of 2 lines of 16 characters each can be used. This “intelligent” display has its own character memory and is programmed with a set of commands, much like the microcontroller chip itself. This device might be used as a programmable thermostat, an alarm clock, or a battery powered portable instrument such as a digital voltmeter.

A PICLab board also can operate as *a remote device*. Connected via a serial RS-232 port, or a much faster USB port, a computer or terminal can accept and display the PICLab’s output data, send the PICLab commands, and even change the program that the microcontroller is executing. Connected to a modem (modulator/demodulator), the PICLab could send an alert via the telephone to inform that the system needs attention. This device might be interfaced to several motion detectors and used as an intrusion alarm system or other household monitoring device, or as a remote data acquisition module.

The PICLab project board was designed at the Physics Department specifically as a convenient platform for several experiments in this course. Later on you will learn the basics of Assembly language programming, A/D and D/A conversion, and other aspects of computer assisted data acquisition and control. In this experiment, you will build your own PICLab workstation, by assembling (soldering) a project board of your own.

4.2 Pre-assembly review of parts and tools

Be sure to examine the schematics diagram of the project board, provided separately. You are not expected to understand all of the details yet, however, you need to learn to recognize the overall relationship between what is on the schematics, and its physical implementation on the project board. The locations of various components on the printed circuit board (see below) are well marked.

Examine, in particular, the keypad part of the circuit diagram. What should happen when you press various normally open (N/O) momentary switches? Note how instead of multiple binary logic lines to the PIC, multiple switches are connected to a single ADC input. Measuring the voltage on this line, the PIC can determine which of the switches is pressed.

The project board is a high quality double sided **printed circuit board**. The conductive traces on the fiberglass substrate are Pre-tinned for ease of soldering and both sides of the board are covered with a solder mask to minimize the possibility of solder connections between adjacent traces. To simplify parts placement, the top or component side of the board is silk-screened with the various

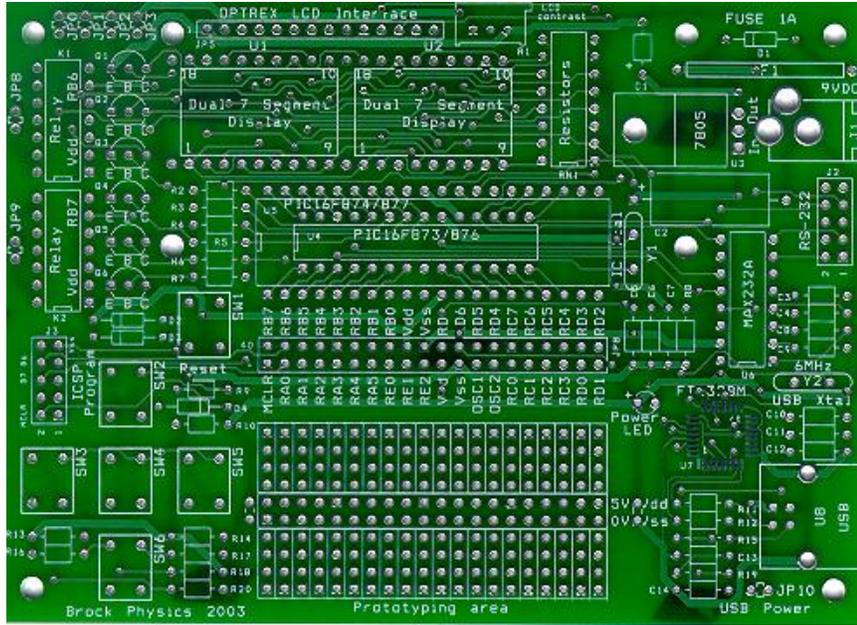


Figure 4.1: A PICLab printed circuit board, version 1.0, the component side

part outlines and corresponding part IDs. All soldering is done on the opposite, or bottom side of the board.

You will be using version 2.0 of the PICLab board, an updated of version 1.0 that no longer supports the RS232 interface or 28-pin PICs but includes a prototyping area with several types of surface-mount pads as well as a TLV431 voltage reference for the A/D converter. Space for two user-configurable trimmer potentiometers is also included.

Table 4.1 lists the components required to assemble a USB-powered printed-circuit board. These component are through-hole parts, inserted and then soldered at their proper location. The PIC itself, and the two 7-segment LED displays are socketed: the components are inserted into the socket in the final step of the assembly. Several other components, such as a voltage regulator and power jack, are required if the board needs more than 250mA of current to operate. In this case, a battery or AC adapter can be used.

Soldering

You will be using a variable temperature soldering station for all your soldering. Turn on the power and set the temperature so that the green LEDs light up but not the red ones. The soldering station may take a minute or two to reach the selected temperature. While you are waiting, moisten the tip-cleaning sponge.

The reliability of your project depends greatly on the quality of your solder connections. Please review the reference materials on soldering techniques provided on the course web site; they contain illustrations that may give you a good idea of what is expected. The following guidelines are a brief summary.

- Each time that you make a solder joint, begin by cleaning the tip of the soldering iron with the moistened sponge, then “tin” the iron by applying a small amount of solder to the tip.

Table 4.1: PICLab board v2.0 basic parts list

#	item	part ID	circuit	function
1	100 Ω resistor	R9	Reset	current limiting resistor
1	47K Ω resistor	R10	Reset	current limiting resistor
1	1N914 diode, glass	D4	Reset	blocking diode during programming
1	N/O mini switch	SW1	Reset	normally open reset switch
1	40 pin IC socket	U5	PIC	for PIC 16F877 controller
1	20.00MHz crystal	Y1	PIC	microcontroller oscillator crystal
2	22 pF capacitor	C5,C6	PIC	oscillator capacitors
1	0.1 μ F capacitor	C7	PIC	decoupling capacitor
1	10 pin header	J3	PIC	ICSP Program interface
1	40 pin IC socket	U1,U2	Display	for RT-DDC563DSA 7-segment displays
8	330 Ω resistor	RN1	Display	segment current limiting resistors
4	2N4401 transistor	Q1-Q4	Display	7-segment digit driver transistors
4	2.2K Ω resistor	R2-R5	Display	transistor base current limiting resistors
5	N/O mini switch	SW2-SW6	Keypad	normally open keypad switches
1	10K Ω resistor	R17	Keypad	voltage divider pullup resistor
1	4.7K Ω resistor	R18	Keypad	SW2 voltage divider resistor
1	8.2K Ω resistor	R20	Keypad	SW3 voltage divider resistor
1	13K Ω resistor	R13	Keypad	SW4 voltage divider resistor
1	22K Ω resistor	R14	Keypad	SW5 voltage divider resistor
1	47K Ω resistor	R16	Keypad	SW6 voltage divider resistor
1	500mA solid state fuse	0.5A	PSU	yellow disc circuit breaker
1	red LED	LED	PSU	power on LED, longer lead is + anode
1	470 Ω resistor	R8	PSU	power LED current limiting resistor
1	6.00MHz crystal	Y2	USB	USB interface oscillator crystal
1	0.033 μ F capacitor	C10	USB	decoupling capacitor
2	22 pF capacitor	C11,C12	USB	oscillator capacitors
1	0.01 μ F capacitor	C13	USB	decoupling capacitor
1	0.1 μ F capacitor	C14	USB	decoupling capacitor
2	27 Ω resistor	R11,R12	USB	current limiting resistors
1	1.5K Ω resistor	R15	USB	pull-up resistor
1	470 Ω resistor	R19	USB	resistor
1	USB B-type connector	USB	USB	USB cable connector

Table 4.2: PICLab board v2.0 optional on-board power supply parts list

	#	item	part ID	circuit	function
	1	1.0A solid state fuse	1A	Power	yellow disc circuit breaker
	1	100 μ F/10V capacitor	C1	Power	output filter capacitor
	1	100 μ F/25V capacitor	C2	Power	input filter capacitor
	1	1N4004	D1	Power	polarity reversal diode
	1	3 pin header		Power	USB/VDC power select
	1	7805	7805	Power	5V regulator
	1	Power jack 2.1mm	J1	Power	external 9VDC voltage input

This procedure will result in better transfer of heat from the iron to the parts to be soldered.

- Apply the tip of the iron where the component lead and the PC board copper trace meet so that *both* are heated at the same time. Apply the solder to the side *opposite* the tip. Do not touch the solder with the iron tip. When both the lead and the trace are sufficiently hot, the solder will melt and form a connection. This may take one or two seconds. Apply only sufficient solder to cover the joint.
- Withdraw the tip without disturbing the solder joint and let the joint cool. A good joint will be smooth and shiny and show a visibly solid connection between the copper trace and the component lead. When insufficient heat is applied to a joint, the solder will fail to flow around the connection and will bead and form globules, resulting in a “dry” joint. To correct this, reheat the joint until the solder melts, apply a touch more solder and let cool.
- When soldering a two lead component such as a resistor or diode, insert the component into the PC board so that it rests flush with the board’s surface, then slightly bend the leads outward where they meet the board. Solder both leads and when cooled snip off the excess lead where it meets the solder joint.
- When soldering a component with several connections such as an IC socket, insert the component flush with the board and hold it in place as you solder the corner pins to the board. If the socket is not properly seated, apply some pressure to the raised region and heat the solder joint. After you are satisfied that the part is flush with the board, solder the remaining pins.

4.3 Assembly of a PICLab project board

The parts IDs are laid out on the board as text on paper, with the lowest index at the top left corner and ID numbers progressing in rows to the lower right corner of the board. To attach the various components to the printed circuit board, adhere to the following assembly sequence. Check off each step as it is completed. Note that many components are polarized and require to be placed on the board in a particular orientation. Follow the philosophy of checking component placement twice and soldering once. The removal and replacement of improperly installed components can be a tedious, time consuming process and if improperly carried out, can lead to board damage.

Note: before proceeding with the assembly, thoroughly read the following instructions in their entirety.

Before soldering any components to the project board, familiarize yourself with the proper *location and orientation* of all the components. Verify that you are installing the correct parts as specified in Table 4.1. If you are uncertain as to the value of a particular resistor, measure it with a multimeter. As you go along, you may find it useful to mark off the steps already completed.

- ❗ Locate the 100 Ω reset circuit resistor R9 and verify the value with an Ohmmeter. Bend the leads at a right angle where they meet the body of the resistor. You can do this by applying pressure to the end of the resistor body with the tip of your finger. Be sure to make a tight angle otherwise the part will not fit into the board. Avoid bending the leads many times as they will likely break off. With the PC board component side up, install resistor R9 flush with the PC board, then bend the leads outward to hold the part in place. Turn over the PC board and solder the resistor leads. Snip the excess lead lengths *after* the solder joint has cooled.
- ❗ Repeat the procedure to install the 47 K Ω reset circuit resistor R10.
- ❗ Install diode D4. The diode has a glass body with a thin black band at one end to indicate the negative cathode. The band should be oriented in the same direction as the part outline on the PC board. Solder and trim the leads.
- ❗ Install the reset switch SW1. The pins have an S shaped bend designed to hold the part in place during the automated assembly process. You will need to carefully straighten the pins of all the switches with pliers so that they can be inserted into the PICLab board. Be sure that the switch is flush with the PC board, then solder it in place.
- ❗ Install the 20 MHz PIC oscillator crystal Y1 and oscillator capacitors C5 and C6.
- ❗ Install the power LED, noting that the negative side of the diode is identified by the notch at the base, the LED current-limiting resistor R8 and 500mA solid-state fuse, a small flat yellow disk, at the location marked 'Fuses, 0.5A'.
- ❗ A three-pin jumper, next to the fuse, can be installed to select the source of power to the board, either from the USB connection (USB) or from an on-board power supply (VDC). To power the board only from the USB interface, connect a piece of wire from the middle hole to the end hole labeled USB.
- ❗ The location RN1 for the display segment current limiting resistors can accept a resistor network, an IC that integrates eight resistors in one package, or discrete resistors. You will use eight discrete 330 Ω resistors for this purpose. Install side by side and solder the eight resistors at location RN1.
- ❗ Install the four 2.2 K Ω resistors R2 to R5 that limit the base current of the transistors Q1 to Q4.
- ❗ The 2N4401 (or 2N3904) transistors Q1 to Q4 must be properly installed. Hold the transistor upright with the part number facing you and the three legs facing downward. From left to right, the legs are identified as E-B-C. The placement of these legs should conform with the markings on the PC board. Generally, the three legs are clearly marked on the transistor

body. Add these transistors to the PC board. If you *are not sure* as to the proper orientation of the transistors, ask the instructor.

- ❗ Install the five keypad switches SW2 to SW6.
- ❗ Install keypad resistors R17, R13, R14, R16, R18, R20. Be careful to place these resistors at their proper location, otherwise the keypad will not function properly. Check their resistance with an Ohmmeter. The reading should be within a couple of percent of the required value.
- ❗ With the project board component side up, insert a 40-pin IC socket for the PIC controller at location U5 on the board. One end of an IC socket is usually indexed with a cutout or some other identifying mark to properly orient the removable IC in the socket. Be sure that the socket orientation corresponds with the indexed outline on the board.
- ❗ With the board solder side up and the IC socket flush with the surface of the board, solder the four corner pins to the board. Check that the socket is properly seated. If it is not, gently apply pressure to the socket and apply some heat to the pin to melt the solder and seat the socket. Solder the remaining pins, being careful to not apply too much solder and short out adjacent pins.
- ❗ Repeat the above procedure to mount the 40-pin socket for the seven-segment displays U1 and U2. Here we are using a socket to allow for the displays to be removable. Orient this IC socket with the index mark next to pin 1 of U1.
- ❗ Locate the 10-pin header J3 required for in-circuit serial programming. The location is labeled “ICSP Program”. Insert the shorter end of the header strip flush with the board and solder it in place.
- ❗ The FT232BM USB interface chip has been pre-soldered to the board. Typically, for proper installation, a surface-mount component requires a fine-tipped soldering iron and very thin solder as well as the aid of a magnifier. Install the other USB-related components: the resistors R11, R12, R15 and R19, then the capacitors C7 and C10-C14, and finally the 6 MHz crystal Y2, making sure that the metal case does not contact the pads of C10.
- ❗ Install the silver USB-B connector by gently pressing the jack into the mounting holes while being careful to make sure that the four small signal wires are properly inserted and protruding from the other side of the board.

Carefully check over the entire board. You can use the illuminated magnifier to verify that all of the solder joints are of good quality and that the components are installed at the correct locations and in the proper orientation. Fig.4.2 shows you what your completed PICLab project board should look like.

4.4 PICLab basic functionality tests

Before putting your project board to a practical use, you must verify that all of the board’s components are functioning as expected. To begin with, always establish that the correct voltage is present and distributed throughout the board.

- ❗ Have the instructor check your board before you perform the following tests.



Figure 4.2: A completely assembled PICLab project board

- ⓘ Connect a USB cable from the board to the host computer. The LED should light up. If it does not, the LED may have been inserted backwards. With a voltmeter, verify that there is 5V DC at the Vdd pin of the PIC expansion bus.
- ⓘ Test the reset circuit. This circuit sets the voltage at the MCLR pin of the controller. A low voltage at this pin resets the processor while a level of +5V puts the processor in run mode. With the Reset switch released, there should be +5V DC present at the MCLR pin of JP8. Press the Reset switch SW1. The voltage should drop to 0V. Release the switch to return the reset line to +5V.
- ⓘ If the above tests have been successful, remove power from the project board. Ground yourself by touching the metal case of an instrument, then install the PIC microcontroller chip on the board. Be sure to properly orient the chip in the IC socket. Without touching the pins, carefully line up the PIC chip with the socket so that all the pins are lined up with the socket below. Gently and evenly press the chip into the socket, being sure that none of the pins are out of alignment and being bent, until it is fully seated in the socket. If the chip resists installation, see the instructor.
- ⓘ Install the two dual 7-segment display ICs. Note the correct orientation. The decimal points of the display should be at the bottom of the display, toward the PIC. Install the first display IC flush with the right side of the socket. The second display is installed flush with the first. The two leftmost pins of the socket will remain empty. That is to say, the displays should appear offset slightly to the right on the socket.
- ⓘ Noting the correct orientation, install the MAX232 serial interface chip into the 16-pin socket following the directions outlined above.
- ⓘ Reconnect power to the project board. If the PIC circuit is functioning properly, the PICLab will test the 7-segment display by displaying the number 8888. The PICLab will then blank

the display and wait for user input. Press the Reset button. The PICLab should once again display 8888, then blank the display. If this happens, the PICLab microcontroller and display circuits are functioning as expected.

The keypad now needs to be tested. The state of the keypad is encoded as specific voltage levels at ADC input channel 0. The switches are organized as follows:

```
SW2 = '2'
SW3 = '3'  SW4 = '4'  SW5 = '5'          SW2 + SW3 = '1'
SW6 = '6'          none = '7'
```

The keypad test routine verifies that the keypad resistors were correctly installed by displaying the switch number on the LED display when a switch is pressed. The following procedure causes PICLab to enter a diagnostic mode that displays keypad data.

- ❗ Press and hold one of the keypad switches. Press and release the reset button. The number 8888 should be displayed, followed by a number that corresponds to the keypad button currently pressed.
- ❗ Release the switch. The number '7' should appear. Press each of the keypad switches in turn and verify that the number corresponding to the switch is displayed. If the number output does not match the switch pressed, an incorrectly valued resistor has been installed. Simultaneously press SW2 and SW3; the digit '1' should be displayed. Press the reset button to exit the diagnostic routine.

Now you can test the operation of the PICLab USB serial interface. The PICLab board is controlled and programmed via a connection to the `picl` software running on a host computer. `picl` can automatically detect the presence of the PICLab board. More on this later...

- ❗ With the PICLab board connected to the host computer, login to your workstation and type 'picl' at the command prompt. The `picl` software should start by opening a 'PICL' window on your desktop, as well as a 'PIC simulator' window. At the top left corner of the 'PICL' window, an icon displaying a single plug shows that the PICLab board is not currently communicating with the `picl` software and `picl` software is running as a PICLab simulator. In this mode, your programs are executed on a virtual duplicate of the PICLab hardware.
- ❗ Check that the port is set to '/dev/ttyUSB0'. Click on the connection icon; it should change to a connected pair of plugs and a message 'Connected to PICLab at 57600 Baud' should be displayed in the status box. The 'PIC simulator' window disappears.
- ❗ From the 'Options' menu, click the 'Reset PIC' button. The PICLab board should momentarily display the '8888' and then blank, just as if you had pressed the Reset button on the board.

Once all of the above tests have been successfully carried out and all problems have been resolved, your PICLab is ready for use.