Chapter 1

Assembly Manual

This chapter presents an introduction to electronic assembly followed by step-by-step instructions to assembling the 6.270 hardware. The instructions assume no prior background in electronics.

Instructions are provided for the following boards and devices:

- Microprocessor Board
- Expansion Board
- Battery Charger Board
- Battery Packs
- Infrared Transmitter Board
- Motor Switching Board
- Sensor Assemblies
- Motor Assemblies
- VAX2000 Cable

1.1 Electronic Assembly Technique

If there are places in life where "neatness counts," electronic assembly is one of them. A neatly-built and carefully soldered board will perform well for years; a sloppily- and hastily-assembled board will cause on-going problems and failures on inopportune occasions.

This section will cover the basics of electronic assembly: proper soldering technique, component mounting technique, and component polarities.

By following the instructions and guidelines presented here, you will make your life more enjoyable when debugging time rolls around.

1.1.1 Soldering Technique

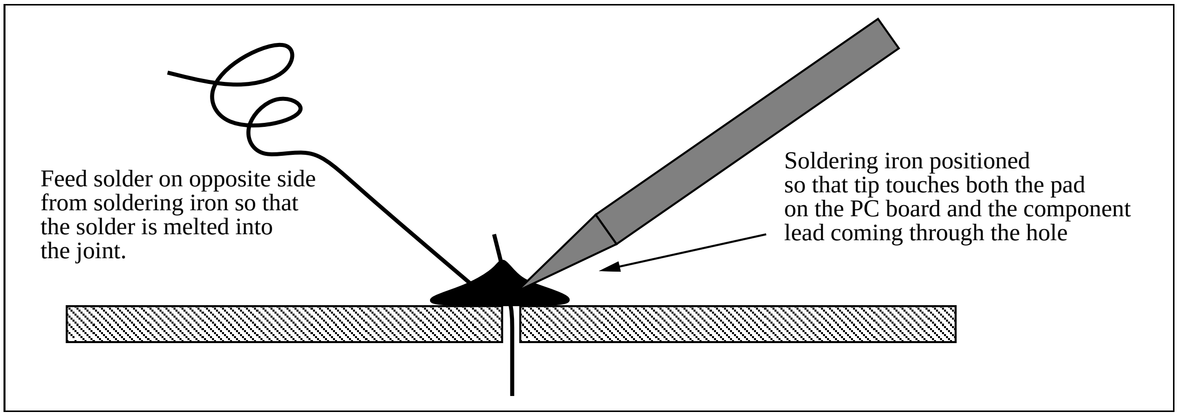


Figure 1.1: Proper Soldering Technique

Figure 1.1 shows proper soldering technique. The diagram shows the tip of the soldering iron being inserted into the joint such that it touches both the lead being soldered *and* the surface of the PC board.

Then, solder is applied into the joint, *not* to the iron directly. This way, the solder is melted *by the joint*, and both metal surfaces of the joint (the lead and the PC pad) are heated to the necessary temperature to bond chemically with the solder.

Figure 1.2 shows the typical result of a bad solder joint. This figure shows what happens if the solder is "painted" onto the joint after being applied to the iron directly. The solder has "balled up," refusing to bond with the pad (which did not receive enough heat from the iron).

With this technique in mind, please read the following list of pointers about electronic assembly. All of these items are important and will help develop good skills in assembly:

1. Keep the soldering iron tips away from everything except the point to be soldered. The iron is *hot* and can easily damage parts, cause burns, or even start a fire. Keep the soldering iron in its holder when it is not being held.

2. Make sure that there is a damp sponge available used for cleaning off and tinning the tip. Soldering is basically a chemical process and even a small amount of contaminants can prevent a good joint from being made.

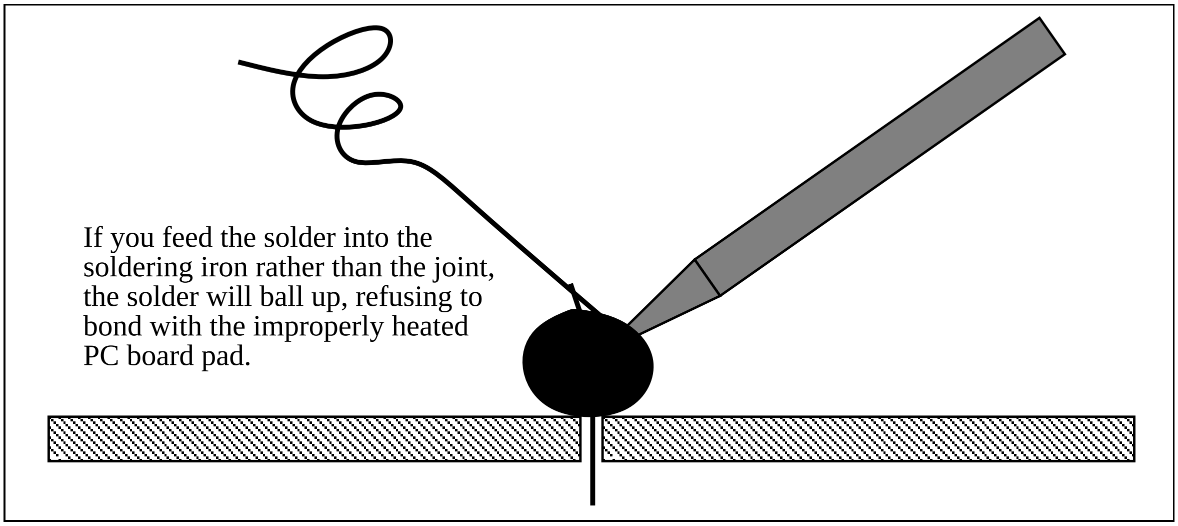


Figure 1.2: Improper Soldering Technique

3. Always make sure that the tip is *tinned* when the iron is on. Tinning protects the tip and improves heat transfer.

   To tin the iron, clean the tip and wipe it on a damp sponge and then immediately melt some fresh solder onto the tip. The tip should be shiny and coated with solder.

   If the iron has been idle for a while, always clean and then re-tin the tip before continuing.

4. The tips of the irons are nickel-plated, so do not file them or the protective plating on the tips will be removed.

5. A *cold solder joint* is a joint where an air bubble or other impurity has entered the joint during cooling. Cold solder joints can be identified by their dull and mottled finish. The solder does not flow and wrap around the terminal like it should.

   Cold joints are brittle and make poor electrical connection. To fix such a joint, apply the tip at the joint until the solder re-melts and flows into the terminal. If a cold solder joint reappears, remove solder with desoldering pump, and re-solder the joint.

6. Do not hold the iron against the joint for an extended period of time (more than 10 seconds), since many electronic components or the printed circuit board itself can be damaged by prolonged, excessive heat. Too much heat can cause the traces on the printed circuit board to burn off.

Some components that are particularly sensitive to heat damage are: diodes, ICs, and transistors.

1.1.2 Desoldering Technique

It takes about ten times as long to desolder a component than it did to solder it in the first place. This is a good reason to be careful and take one's time when assembling boards; however, errors will inevitably occur, and it's important to know how to fix them.

The primary reasons for performing desoldering are removing an incorrectly-placed component, removing a burnt-out component, and removing solder from a cold solder joint to try again with fresh solder.

Two main methods of desoldering are most common: desoldering pumps and desoldering wick. The 6.270 toolkit includes a desoldering pump as standard equipment.

To use a desoldering pump, first load the pump by depressing the plunger until it latches. Grasp the pump in one hand and the soldering iron the other, and apply heat to the bad joint. When the solder melts, quickly remove the soldering iron and bring in the pump in one continuous motion. Trigger the pump to suck up the solder while it is still molten.

Adding additional solder to a troublesome joint can be helpful in removing the last traces of solder. This works because the additional solder helps the heat to flow fully into the joint. The additional solder should be applied and de-soldered as quickly as possible. Don't wait for the solder to cool off before attempting to suck it away.

The desoldering pump tip is made of Teflon. While teflon is heat-resistant, it is not invincible, so not jam the teflon tip directly into the soldering iron. Solder will not stick to Teflon, so the desoldering operation should suck the solder into the body of the pump.

1.1.3 Component Types and Polarity

There will be a variety of electronic components in use when assembling the boards. This section provides a brief introduction to these components with the goal of teaching you how to properly identify and install these parts when building the boards.

Component Polarity

Polarity refers to the concept that many electronic components are not symmetric electrically. A polarized device has a right way and a wrong way to be mounted. Polarized components that are mounted backwards will not work, and in some cases will be damaged or may damage other parts of the circuit.

The following components are always polarized:

- diodes (LEDs, regular diodes, other types)
- transistors
- integrated circuits

Capacitors are an interesting case, because some are polarized while others are not. Fortunately, there is a rule: large capacitors (values 1 μF and greater) are generally polarized, while smaller ones are not.

Resistors are a good example of a non-polarized component: they don't care which direction electricity flows through them. However, in the 6.270 board, there are *resistor packages*, and these have non-symmetric internal wiring configurations, making them polarized from a mounting point of view.

Incandescent lamps are another non-polarized component.

The following paragraphs discuss the aforementioned components individually, explaining standardized component markings for identifying a component's polarity.

Resistors Resistors are small cylindrical devices with color-coded bands indicating their value (how to read color-coding is explained in a subsequent section).

Most of the resistors in the 6.270 kit are rated for $\frac{1}{8}$ watts, which is a very low power rating. Hence they are quite tiny devices.

A few resistors are much larger. A 2 watt resistor is a large cylindrical device, while a 5 watt resistor has a large, rectangular package.

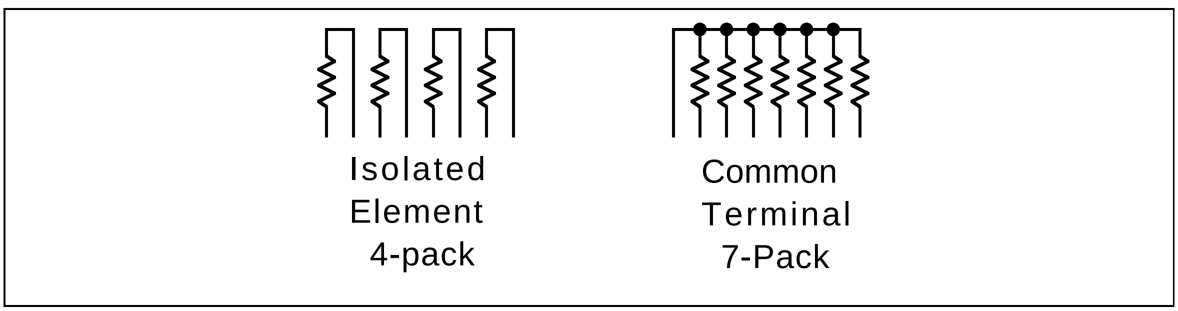


Figure 1.3: Resistor Pack Internal Wiring

Resistor Packs Resistor packs are flat, rectangular packages with anywhere from six to ten leads. There are two basic types of resistor pack:

- **Isolated Element.** Discrete resistors; usually three, four, or five per package.
- **Common Terminal.** Resistors with one pin tied together and the other pin free. Any number from three to nine resistors per package.

Figure 1.3 illustrates the internal wiring of an 8-pin resistor pack of each style.

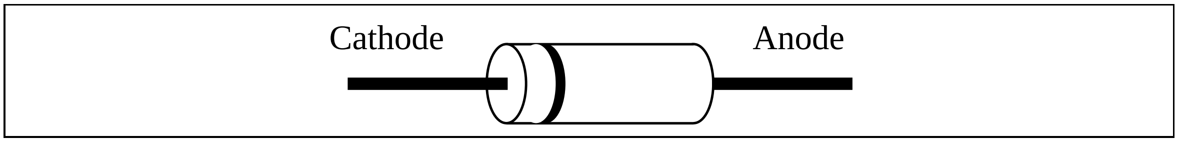


Figure 1.4: Typical Diode Package

Diodes Diodes have two leads, called the *anode* and *cathode*. When the anode is connected to positive voltage with respect to the cathode, current can flow through the diode. If polarity is reversed, no current flows through the diode.

A diode package usually provides a marking that is closer to one lead than the other (a band around a cylindrical package, for example). This marked lead is always the *cathode*.

Figure 1.4 shows a typical diode package.

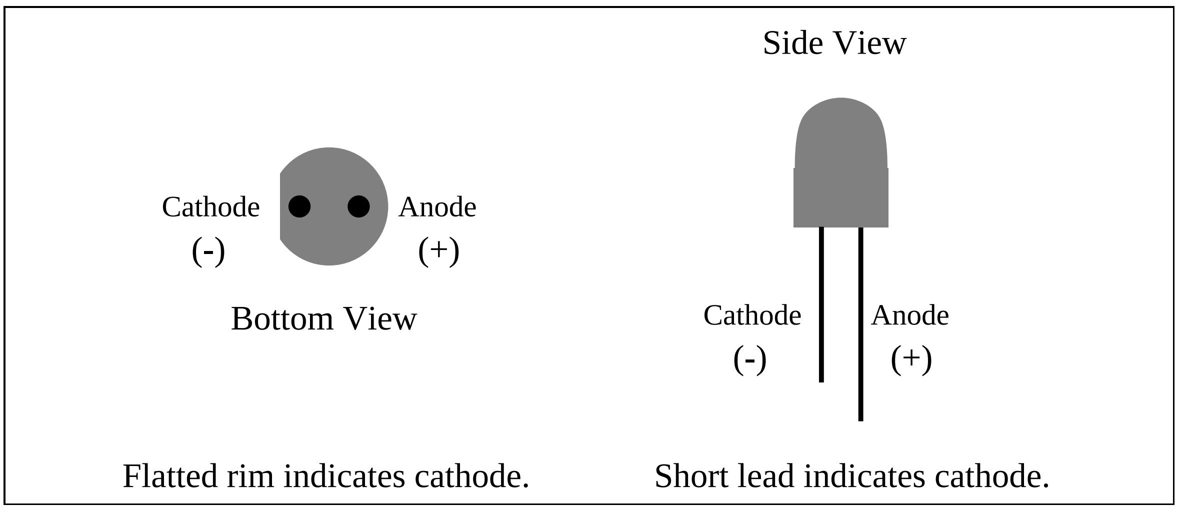


Figure 1.5: Identifying LED Leads

LEDs *LED* is an acroynm for "light emitting diode," so it should not come as a surprise that LEDs are diodes too. An LED's cathode is marked either by a small flat edge along the circumference of the diode casing, or the shorter of two leads.

Figure 1.5 shows a typical LED package.

Integrated Circuits Integrated circuits, or ICs, come in a variety of package styles. Two common types, both of which are used in the 6.270 board design, are called the *DIP* (for *dual-inline package*), and the *PLCC* (for *plastic leaded chip carrier*).

In both types, a marking on the component package signifies "pin 1" of the component's circuit. This marking may be a small dot, notch, or ridge in the package.

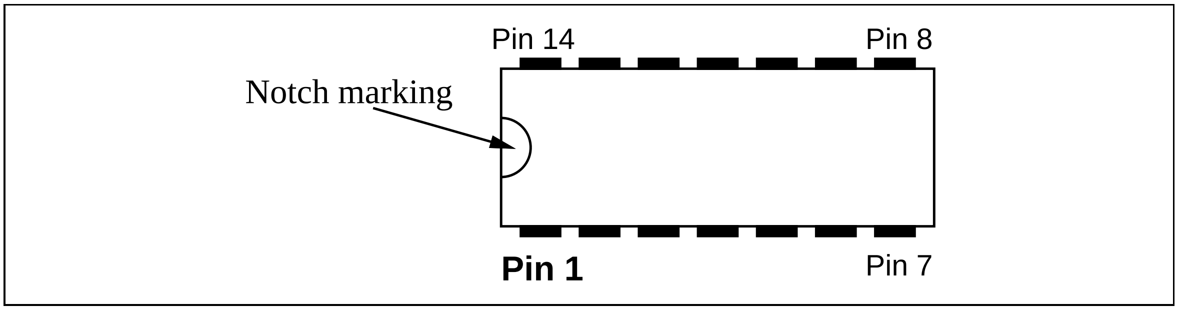


Figure 1.6: Top View of 14-pin DIP

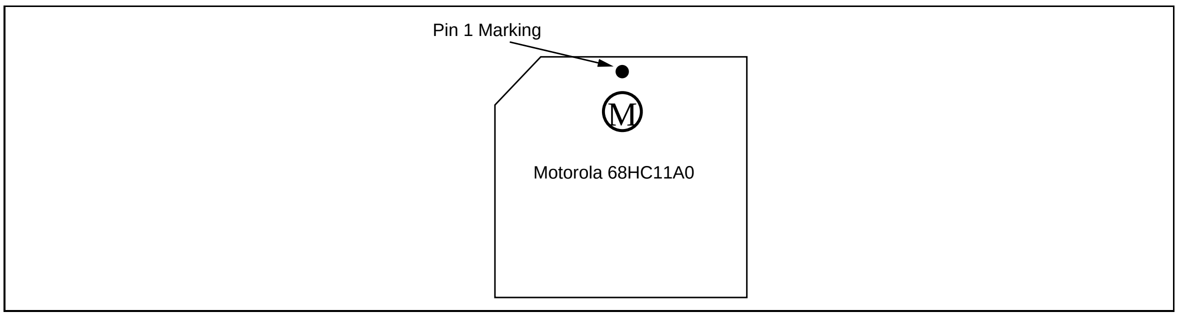


Figure 1.7: Top View of 52-pin PLCC

After pin 1 is identified, pin numbering proceeds sequentially in a counter-clockwise fashion around the chip package.

Figure 1.6 shows the typical marking on a DIP package. Figure 1.7 is a drawing of the PLCC package.

DIP Sockets Most of the integrated circuits (ICs) are socketed. This means that they are not permanently soldered to the 6.270 board. Components that are socketed can be easily removed from the board if they are damaged or defective.

Do not place the components into the sockets before you mount the sockets onto the board! Sockets are also used to avoid the need to solder directly to ICs, reducing the likelihood of heat damage.

DIP sockets also have a similar marking to those found on the components they will be holding. DIP sockets are not mechanically polarized, but the marking indicates how the chip should be mounted into the socket after the socket has been soldered into the board.

PLCC Sockets PLCC sockets *are* polarized, however: a PLCC chip can only be inserted into the its socket the "correct" way. Of course, this way is only correct if the socket is mounted right in the first place.

When assembling the 6.270 board, a marking printed onto the board indicates the correct orientation of the PLCC socket.

Capacitors Quite a few different kinds of capacitors are made, each having different properties. There are three different types of capacitors in the 6.270 kit:

- **Monolithic.** These are very small-sized capacitors that are about the size and shape of the head of a match from a matchbook. They are excellent for use when small values are needed (0.1 μF and less). They are inexpensive and a fairly new capacitor technology. Monolithic capacitors are always non-polarized.

- **Electrolytic.** These capacitors look like miniature tin cans with a plastic wrapper. They are good for large values (1.0 μF or greater). They become bulky as the values increase, but they are the most inexpensive for large capacitances.

  Electrolytics can have extremely large values (1000 μF and up). They are usually polarized except for special cases; all the electrolytics in the 6.270 kit are polarized.

- **Tantalum.** These capacitors are compact, bulb-shaped units. They are excellent for larger values (1.0 μF or greater), as they are smaller and more reliable than electrolytic. Unfortunately they are decidedly more expensive. Tantalum capacitors are always polarized.

As indicated, some capacitors are non-polarized while other types are polarized. It's important to mount polarized capacitors correctly.

On the 6.270 boards, all polarized capacitor placements are marked with a plus symbol (+) and a minus symbol (−). The capacitors themselves are sometimes are obviously marked and sometimes are not. One or both of the positive or negative leads may be marked, using (+) and (−) symbols. In this case, install the lead marked (+) in the hole marked (+).

Some capacitors may not be marked with (+) and (−) symbols. In this case, one lead will be marked with a dot or with a vertical bar. This lead will be the positive (+) lead.

Polarized capacitors that are mounted backwards won't work. In fact, they often overheat and explode. Please take care to mount them correctly.

Inductors The inductor used in the 6.270 kit looks like a miniature coil of wire wound about a thin plastic core. It is about the size of a resistor.

Some inductors are coated with epoxy and look quite like resistors. Others are big bulky coils with iron cores.

Inductors are not polarized.

Transistors The transistors used in the 6.270 kit are small, three-wire devices. They are distinctive because they are the only three-wire devices used.

Transistors are polarized devices.

The table shown in Figure 1.8 summarizes this discussion with regard to polarity issues.

Device	Polarized?	Effect of Mounting Incorrectly
Resistor	no	
Isolated R-Pack	no	
Common R-Pack	yes	circuit doesn't work
Diode	yes	circuit doesn't work
LED	yes	device doesn't work
Monolithic capacitor	no	
Tantalum capacitor	yes	explodes
Electrolytic capacitor	yes	explodes
DIP socket	yes	user confusion
PLCC socket	yes	52-pin severe frustration
Integrated circuit	yes	overheating; permanent damage
Inductor	no	
Transistor	yes	circuit doesn't work

Figure 1.8: Summary of Polarization Effects

1.1.4 Component Mounting

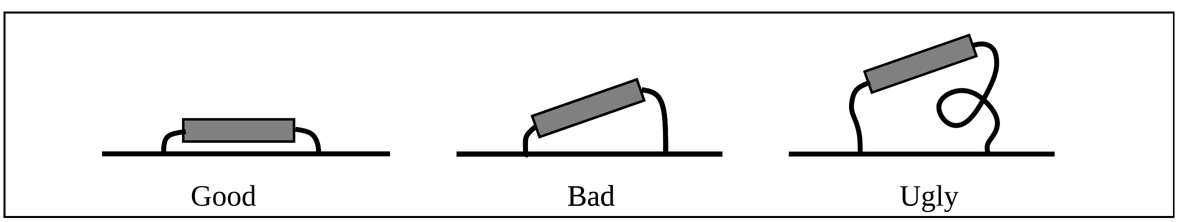


Figure 1.9: Flat Component Mounting

When mounting components, the general rule is to try to mount them as close to the board as possible. The main exception are components that must be folded over before being soldered; some capacitors fall into this category.

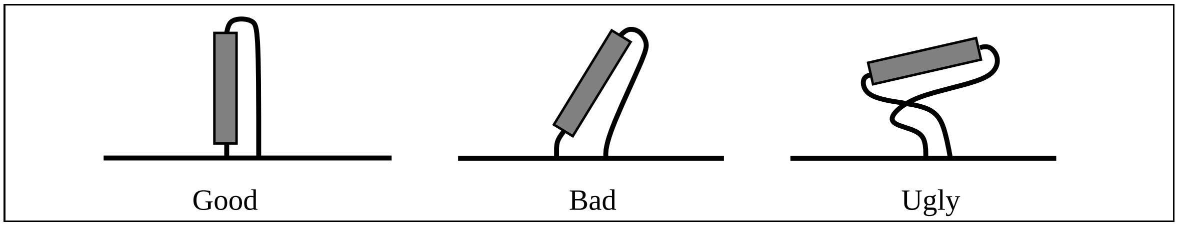


Figure 1.10: Upright Component Mounting

Most resistors and diodes must be mounted upright while others may lay flat. If space has been provided to mount the component flat, then do so, and try to keep it as close to the board as possible. If not, then just bend one lead over parallel to the component, and mount the component tightly.

See Figures 1.9 and 1.10 for clarification.

1.1.5 Component Value Markings

Various electronic components have their values marked on them in different ways. For the same type of component, say, a resistor, there could be several different ways that its value would be marked.

This section explains how to read the markings on resistors and capacitors. Other devices, such as transistors and integrated circuits, have their part number printed clearly on the device package.

Resistors

The largest resistors—in terms of wattage, not resistive value—simply have their value printed on them. For example, there are two large, rectangular 7.5Ωresistors in the 6.270 kit that are marked in this fashion.

Other resistors are labelled using a standard *color code*. This color code consists of three value bands plus a tolerance band. The first two of the three value bands form the value mantissa. The final value band is an exponent.

It's easiest to locate the tolerance band first. This is a metallic silver- or gold-colored band. If it is silver, the resistor has a tolerance of 10%; if it is gold, the resistor has a tolerance of 5%. If the tolerance band is missing, the tolerance is 20%.

The more significant mantissa band begins opposite the tolerance band. If there is no tolerance band, the more significant mantissa band is the one nearer to an end of the resistor.

Figure 1.11 shows the meaning of the colors used in reading resistors.

A few examples should make this clear.

- *brown, black, red*: 1,000Ω, or 1kΩ.

Color	Mantissa Value	Multiplier Value
Black	0	1
Brown	1	10
Red	2	100
Orange	3	1000
Yellow	4	10,000
Green	5	100,000
Blue	6	1,000,000
Violet	7	
Grey	8	
White	9	

Figure 1.11: Resistor Color Code Table

- *yellow, violet, orange*: 47,000Ω, or 47kΩ.
- *brown, black, orange*: 10,000Ω, or 10kΩ.

Capacitors

Reading capacitor values can be confusing because there often are numbers printed on the capacitor that have nothing to do with its value. So the first task is to determine which are the relevant numbers and which are the irrelevant ones.

For large capacitors (values of 1μF and greater), the value is often printed plainly on the package; for example, "4.7μF". Sometime the "μ" symbol acts as a decimal point; e.g., "4μ7" for a 4.7μF value.

Capacitors smaller than 1μF have their values printed in picofarads (pF). There are 1,000,000 pF in one μF.

Capacitor values are similar to resistor values in that there are two digits of mantissa followed by one digit of exponent. Hence the value "472" indicates 47×10^2 picofarads, which is 4700 picofarads or 0.0047 μF.

1.2 The Microprocessor Board

The 6.270 Microprocessor Board is the brains and brawn of the 6.270 Robot Controller system. It uses a Motorola 6811 microprocessor equipped with 32K of non-volatile memory. It has outputs to drive four motors, inputs for a variety of sensors, a serial communications port for downloading programs and user interaction, and a host of other features.

1.2.1 Assembling the Microprocessor Board

Before beginning assembly, make sure to have a well-lighted, well-ventilated workspace. Make sure that all of the electronic assembly tools are available.

All of the 6.270 boards have component placements silkscreened directly onto the board. In addition, diagrams in these instructions will provide copies of the diagrams printed on the boards, often at better resolution. Refer to the printed diagrams as often as necessary to be sure that components are being placed correctly.

Figure 1.12 illustrates the component placement on the microprocessor board.

The instruction checklist may be marked off as each step is completed.

The component numbering for parts on the microprocessor board increments in a counter-clockwise fashion around the board for resistors, capacitors, and resistor packs.

1–☐ **Get the 6.270 Microprocessor Board, and determine which is the "component side."** The Microprocessor Board is the largest of the 6.270 boards.

The side of the board that has been printed with component markings is the "component side." This means that components are mounted by inserting them down from the printed side; then they are soldered on the obverse, the unprinted side.

Please make sure that the components are mounted on the proper side of the board! It would be a terrible mistake to mount everything upside down.

2–☐ **Resistor Packs.**

Begin by installing the resistor packs. Most of the resistor packs are polarized: the common terminal end is marked with a dot or band. On the 6.270 board, find a *square metal pad* at one end of the area that each resistor pack will mount. *Insert the resistor pack such that the marked end mounts in the square hole.* (The square hole is more easily discernable on the unprinted solder side of the board.)

The "caddy-cornering" technique of soldering the two end terminals first is helpful here.

- ○ **RP1**–47k$\Omega\times$9, 10 pins, polarized, *marked "E47KΩ."*
- ○ **RP2**–47k$\Omega\times$4, 5 pins, polarized, *marked "E47KΩ."*
- ○ **RP3**–1k$\Omega\times$3, 6 pins, non-polarized, *marked "V1KΩ."*
- ○ **RP4**–1k$\Omega\times$5, 6 pins, polarized, *marked "E1KΩ."*
- ○ **RP5**–22k$\Omega\times$3, 6 pins, non-polarized, *marked "B223GA."*

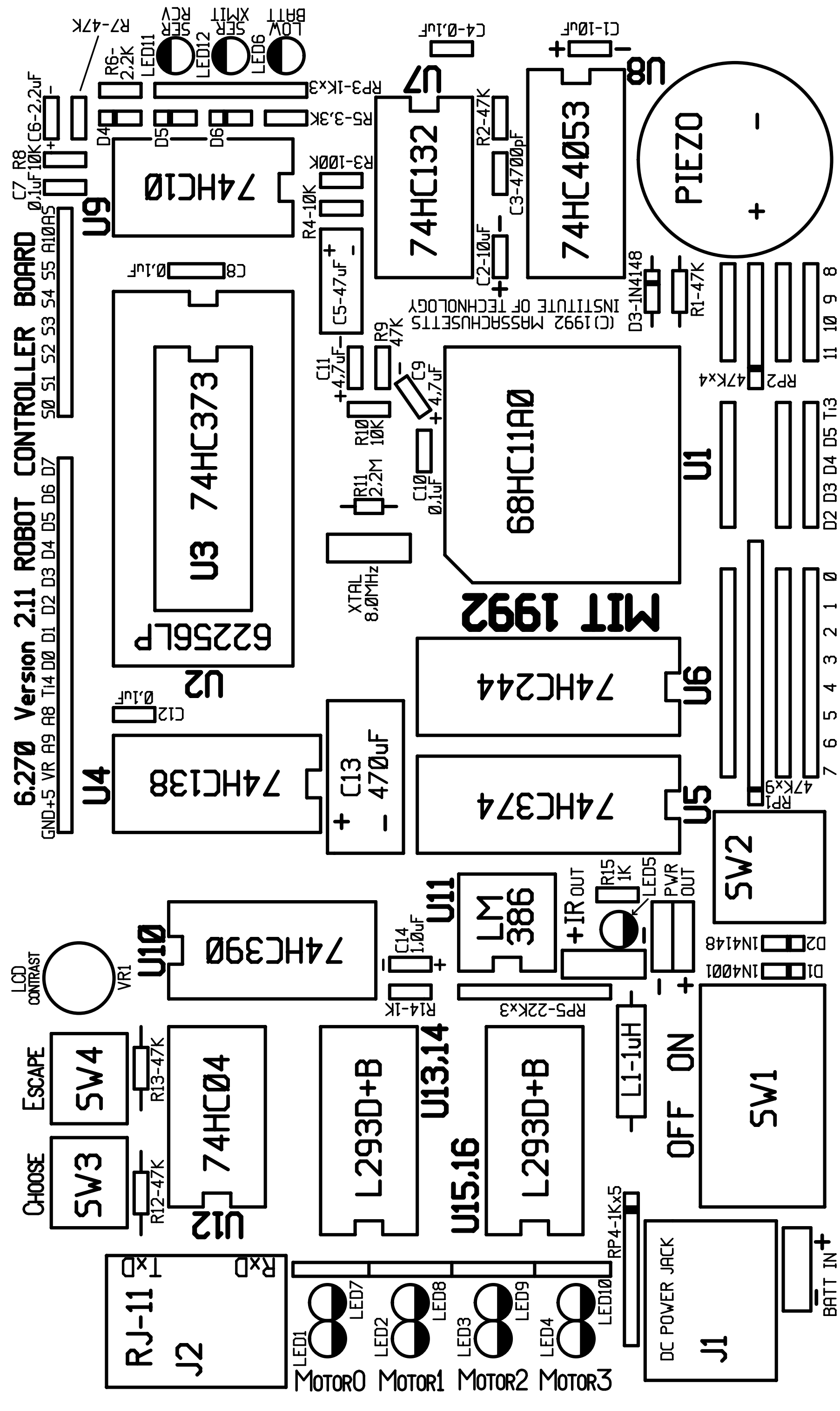


Figure 1.12: 6.270 Microprocessor Board Component Placement

3–☐ Non-polarized Capacitors.

These capacitors are not polarized. After installing, solder and clip leads close to the board.

- ◯ **C3**–4700 pF, *marked "472."*
- ◯ **C4**–0.1 μF, *marked "104."*
- ◯ **C7**–0.1 μF, *marked "104."*
- ◯ **C8**–0.1 μF, *marked "104."*
- ◯ **C10**–0.1 μF, *marked "104."*
- ◯ **C12**–0.1 μF, *marked "104."*

4–☐ IC Sockets.

Mount the DIP sockets such that the notch in the socket lines up with the notch marking in the rectangular outline printed on the PC board. "DIP4" means the DIP socked for integrated circuit U4.

Note that there are two varieties of 16-pin DIP socket. One type is gold-plated and costs about ten times as much as the inexpensive variety. This type is to be used for the motor driver ICs to make better contact and is installed as indicated in the instructions.

The caddy-cornering technique should help here too. After inserting a DIP into the board, solder its two opposite-corner pins first. This will hold the chip in place. Make sure it is pressed down as far as it can go; then solder the other pins.

- ◯ **DIP4**–16 pins
- ◯ **DIP5**–20 pins
- ◯ **DIP6**–20 pins
- ◯ **DIP7**–14 pins
- ◯ **DIP8**–16 pins
- ◯ **DIP9**–14 pins
- ◯ **DIP10**–16 pins
- ◯ **DIP11**–8 pins
- ◯ **DIP12**–14 pins
- ◯ **DIP13/14**–16 pins, gold-plated pins
- ◯ **DIP15/16**–16 pins, gold-plated pins

5–☐ Direct Mount Chip.

One chip is soldered directly to the board. Be careful not to apply too much heat to its pins when soldering. The soldering iron should not be in contact with any given pin for more than about eight seconds. It's okay to wait for things to cool down and try again if problems arise.

Mount this chip such that its notch is aligned with the rectangular notch printed on the PC board.

- ○ **U3**–74HC373.

6–☐ Remaining Sockets.

- ○ With the orange utility knife, cut center support from **DIP2**, a 28-pin socket. Install on top of **U3**, with the notch marking as indicated. Solder.
- ○ Install **PLCC1**, 52-pin square socket for the 6811. The Pin 1 marking is indicated by the numeral "1" and an arrow in the socket; this marking mounts nearest to **U2**, the 32K RAM chip. There should be a beveled notch in the upper-left corner of the chip and the outline printed on the board, with respect to the pin 1 marking. *Be absolutely sure to mount this socket correctly; the socket is polarized and will only let you mount the chip into it one way.* Solder.

7–☐ Female Socket Headers.

To cut socket headers to length, repeatedly score between two pins using the orange knife. Score on both sides of one division and then snap the strip in two. *Do not try to snap header pieces before they have been sufficiently scored,* or they will break, destroying one or both of the end pieces in question.

When mounting the sockets, pay attention to how well they are lining up vertically. Sometimes reversing the way a strip is mounted will help its connections to line up better with the others. It may be helpful to insert a strip of male header into the socket to hold them at proper horizontal and vertical placement before soldering.

Refer to Figure 1.13 for placement of these parts.

- ○ Cut three 8-long strips, *or* use six 4-long strips. Install the **Digital Input** connector block. Solder.
- ○ Cut three 5-long strips. Install the **Port D I/O** connector block. Solder.
- ○ Use three 4-long strips. Install the **Analog Input** connector block. Solder.
- ○ Cut one 12-long strip. Install the **Motor Output** connectors. Solder.

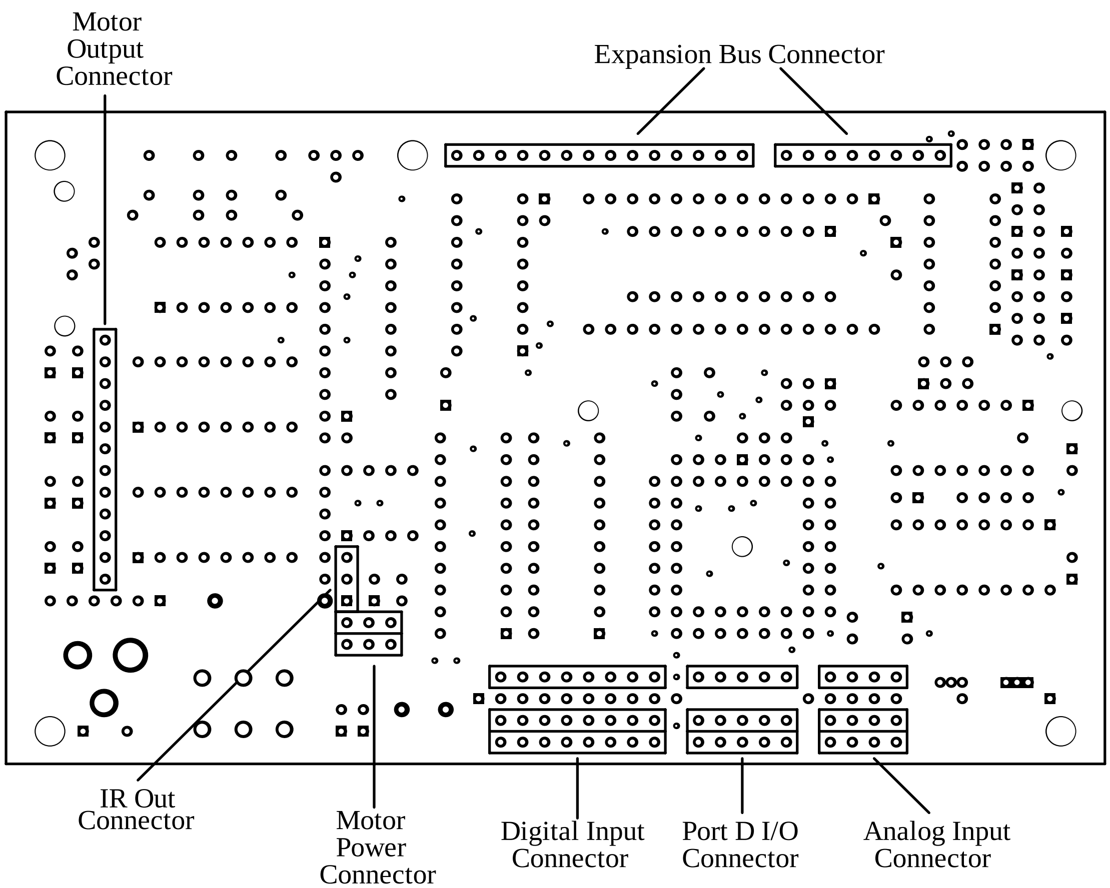


Figure 1.13: 6.270 Microprocessor Board Header Placement

- ◯ Cut one 8-long and one 14-long strip. Install the **Expansion Bus** connector. Solder.
- ◯ Cut two 3-long strips. Install the **Motor Power** connector. Solder.
- ◯ Cut one 3-long strip. Install the **IR Out** connector. Solder.

8–☐ LEDs.

LEDs must be mounted so that the *short lead* (the cathode) is inserted into the *shaded half* of the LED placement marking.

Be sure to mount LEDs properly as it is very difficult to desolder them if they are mounted backward.

- ◯ **LED1**–red
- ◯ **LED2**–red
- ◯ **LED3**–red
- ◯ **LED4**–red
- ◯ **LED5**–red
- ◯ **LED6**–red
- ◯ **LED7**–green
- ◯ **LED8**–green
- ◯ **LED9**–green
- ◯ **LED10**–green
- ◯ **LED11**–green
- ◯ **LED12**–yellow

9–☐ Resistors.

Most resistors mount vertically: try to mount them perfectly upright, with one end very close to the board, and the wire lead bent around tightly.

Others mount flat on the board: try to get the body of the resistor very close to the board.

If you have trouble discerning colors, you may wish to have your teammates handle this task. It is fairly difficult to read the color bands from $\frac{1}{8}$ watt resistors, even to the trained eye.

- ◯ **R1**–47kΩ, *yellow, violet, orange*
- ◯ **R2**–47kΩ, *yellow, violet, orange*

- ◯ **R3**–100kΩ, *brown, black, yellow*
- ◯ **R4**–10kΩ, *brown, black, orange*
- ◯ **R5**–3.3kΩ, *orange, orange, red*
- ◯ **R6**–2.2kΩ, *red, red, red*
- ◯ **R7**–47kΩ, *yellow, violet, orange*
- ◯ **R8**–10kΩ, *brown, black, orange*
- ◯ **R9**–47kΩ, *yellow, violet, orange*
- ◯ **R10**–10kΩ, *brown, black, orange*
- ◯ **R11**–2.2MΩ, *red, red, green*
- ◯ **R12**–47kΩ, *yellow, violet, orange*
- ◯ **R13**–47kΩ, *yellow, violet, orange*
- ◯ **R14**–1kΩ, *brown, black, red*
- ◯ **R15**–1kΩ, *brown, black, red*

10–☐ Large Capacitors.

All of these capacitors are polarized. Make sure that the lead marked (+) on the capacitor goes into the hole that is marked (+). If the capacitor leads are not marked (+) or (−), the lead marked with a dot or bar is the (+) lead.

- ◯ **C1**–10 μF
- ◯ **C2**–10 μF
- ◯ **C5**–47 μF. Fold capacitor flat to the board before soldering.
- ◯ **C6**–2.2 μF
- ◯ **C9**–4.7 μF
- ◯ **C11**–4.7 μF
- ◯ **C13**–470 μF. Fold capacitor flat to the board before soldering.
- ◯ **C14**–1 μF

11–☐ Diodes.

Diodes are polarized. Mount them such that the lead nearer the banded end goes into the square hole on the circuit board.

- ◯ **D1**–1N4001. This diode has a black epoxy body and fairly thick leads.
- ◯ **D2**–1N4148. This is a glass-body diode.

- ◯ **D3**–1N4148
- ◯ **D4**–1N4148
- ◯ **D5**–1N4148
- ◯ **D6**–1N4148

12–☐ Ceramic Resonator.

Install **XTAL1**, 8 Mhz. ceramic resonator.

13–☐ Inductor.

Install **L1**, 1 uH.

14–☐ Switches.

- ◯ **SW1**–DPDT slide switch
- ◯ **SW2**–large red pushbutton switch
- ◯ **SW3**–miniature pushbutton switch
- ◯ **SW4**–miniature pushbutton switch

15–☐ Trimpot.

Install **VR1**, 100kΩ.

16–☐ Piggy-Backing the L293 Chips.

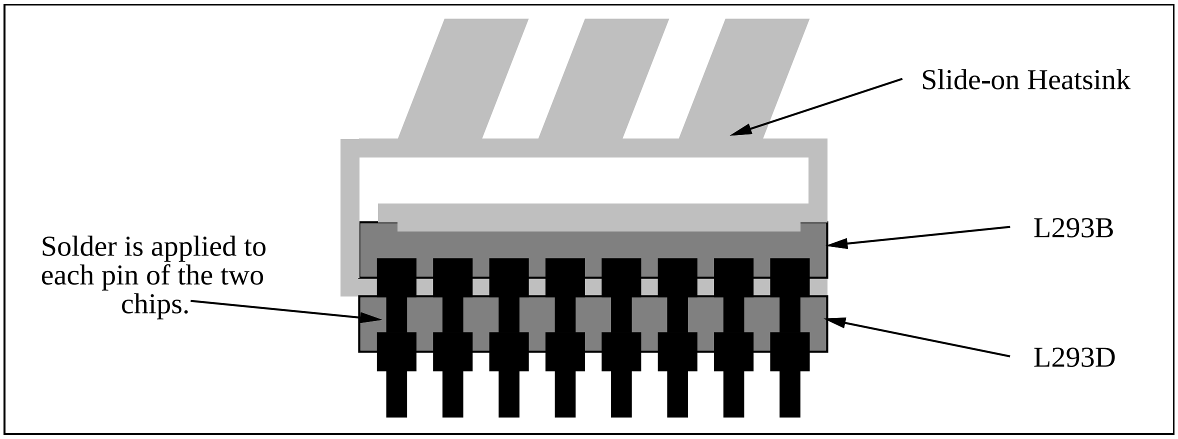


Figure 1.14: Motor Chip Stacking Technique

Motor driver chips **U13/14** (L293D plus L293B) and **U15/16** (L293D plus L293B) will be piggy-backed and soldered together before installing in their socket.

The instructions will be given for one pair and can be repeated for the second pair. *Make sure* that each pair consists of one L293D and one L293B chip!

Begin by sliding the gold-colored heat sink over an L293B chip. Then, press this assembly onto an L293D chip, as indicated in Figure 1.14. Make sure that the two chips have their notches lined up. Also, be sure to remember where which way the notches face, as they may be obscured.

Finish by soldering the two chips together, pin by pin. Try to have them pressed together as is possible, so that both press firmly against the heat sink.

Repeat for the other pair of motor driver chips.

17–☐ Power Jack.

Install **J1**, DC power jack. When soldering, use ample amounts of solder so that solder completely fills mounting pads.

18–☐ Phone Jack.

Install **J2**, modular phone jack.

19–☐ Piezo Beeper.

Mount the piezo beeper so that it is centered on circular outline. Polarity does not matter.

20–☐ Battery pack.

- ◯ Clip connector and about 1" of length off battery pack leads.
- ◯ *From bottom of board*, insert leads for battery pack. Note polarization: black lead goes in hole marked (−), red lead in hole marked (+). Solder from top of board and clip leads.

1.2.2 Testing the Microprocessor Board

This section explains a few simple tests to be performed *before* installing the ICs in the sockets.

Full board testing and debugging will be handled in the laboratory.

1–☐ Check the solder side of the board for proper solder connections. Specifically: look for solder bridges and cold solder joints.

Solder bridging is when a piece of solder "bridges" across to adjacent terminals that should not be connected.

Cold solder joints are recognized by their dull luster. A cold solder joint typically makes a flaky electrical connection. Make sure that all of the solder joints are shiny with a silver color.

Make sure that joints do not have too much solder.

2–☐ Check continuity (resistance) between power and ground of your board. Power may be obtained from the cathode of D1 and ground from the black lead of the battery pack.

Resistance should increase as the board capacitor charges. The board resistance should measure between 1kΩ and 10kΩ. *If a reading of zero ohms is observed, the board probably has a power to ground short.* Do not proceed with testing until this is corrected.

3–☐ Insert 4 AA batteries into battery holder.

4–☐ Turn on board power switch.

5–☐ Examine the yellow LED: it should be glowing slighly. If not, turn off board power immediately. Check for power short.

6–☐ Measure board voltage (as above with continuity check). You should have approximately 5.5 volts.

7–☐ Install ICs in the board. *Be careful not to damage the component leads when installing the chips into their sockets!* Make sure to get the orientation correct—refer to Figure 1.12 if necessary.

- ○ **U1**–68HC11A0 microprocessor
- ○ **U2**–62256LP 32K static RAM
- ○ **U3**–74HC373 (already soldered to board)
- ○ **U4**–74HC138
- ○ **U5**–74HC374
- ○ **U6**–74HC244
- ○ **U7**–74HC132
- ○ **U8**–74HC4053
- ○ **U9**–74HC10
- ○ **U10**–74HC390
- ○ **U11**–LM386
- ○ **U12**–74HC04

○ **U13,14**–L293D + L293B assembly with heatsink

○ **U15,16**–L293D + L293B assembly with heatsink

1.2.3 After Board Checkout

The following final assembly step should be done only after the board has been shown to work properly. It is difficult to debug a board once the battery pack has been bolted on.

1–☐ Use 2×56 metal bolts, nylon washers, and nuts to attach battery pack to board. Insert bolts into battery pack and then up from the underside of the board so that the nuts screw down from the top of the board. *Make sure* to use nylon washers to protect the top of the board from the metal nuts.

1.3 The Expansion Board

The 6.270 Expansion Board plugs on top of the 6.270 Microprocessor Board, using the Expansion Bus connector. The Expansion Board adds the following capabilities:

- analog multiplexers to provide eight times more analog inputs;
- four DIP configuration switches;
- a user-adjustable "frob knob" for analog input;
- drivers for two additional motors;
- drivers for two LED/lamp circuits;
- a general purpose prototyping construction area.

Figure 1.15 is a component placement guide for the Expansion Board.

1.3.1 Assembling the Expansion Board

1–☐ **Get the 6.270 expansion board, and determine which is the component side.**

As with the microprocessor board, the side that has white component markings is the component side. The obverse is the solder side.

2–☐ **Resistor Pack.**

RP6, 1kΩ×7, 8 pins, polarized, *marked "E1KΩ."* Mount so that marked end of resistor pack goes in square hole on board.

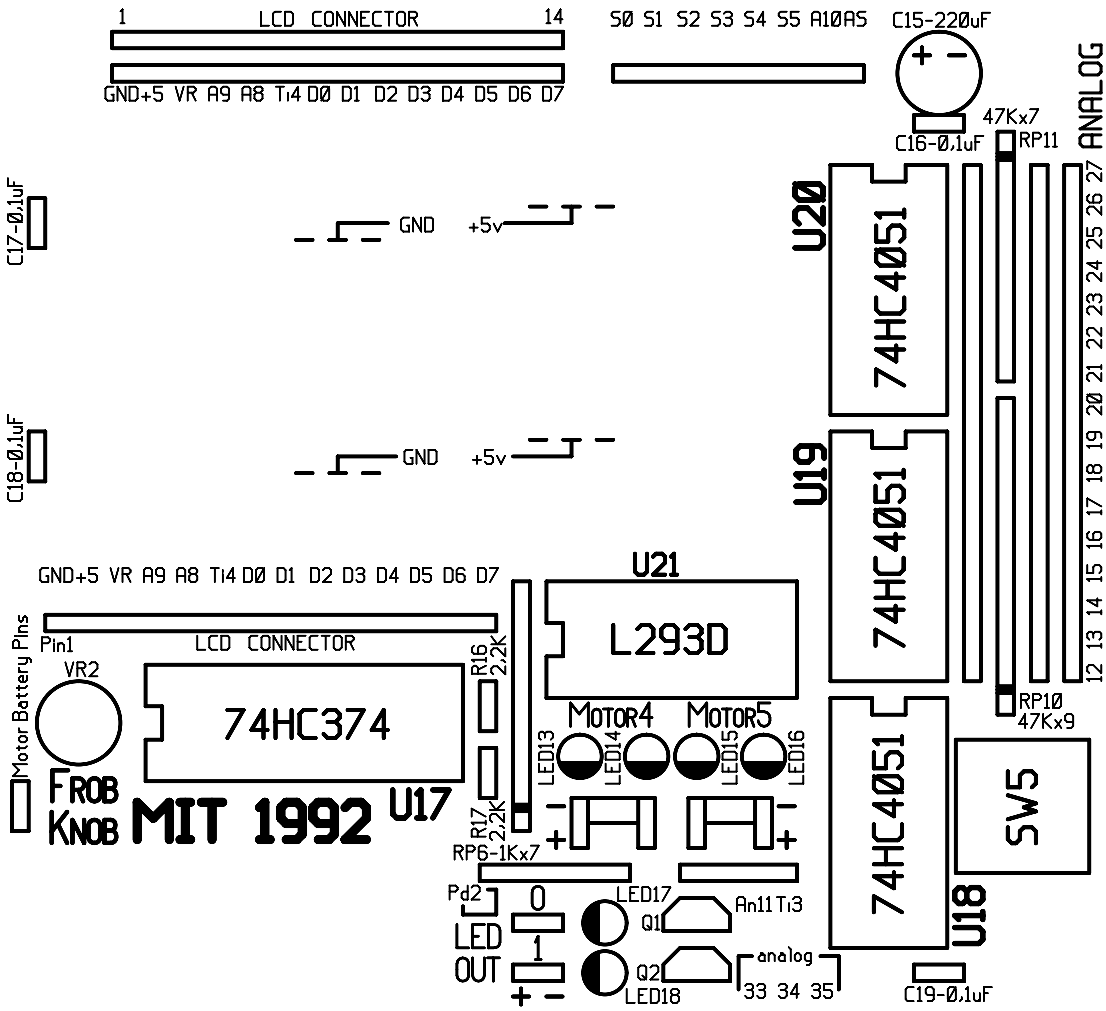


Figure 1.15: Expansion Board Component Placement

3–☐ IC Sockets.

Align notch marking of socket with notch on printed chip outline on board.

- ◯ **DIP17**–20 pins
- ◯ **DIP18**–16 pins
- ◯ **DIP19**–16 pins
- ◯ **DIP20**–16 pins
- ◯ **DIP21**–16 pins, gold-plated pins

4–☐ LEDs.

Install LEDs so that the short lead mounts in the shaded half of the placement marking. Be careful to get polarity correct.

- ◯ **LED13**–red
- ◯ **LED14**–green
- ◯ **LED15**–red
- ◯ **LED16**–green
- ◯ **LED17**–red
- ◯ **LED18**–red

5–☐ Trimpot.

Install **VR2**, 100kΩ.

6–☐ Resistors.

- ◯ **R16**, 2.2kΩ, *red, red, red.* Value of "4.7K" printed on board is incorrect.
- ◯ **R17**, 2.2kΩ, *red, red, red.* Value of "4.7K" printed on board is incorrect.

7–☐ Capacitors.

- ◯ **C15**–220μF, *polarized.* Be sure to mount with correct polarity.
- ◯ **C16**–0.1μF, non-polarized
- ◯ **C17**–0.1μF, non-polarized
- ◯ **C18**–0.1μF, non-polarized
- ◯ **C19**–0.1μF, non-polarized

8–☐ Transistors.

Install transistors **Q1** and **Q2** (type MPS2222A) where indicated on the Expansion Board. The transistors mount so that their flat edge is above the flat edge of the placement marking.

9–☐ Female socket headers.

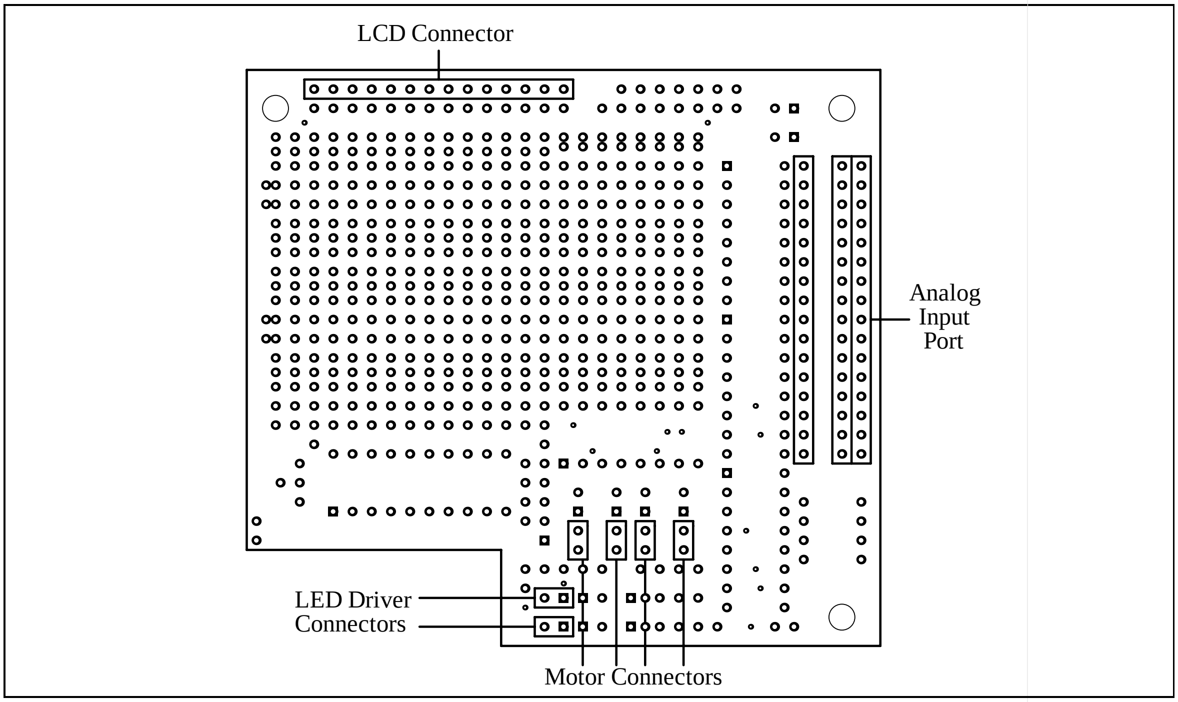


Figure 1.16: Expansion Board Female Header Mounting

Refer to Figure 1.16 to be sure of placement of these parts.

- ◯ Cut three 16-long strips. Install the **Analog Input Port**. Solder.
- ◯ Cut one 14-long strip. Install the **LCD Connector**. *Note*: The correct position for this header is *not* the location marked *LCD CONNECTOR* on the board. The correct position is indicated properly in Figure 1.16, at the top edge of the board.
- ◯ Cut six 2-long strips. Install **Motor Connectors** and **LED Driver Connectors**.

10–☐ DIP Switches.

Install **SW5**, 4-position DIP switch. Install so that switch handles face outward over edge of board and are easy to manipulate.

11–☐ Male Header Pins.

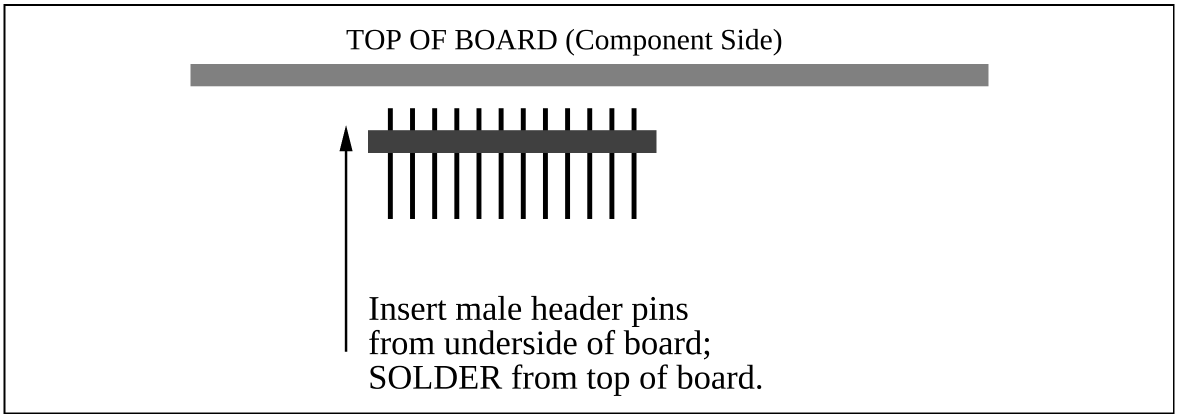


Figure 1.17: Mounting Method for Male Header Pins

The following steps deal with the interface pins that protrude from the Expansion Board to the Microprocessor Board.

When mounting these pins, insert upward from the underside of the board so that the maximal pin lengths protrude downward (see Figure 1.17). These pins are then soldered from the top, component side of the board.

Be careful to make sure the pins are mounted perfectly normal to the surface of the Expansion Board, as there are quite a few pins that must all mate properly with the Microprocessor Board.

For the following instructions, refer to Figure 1.18 for pin placement.

- ○ **Motor Battery Pins**–a 2-long strip
- ○ **Port D Connector**–a 5-long strip
- ○ **Analog Port Connector**–a 4-long strip
- ○ **Expansion Bus Connector**–one 14-long and one 8-long strip

1.3.2 Testing the Expansion Board

As with the Microprocessor Board, run through the following checklist before mounting the chips into the Expansion Board. Thorough testing will be performed in lab.

1–☐ Check the solder side of the board for proper solder connections. Specifically: look for solder bridges and cold solder joints.

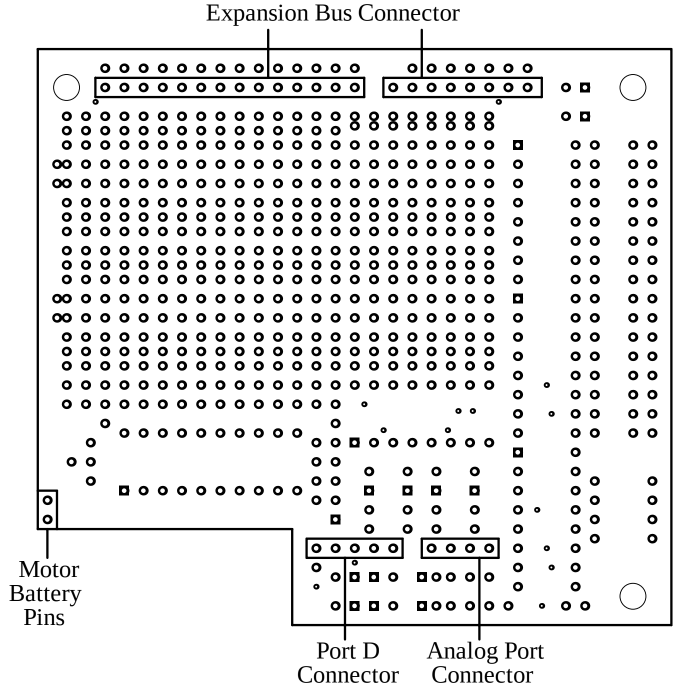


Figure 1.18: Expansion Board Male Header Pin Placement

2–☐ Check continuity (resistance) between power and ground of the board. Power and ground can be located in the prototyping area.

Resistance should increase as the board capacitor charges. There should be a reading of between one and ten kilo-ohms. *If there is a reading of zero ohms, or near zero ohms, the board has a power short.* Do not proceed with testing until this is corrected.

3–☐ Install ICs in the board, observing correct polarity:

- ◯ **U17**–74HC374
- ◯ **U18**–74HC4051
- ◯ **U19**–74HC4051
- ◯ **U20**–74HC4051
- ◯ **U21**–L293D. Slide gold heat sink onto chip before installing in socket.

4–☐ See a lab TA for final board checkout.

1.3.3 After Board Testing

After both the Microprocessor Board and the Expansion Board have been tested and are working, the two boards may be bolted together at three points with the 6-32 $\times \frac{1}{2}$" nylon standoffs and screws.

The standoff that is installed near the piezo beeper will need to be whittled a bit in order to mount properly.

1.4 The LCD Display

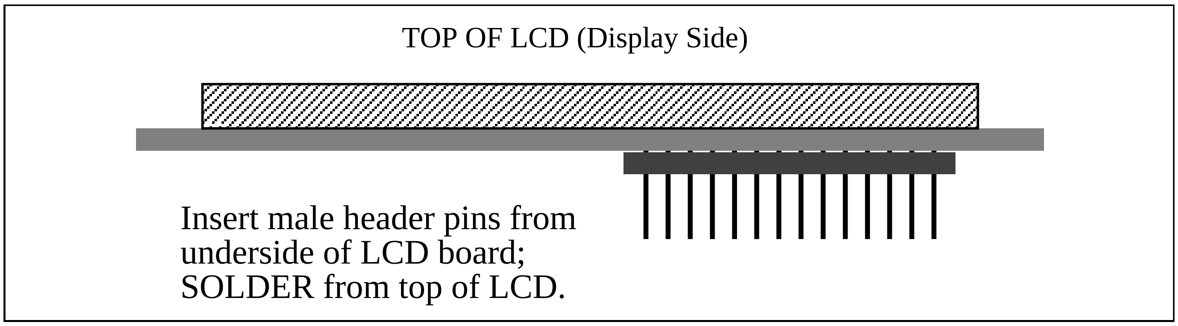


Figure 1.19: LCD Connector Mounting

The LCD display provided in this year's 6.270 kit can display two rows of 16 characters. The system software makes it easy to write code that prints messages to this display, for status, debugging, or entertainment purposes.

The display needs to have a 14-pin male header soldered to its interface. Figure 1.19 shows how these pins should be installed, in a similar fashion to the pins protruding from the Expansion Board.

Cut a 14-long male header strip and mount and solder to the LCD as indicated in the figure.

1.5 The Battery System

The 6.270 Robot Controller system has two battery power supplies. The first is the four AA alkaline cells that snap into the Microprocessor Board. These are used to run the microprocessor and sensors. They are also used to keep the program in the RAM when the board is switched off.

These batteries should power the microprocessor board for about fifty hours of operation before needing to be replaced. The board should not be left on inadvertently because the batteries will be drained.

The second power supply plugs into the motor power jack. The reason for having a separate battery for the motors is to provide isolation between the two supplies. When a motor turns on or reverses direction, it draws a huge surge of current. This causes fluctuations in the battery voltage. For motors, this is not a problem, but a microprocessor circuit could fail. For this reason, separate batteries are used for the motors and the microprocessor.

The motor battery is a bank of three Gates 2 volt lead-acid cells wired in series, yielding a 6 volt supply. Each cell is rated for 2.5 ampere-hours of operation.

These lead-acid cells are extremely powerful devices. Car batteries are constructed of similar lead-acid technology. *When handling the batteries, be extremely careful not to short the (+) an (−) terminals of the battery together.* A huge surge of current will flow, melting the wire and causing burns. In extreme cases, batteries can explode and cause serious injury.

The Gates cells were donated to 6.270 by Gates Energy Products, Inc.

The following instructions explain how to build the battery recharger and how to wire the Gates cells into power-packs. Note that contest rules prohibit using the Gates cells in any configuration other than what is presented here.

1.5.1 The Battery Charger

The battery charger can charge two 6 volt battery packs simultaneously. Each pack can be charged at either of two rates:

- **Normal charge.** Marked SLOW on the charger board, this is the normal charge position. A battery pack will recharge completely in about ten to fourteen hours. When the batteries become slightly warm they are fully charged.

  When operating in normal mode, a green LED will be lit to indicate proper charging. In this mode, it is safe to leave batteries on charge for periods of up to 24 hours without causing damage.

- **Fast charge.** Marked FAST on the charger board, this position will recharge a battery pack in five to seven hours.

  Batteries being charged in fast mode should be monitored closely; as soon as the pack becomes warm to the touch, the batteries are completely charged and should be removed from the charger.

Permanent damage to the battery pack can occur if left on fast charge for more than ten hours. Needless to say, this mode should be used with care.

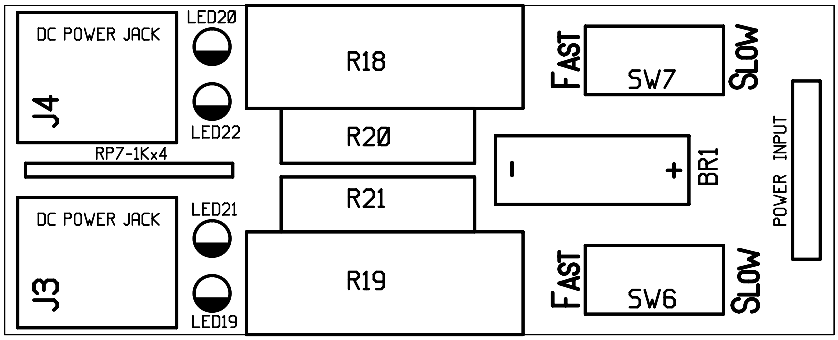


Figure 1.20: Battery Charger Component Placement

Assembly Instructions

Figure 1.20 shows component placement on the battery charger board.

1–☐ **Get the battery charger board and determine which is the component side.** The component side is marked with the placement guidelines.

2–☐ **Resistor Pack.**

Install **RP7**, 1.2kΩ×4, 8 pins, *marked "B122GA." The board is labelled for 1kΩ; this marking is incorrect.* This resistor pack consists of four isolated resistors so orientation is not significant.

3–☐ **LEDs.**

Mount LEDs so that the short lead is inserted in the shaded half of the placement marking.

- ◯ **LED19**–red
- ◯ **LED20**–red
- ◯ **LED21**–green
- ◯ **LED22**–green

4–☐ **DC Power Jacks.**

Install **J3** and **J4**, DC power jacks. When soldering, use ample amounts of solder to fill the mounting holes completely.

5–☐ **Power Resistors.**

- ◯ **R18**–7.5Ω, 5 watts

- ○ **R19**–7.5Ω, 5 watts
- ○ **R20**–15Ω, 2 watts, *brown, green, black*
- ○ **R21**–15Ω, 2 watts, *brown, green, black*

6–☐ Slide Switches.

- ○ **SW6**–miniature SPDT slide switch
- ○ **SW6**–miniature SPDT slide switch

7–☐ Bridge Rectifier.

Install **BR1**, rectangular bridge rectifier. *Observe polarity*: make sure (+) symbol on bridge rectifier is inserted into hole marked (+) on circuit board.

8–☐ Power Cord.

Get large DC power adapter. Clip off and discard the unusual power plug near the base of the plug. Strip $\frac{1}{4}$" of insulation from power wires. Insert stripped wires into holes marked POWER INPUT from component side of board; solder from solder side.

The polarity of the power connection is not significant.

9–☐ After Checkout.

After the battery charger is checked in lab, add a glob of hot glue as a strain relief at the base of the POWER INPUT connection.

1.5.2 Battery Pack Construction

The 6.270 kit includes 6 Gates cells, enough to make two battery packs. It is recommended that contest robots be designed in a fashion that facilitates battery pack swapping. This will prove invaluable in the final days of the course, when robots are being worked on continuously. One battery pack can be used to operate the robot while the other is being charged.

Two obvious alternatives for battery pack construction are depicted in Figure 1.21: a rectangular configuration and a triangular one. Other possibilities may be explored.

Wiring the Battery Cable

Figure 1.22 illustrates how to wire the battery plug and cable assembly.

- ○ Cut a 12" to 16" length of the black/red twisted pair cable for use in making the battery cable. Strip and tin the wire ends.

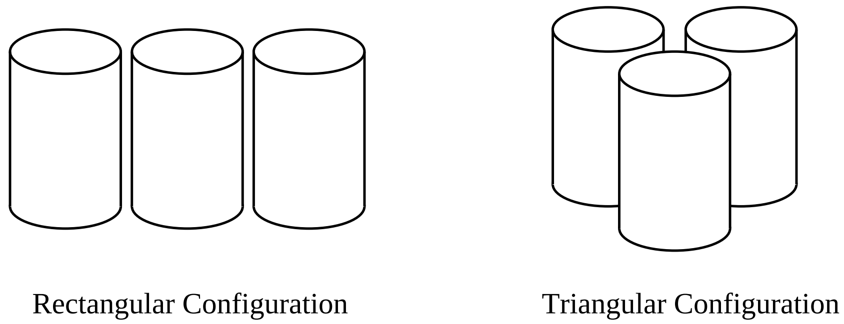


Figure 1.21: Two Battery Pack Configurations

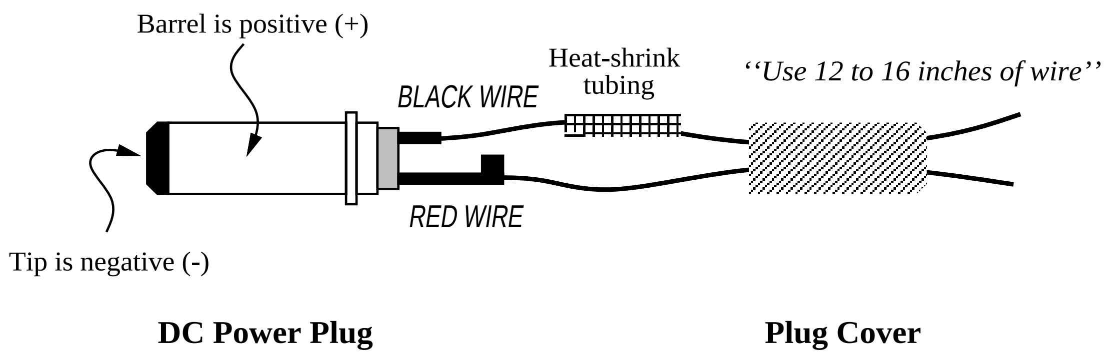


Figure 1.22: Battery Plug and Cable Wiring Diagram

- ◯ Heat shrink tubing is used on the shorter terminal of the DC power plug. The tubing acts as an insulator to minimize the likelihood of an electrical short at the plug terminals. *It is essential that this wiring be performed carefully because a short in the power plug will short out the battery terminals and create a serious hazard.*

- ◯ Proper polarity is important. The use of red wire to signify the (+) terminal and black wire to signify the (−) terminal is an international standard. Mount the black wire to the short terminal and the red wire to the long terminal.

- ◯ After soldering, slide the heat shrink tubing down over the short terminal and shrink it. Also, crimp the prongs of long terminal onto the red wire as a stress relief.

- ◯ Screw the plug cover onto the plug.

- ◯ *Before installing the cable onto a battery pack, use an ohmmeter to make absolutely sure that the cable is not shorted.* The cable should measure open circuit or infinite resistance. If a short is placed across the terminals of lead-acid batteries (like the Gates cells), a huge surge of current will flow, melting the wire causing the short and possibly causing the battery to explode.

Constructing the Battery Pack

Wire the 3-cell pack to the battery cable as indicated in Figure 1.23. Use the red and black wire to make the two jumpers between the cells (color of these jumpers does not matter). *Make sure to get polarities correct.*

After the battery pack is wired, an overall configuration (as suggested in Figure 1.21 can be selected. The battery pack may be held in the desired configuration using a variety of materials, including rubber bands, cable ties, glue, and/or electrical tape.

1.6 The Infrared Transmitter

The infrared (IR) transmitter board emits modulated infrared light that can be detected by the Sharp IR sensors (of type GP1U52). The board has infrared transmitting LEDs that are driven by an oscillator circuit (the 74HC390 chip) and a power op-amp (LM386) on the Microprocessor Board.

Each infrared LED is wired in series with a visible LED, so that if current is flowing through the infrared LED, it must also flow through the corresponding visible LED. It should therefore be easy to determine if the IR LEDs are emitting light.

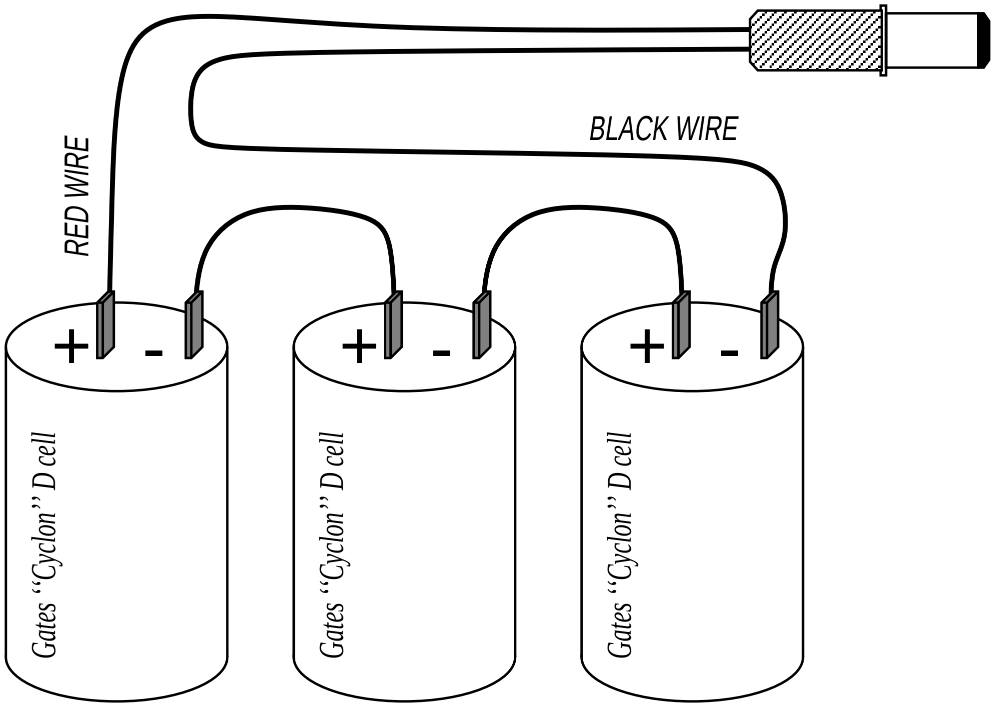


Figure 1.23: Battery Pack Wiring Diagram

1.6.1 Assembly Instructions

Figure 1.24 illustrates component placement on the infrared transmitter board. *Note that the LED numbering that was printed on the actual boards is incorrect.* The numbering shown in the figure is correct.

1–☐ Resistor Packs.

Both of the resistor packs are polarized. Mount so that the marked end of the resistor pack is placed into the square pad on circuit board.

◯ **RP8**–47Ω×4, 5 pins, *marked "E47Ω."*

◯ **RP9**–47Ω×4, 5 pins, *marked "E47Ω."*

2–☐ Visible LEDs.

The visible LEDs used on the infrared transmitter board have *clear lenses.* That is, they should look either clear or milky-white when they are unlit. *Be sure to use this variety of LED here.* These LEDs can handle more current than the LEDs that have been used in other circuitry. The LEDs will glow red when powered.

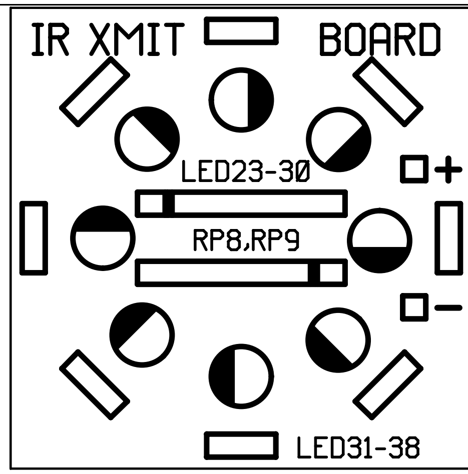


Figure 1.24: Infrared Transmitter Component Placement

Mount LEDs so that the short lead is inserted in the shaded half of the placement marking.

- ◯ **LED23**–clear lens, red element
- ◯ **LED24**–clear lens, red element
- ◯ **LED25**–clear lens, red element
- ◯ **LED26**–clear lens, red element
- ◯ **LED27**–clear lens, red element
- ◯ **LED28**–clear lens, red element
- ◯ **LED29**–clear lens, red element
- ◯ **LED30**–clear lens, red element

3–☐ Infrared LEDs.

The infrared LEDs come in a small rectangular package.

When mounting, make sure that *the face with a small bubble* aims *outward* from the ring of LEDs. The bubble is the lens in front of the actual emitter element.

The face with the colored stripes must be on the *inside* of the ring.

- ◯ **LED31**–MLED71 IR LED
- ◯ **LED32**–MLED71 IR LED
- ◯ **LED33**–MLED71 IR LED

○ **LED34**–MLED71 IR LED

○ **LED35**–MLED71 IR LED

○ **LED36**–MLED71 IR LED

○ **LED37**–MLED71 IR LED

○ **LED38**–MLED71 IR LED

4–☐ **Cable and Connector.**

○ Cut a 12" length of the twisted-pair red/black cable. Strip $\frac{1}{4}$" of insulation from the wire on both ends.

○ From *underside* of IR board, insert red wire into hole marked (+) and black wire into hole marked (−). Solder from *top* of board.

○ Mount other end of wire to outside pins of a three-pin male connector. Use guideline shown in Section 1.8.

The infrared transmitter plugs into the connector labelled IR OUT on the Microprocessor Board (see Figure 1.13), with the red lead inserted into the end marked (+) on the board.

1.7 The Motor Switch Board

The Motor Switch Board allows manual control of up to four motors. This is useful when testing and debugging mechanisms because the motors can be switched on forward, backward, and off easily.

It is important to realize that the amount of power delivered to the motors by the Motor Switch Board will be different than the amount delivered when the motors are driven by the electronics on the Microprocessor Board. The Motor Switch Board has diode circuitry to simulate the power loss of the Microprocessor Board's control electronics, but there will still be a difference.

Motors driven from the Expansion Board will operate at even less power than those driven by the Microprocessor Board.

The careful designer will test mechanisms both from the Switch Board and from the Microprocessor Board before committing to them.

1.7.1 Assembly Instructions

Figure 1.25 provides a reference to parts mounting on the Motor Switch Board.

1–☐ **Get Motor Switch Board, and determine which side is the component side.** The component side is marked with the parts placement layout.

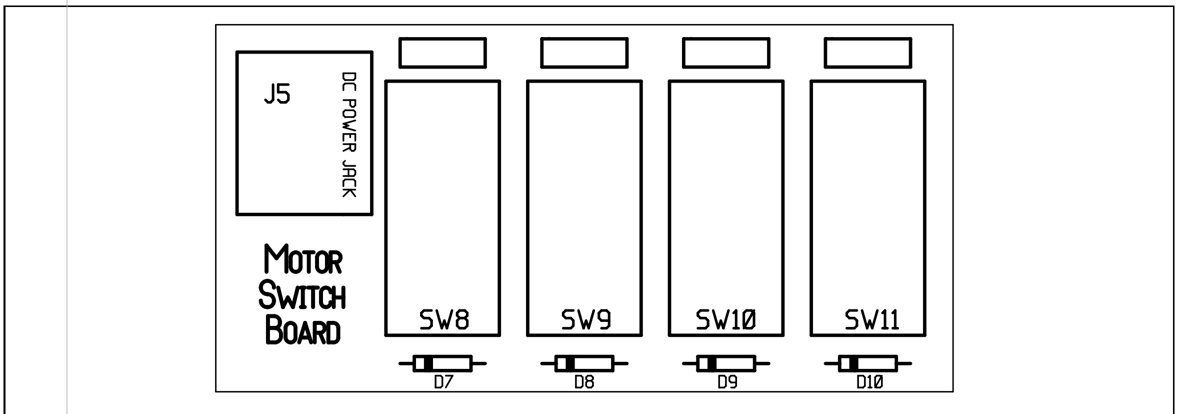


Figure 1.25: Motor Switch Board Component Placement

2–☐ Diodes.

These diodes have black epoxy bodies. Polarity matters: Install the diodes with the banded end as marked on the circuit board.

- ○ **D7**–1N4001
- ○ **D8**–1N4001
- ○ **D9**–1N4001
- ○ **D10**–1N4001

3–☐ DC Power Jack

Install **J5**, a DC power jack. Fill mounting holes completely with solder when soldering.

4–☐ Switches.

- ○ **SW8**–2 pole, 3 position slide switch
- ○ **SW9**–2 pole, 3 position slide switch
- ○ **SW10**–2 pole, 3 position slide switch
- ○ **SW11**–2 pole, 3 position slide switch

5–☐ Female Socket Headers.

Cut four 3-long pieces of female socket header. Mount in remaining holes on board where marked.

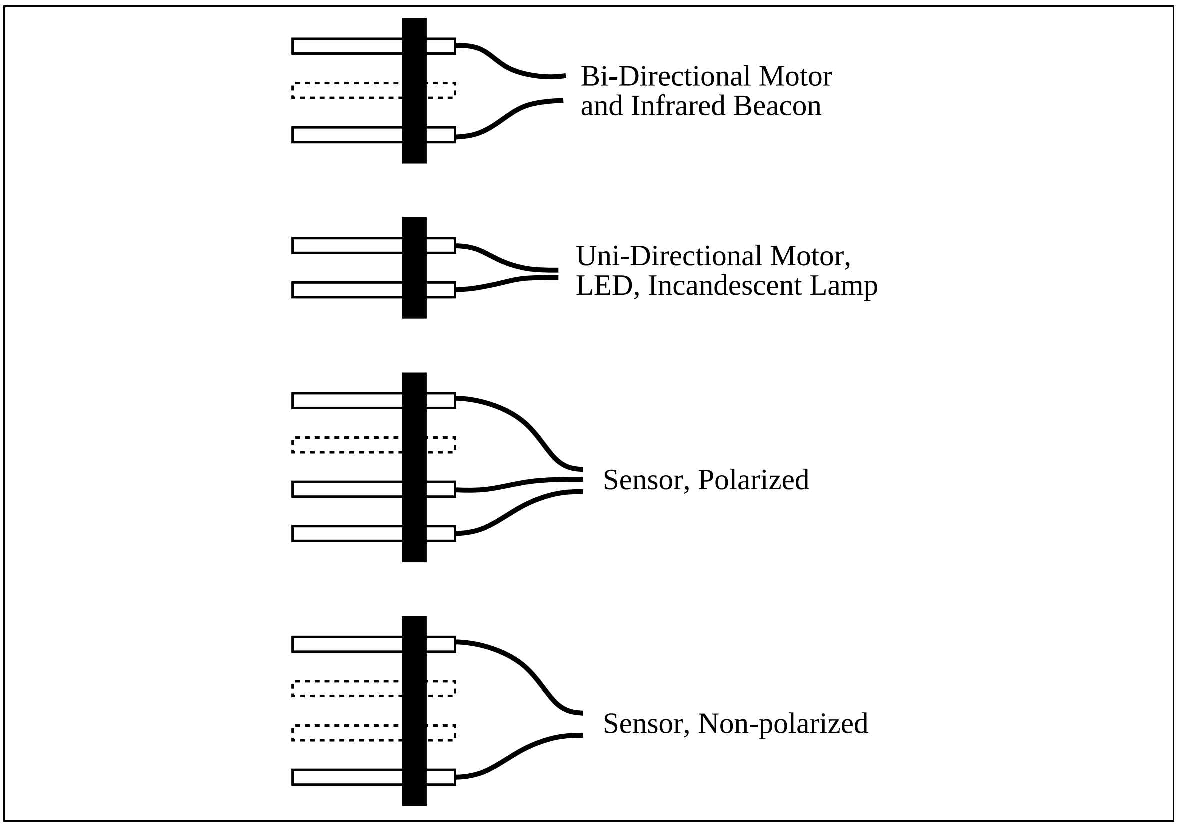


Figure 1.26: Standard Connector Plug Configurations

1.8 Cable and Connector Wiring

This section explains how to build reliable cables and connectors for the motors and sensors that will plug into the robot's controller boards.

Sturdy and reliable connectors are critical to the success of a robot. If a robot's connectors are built sloppily, hardware problems will occur. Well-built connectors will help make the robot more reliable overall and will ease development difficulties.

Sensors and motors are built with integral wiring; that is, a sensor or motor will have a fixed length of wire terminating in a connector. It is possible to build extension cables, but it is more time-efficient to build cables that are the proper length already.

The average robot has its control electronics near the physical center of the robot; hence, motors and sensor cables need to reach from the center of the robot to their mounting position. Given this geometry, most robots will need sensor and motor cables between 6 and 12 inches long.

Several different connector styles are used depending on the device which is being connected to. Figure 1.26 shows the connector configurations used for bidirectional motors, unidirectional motors, sensors, and the infrared beacon.

The ribbon cable provided in the 6.270 kit is best for making sensor and motor cables.

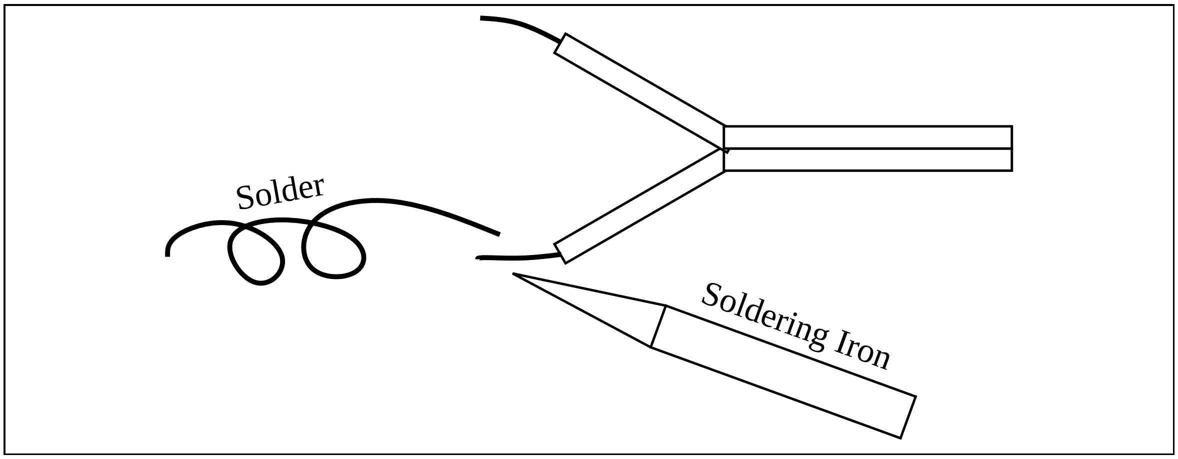
Figures 1.27 through 1.30 illustrate the recommended method for wiring to a connector plug. When assembled properly, this method will provide for a sturdy, well-insulated connector that will be reliable over a long period of use.

The example shows wiring to opposite ends of a three-pin plug, as would commonly be used when wiring to a motor. The method, however, is suitable for all kinds of connectors.

1.9 Sensor Wiring

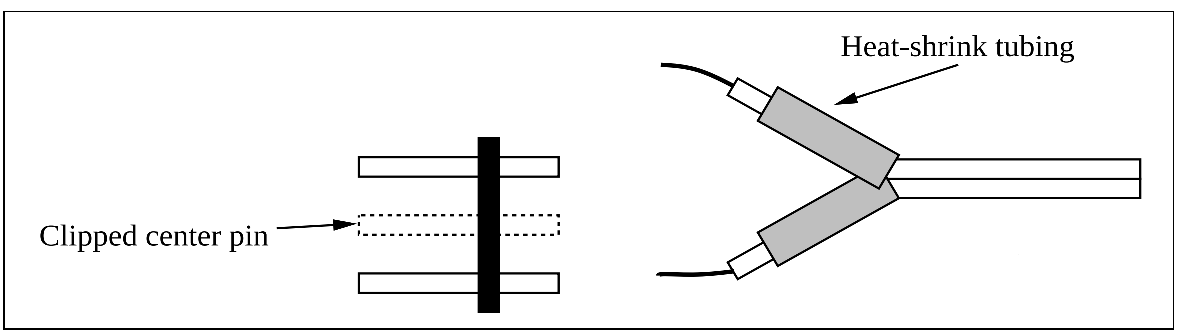
This section shows wiring diagrams for the following sensors:

- Touch sensors
- Photocell light sensor
- Infrared reflectance sensor
- Bend sensors
- Sharp infrared sensor
- Potentiometer position sensors
- Slotted optical switch



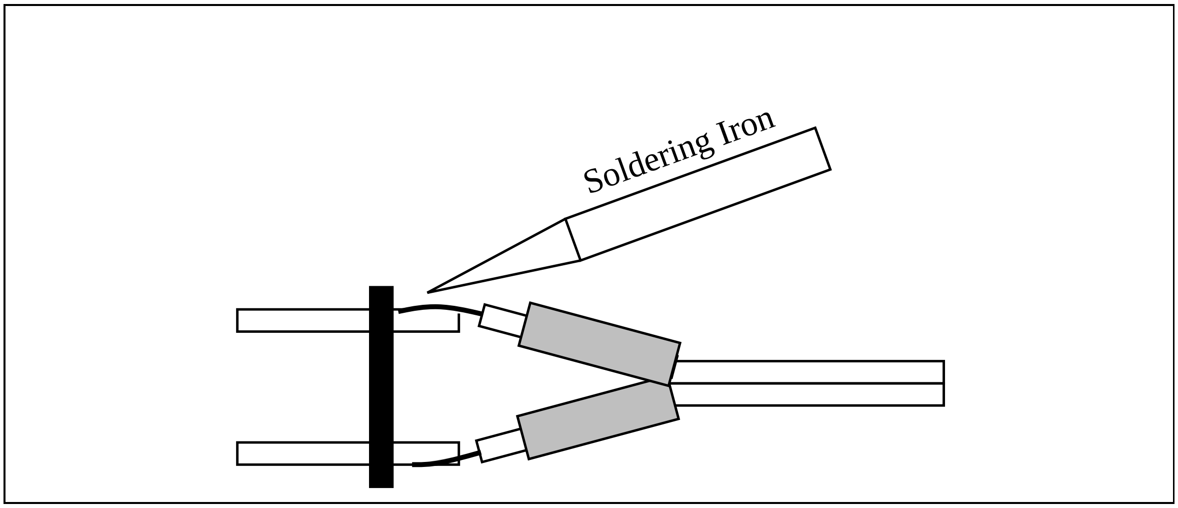
Strip a small amount of insulation off the wire ends. Tin the wire ends by applying a thin coat of solder to them.

Figure 1.27: Step One of Connector Wiring



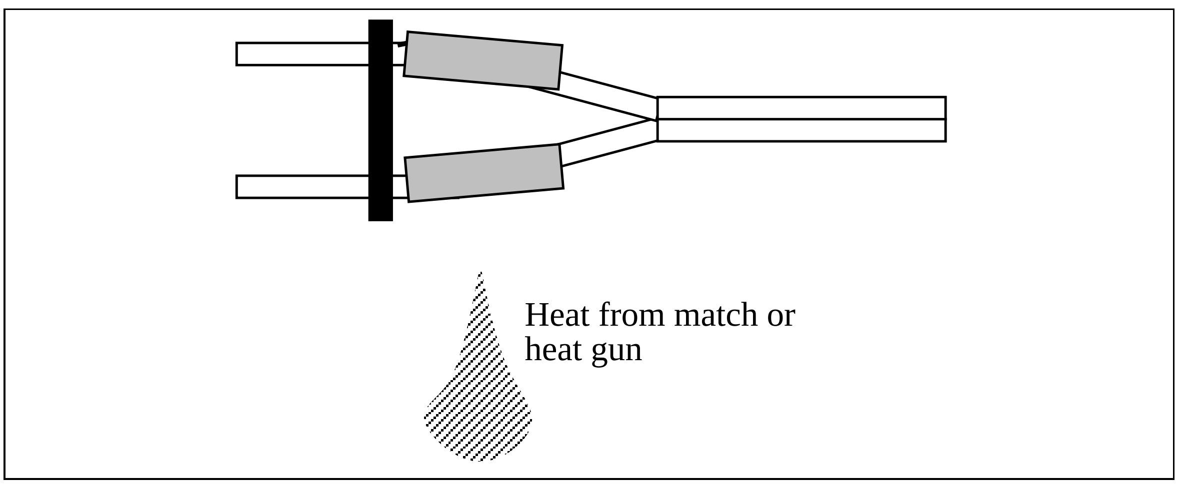
Cut the male connector to size. This example shows a plug that can be used to wire a motor or the infrared transmitter. Cut $\frac{1}{2}$ inch length pieces of heat-shrink tubing, and slide over tinned wires.

Figure 1.28: Step Two of Connector Wiring



Hold the connector and wires in place and solder together. It may be helpful to clip wires to the length of the male pins before soldering.

Figure 1.29: Step Three of Connector Wiring



Slide pieces of heat-shrink tubing over connections. Shrink using heat gun, flame from a match or lighter, or the side of a soldering iron.

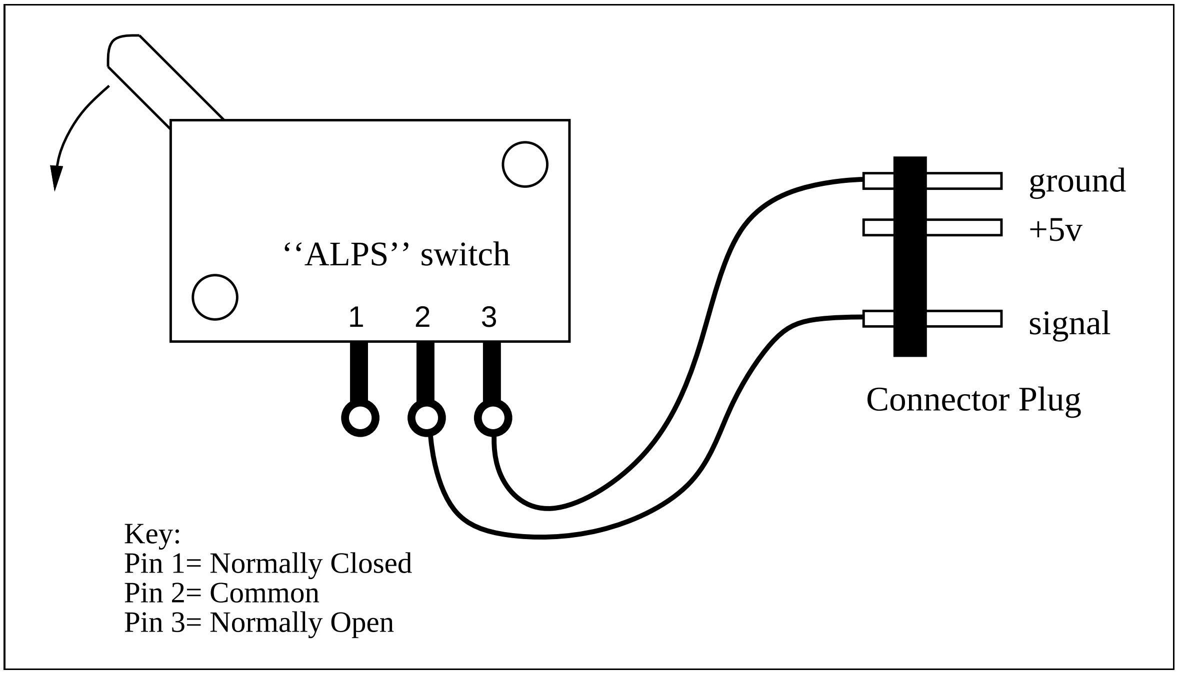
Figure 1.30: Step Four of Connector Wiring

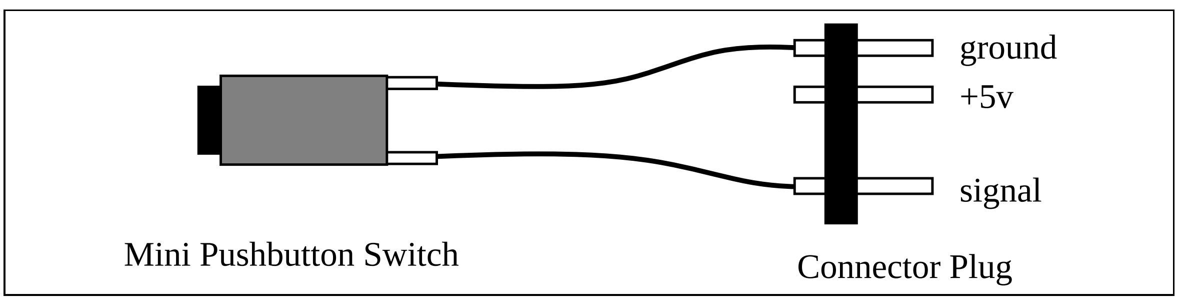
- Hall effect (magnetic) sensor

In most cases, some discussion of the sensor's principle of operation accompanies the wiring diagram. Further information on the use of all sensors is elaborated in Chapter 5 on robotic sensors.

1.9.1 Touch Sensors

Several switches in the 6.270 kit may be used to make touch sensors. Diagrams for the white "ALPS" switch and the small black button switch are shown.

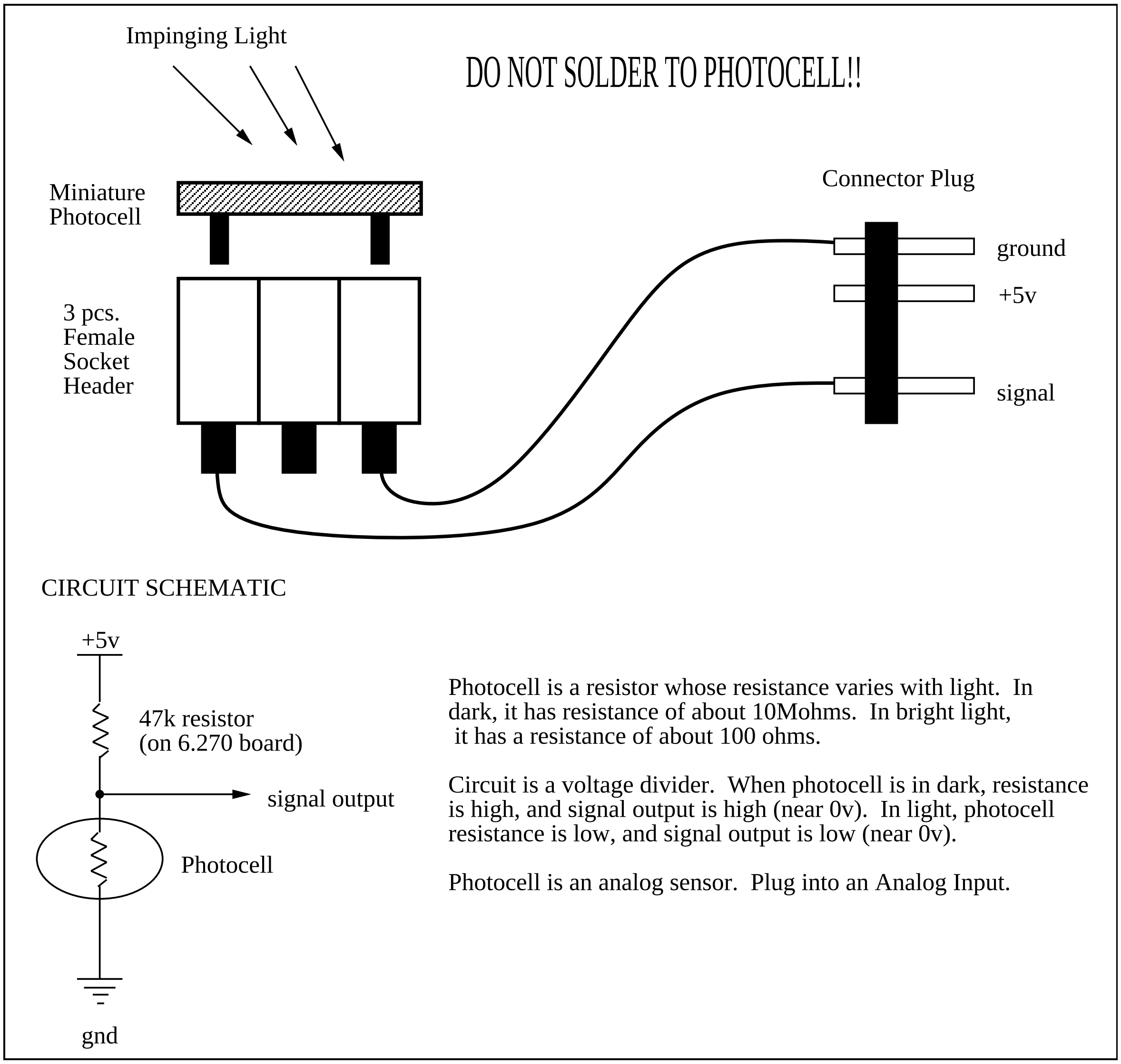




Touch switches should be wired in a normally open configuration, so that the signal line is brought to ground only when the switch is depressed.

1.9.2 Photocell Light Sensor

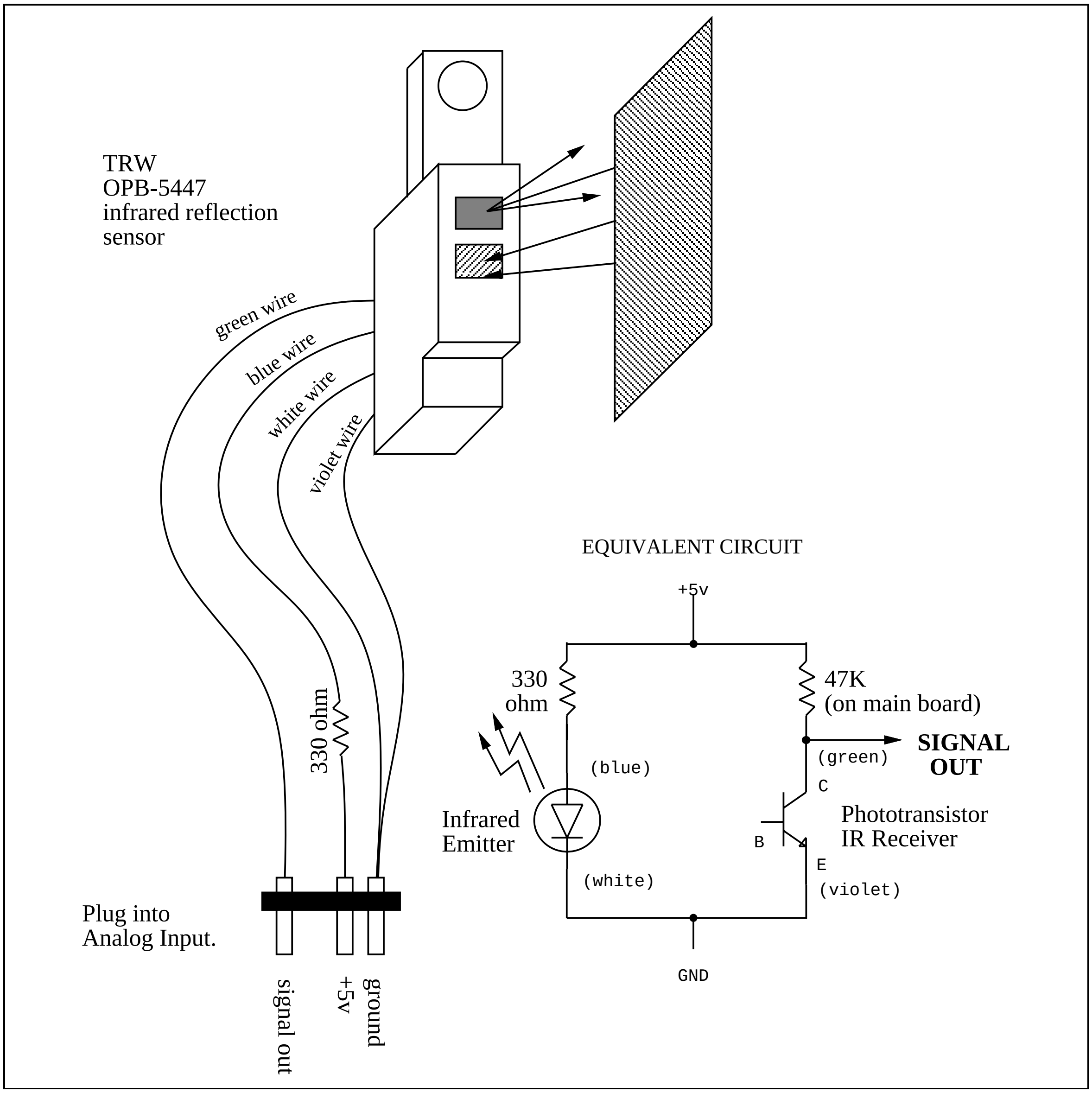
The photocell is a special type of resistor which responds to light. The more light hitting the photocell, the lower its the resistance.



The output signal of the photocell is an analog voltage corresponding to the amount of light hitting the cell. Higher values correspond to less light.

1.9.3 Infrared Reflectance Sensor

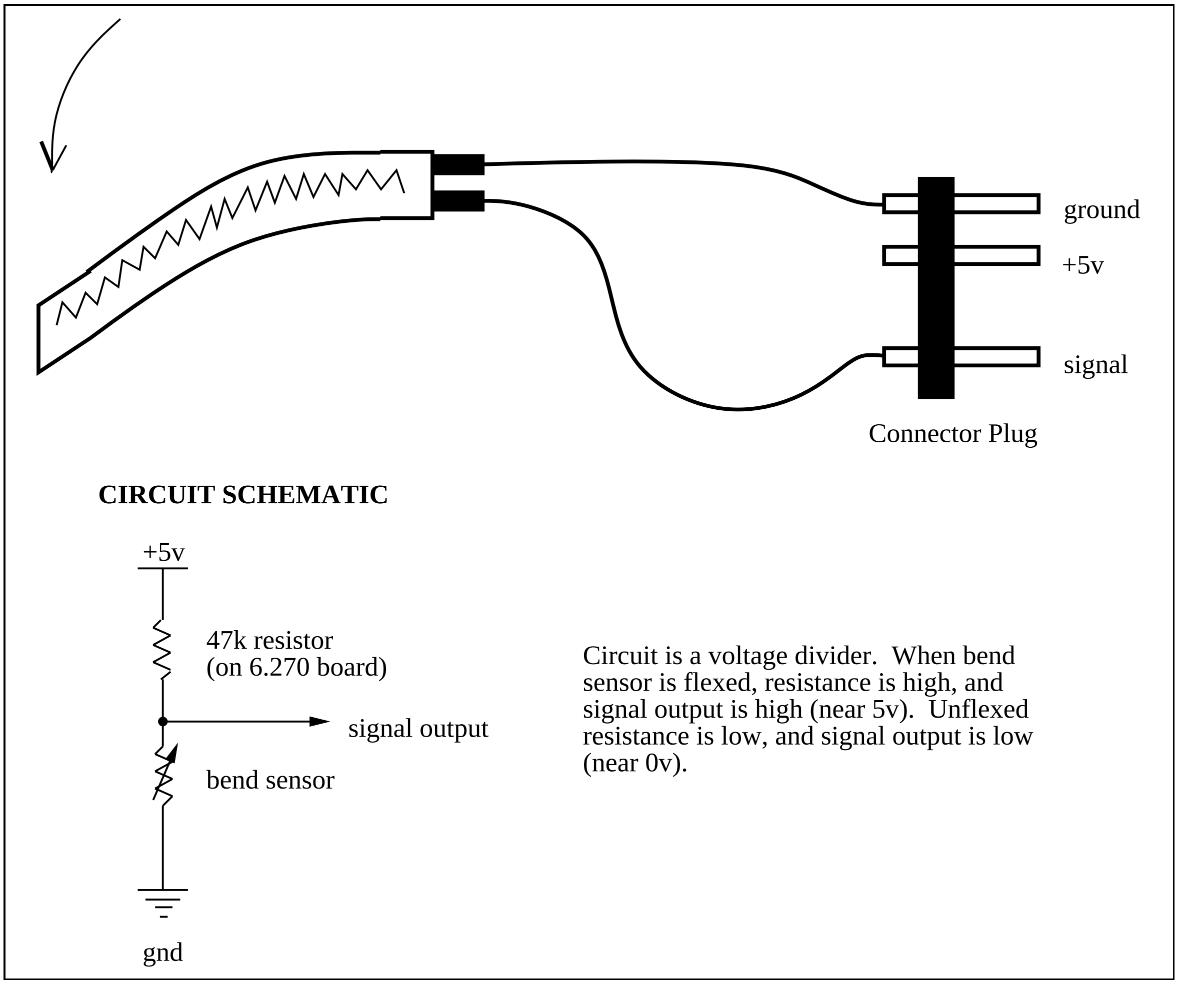
The TRW model OPB-5447 is a matched pair infrared transmitter and infrared receiver. It works by measuring the amount of light that is reflected into the receiver. Because the receiver also responds to ambient light, the device works best when well shielded from ambient light.



The output signal of the phototransistor receiver is an analog voltage corresponding to the amount of light hitting the phototransistor. Higher values correspond to less light, and hence a smaller degree of surface reflectivity.

1.9.4 Single Bend Sensor

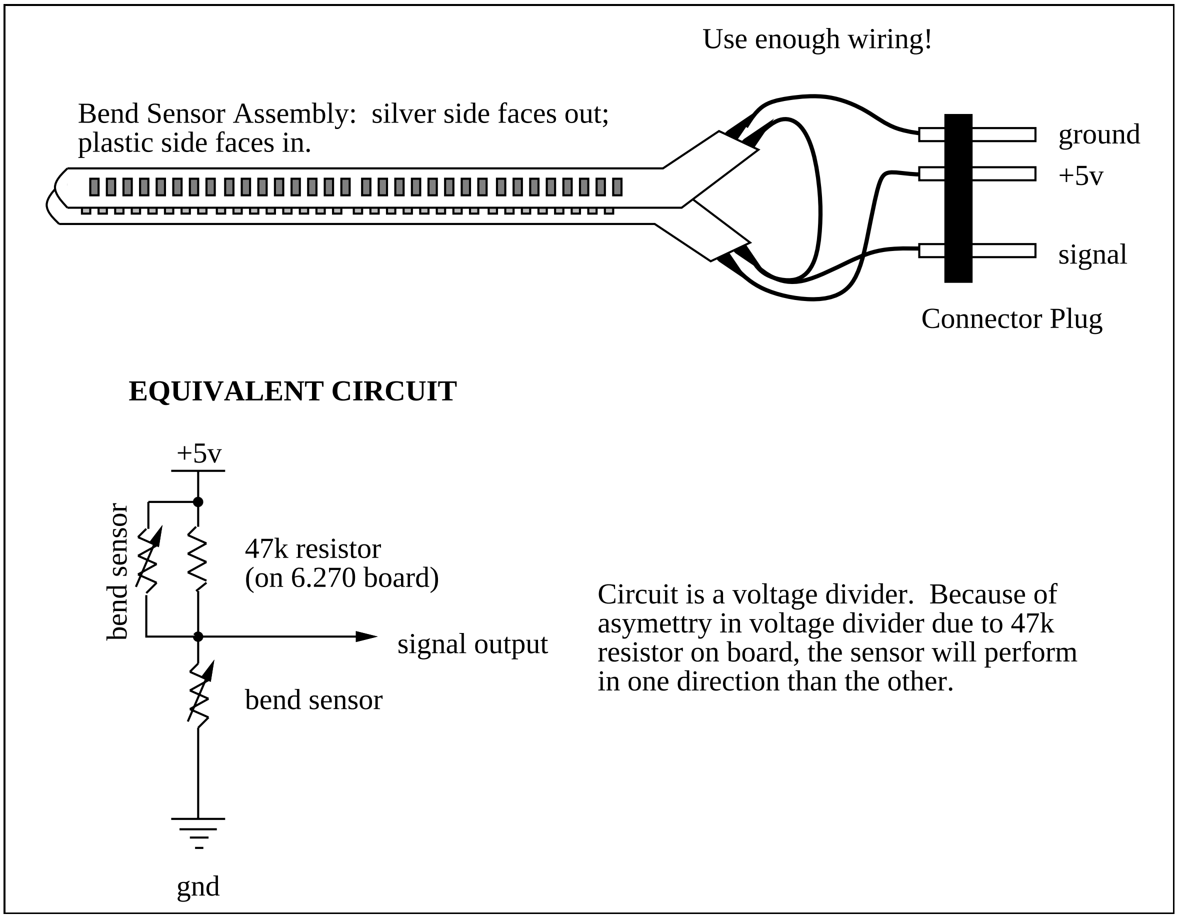
The bend sensor element is a resistive device that changes in resistance when it is deformed. The sensors are only sensitive to being bent in one direction—the one that stretches the silver material. Bending them in this direction increases their resistance. Bending them in the opposite direction does not change the resistance.



The sensors have a relaxed resistance of about 50kΩ and a fully bent resistance of about 300kΩ.

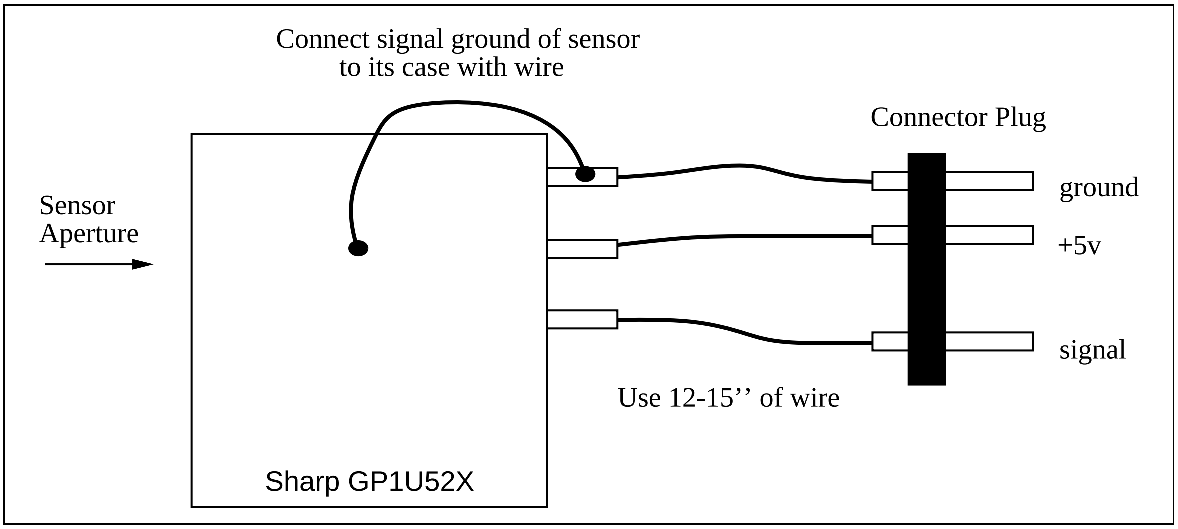
1.9.5 Dual Bend Sensor

By using two bend sensor strips that are mounted back-to-back, a sensor assembly can be created that is sensitive to bending in either direction.



1.9.6 Sharp Infrared Sensor

The Sharp GP1U52X sensor detects infrared light that is modulated (e.g., blinking on and off) at 40,000 Hz. It has an active low digital output, meaning that when it detects the infrared light, its output is zero volts.

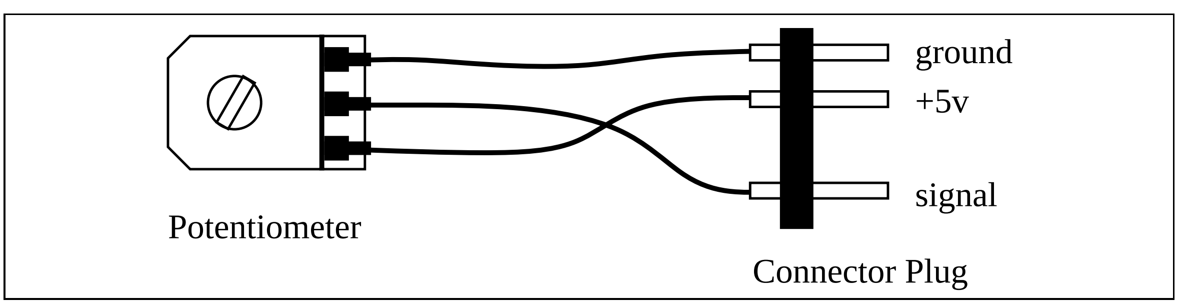


The metal case of the sensor must be wired to circuit ground, as indicated in the diagram. This makes the metal case act as a Faraday cage, protecting the sensor from electromagnetic noise.

Use of the Sharp sensor is discussed in Section 7.8.2. An explanation of how the infrared system works is given in Section B.7.

1.9.7 Potentiometer

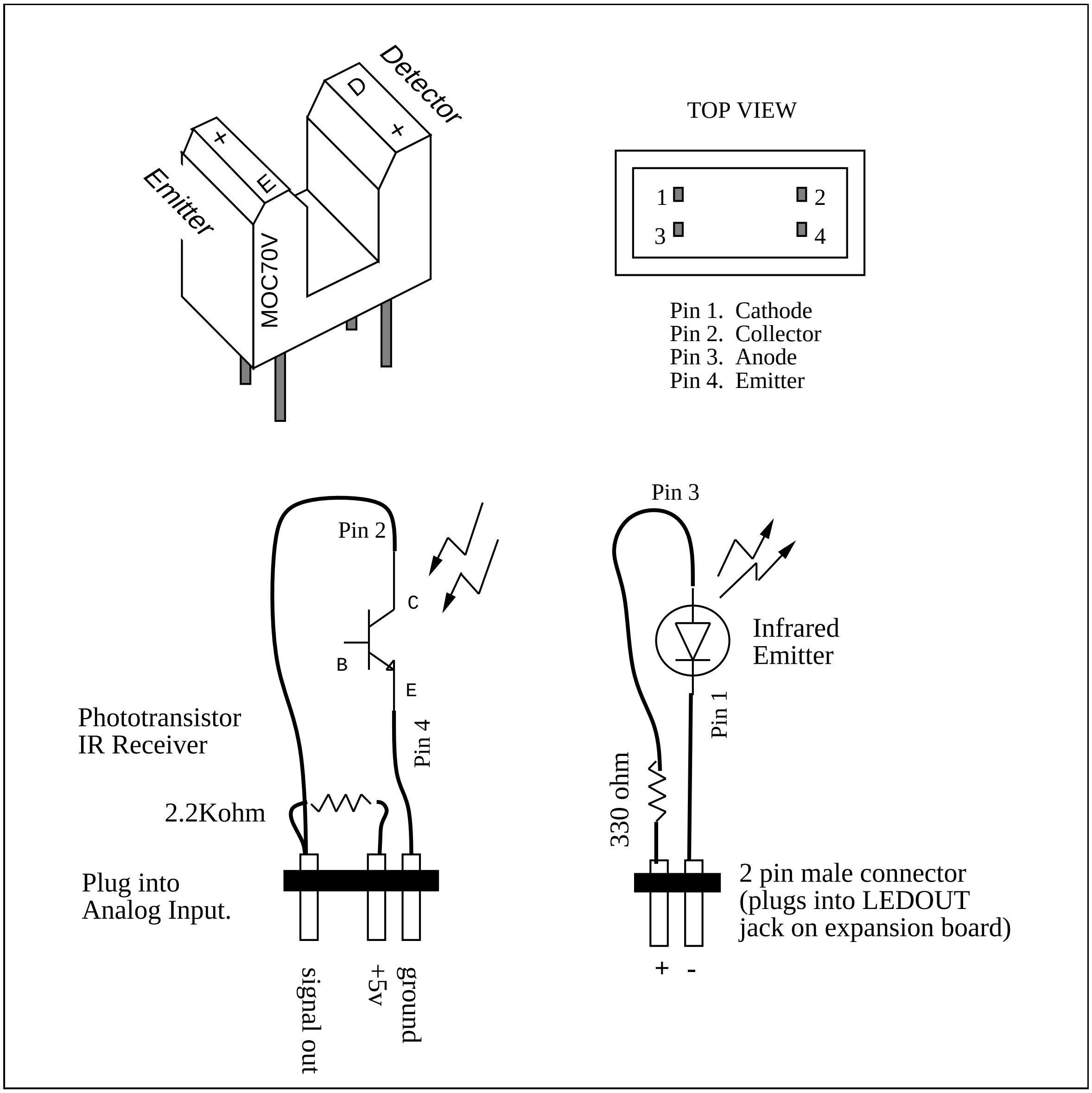
The potentiometer can be used as a rudimentary rotary position sensor.



The linear potentiometer may also be wired in this fashion.

1.9.8 Slotted Optical Switch

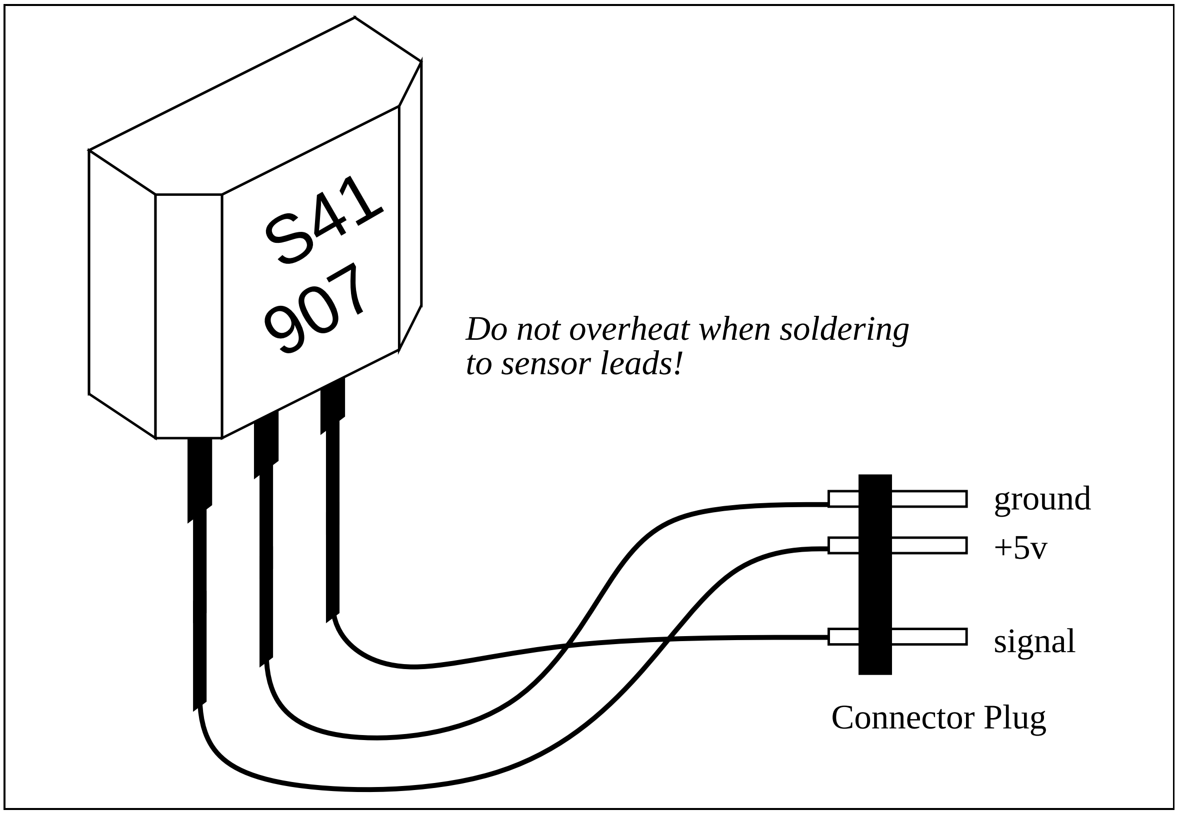
The Motorola model MOC70V is a matched pair infrared transmitter and infrared receiver. It works by measuring the amount of light transmitted from the transmitter to the receiver. Best results are achieved when ambient light is shielded from the device.



The output signal of phototransistor element is an analog voltage that corresponds to the amount of light hitting the phototransistor. Higher values indicate less light. This output signal can be sampled by software to count holes in a wheel rotating through the slot.

1.9.9 Hall Effect Sensor

The SS41 series Hall effect sensor detects the presence of a magnetic field. After it latches a south pole field (positive magnetic gauss) it produces a zero volt output. It then requires a north pole field to be reset.



The device can be easily damaged during soldering. Be careful not to apply too much heat or stress the device leads.

1.10 Motor Wiring

This section explains how to wire the Polaroid motors and the servo motor, and how to prepare the Polaroid motor for mounting on a LEGO device.

1.10.1 The Polaroid Motor

The Polaroid motors are used to eject film in their instant cameras and are particularly powerful DC motors. They are manufactured by Mabuchi, a leading Japanese motor manufacturer. The Polaroid motors have been donated to the 6.270 course by Polaroid.

The process of preparing the motor can be broken into three separate parts. The first part is to place a LEGO gear on the shaft of the motor. The second part is to mount the motor onto a platform. The third part is wiring a cable and plug to the motor assembly.

These instructions will specify that an eight-tooth LEGO gear be permanently installed on the motor shaft. In general, this is the most useful motor configuration. Other possibilities include mounting a LEGO pulley wheel or a larger diameter gear on the shaft.

It is recommended that two motors with the eight-tooth gear mount be built and evaluated. Later, it can be decided if the remaining motors should be build differently. Only for unusual applications will another configuration be preferable.

Attaching a Gear to the Polaroid Motor

- ○ The motors come with a metal gear that is press-fit onto the shaft of the motor. The first step is to remove this gear.

  The gear is removed using a pair of of wire strippers. Place the jaws of the strippers between the motor and the gear. When the strippers are closed, the bevel in the cutters should pry off the gear.

  The cutters should provide a uniform force around the gear so that it does not get stuck on the shaft when being pried off.

- ○ Cut a piece of thin plastic tubing to the size of the length of one 8-tooth gear and place it on the shaft. Make sure that the tubing is not rubbing against the motor housing when the shaft turns. This could cause a slight decrease in the performance of the motor. The LEGO gear should be able to fit snuggly over the shaft and the tubing.

- ○ Place a drop of super glue around the outer area of the tubing that is furthest away from the motor housing as shown in Figure 1.31. *Make sure that too much* *glue is not used. If there is too much super glue, it may leak into the motor housing and jam up the motor.* Using a paper napkin, pat off any of the excess super glue.

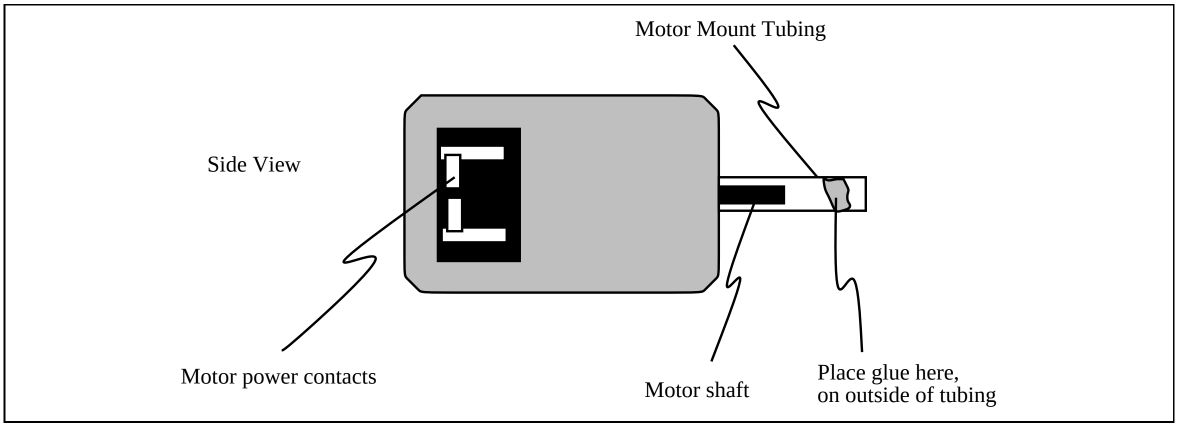


Figure 1.31: Motor Housing with Tubing

- ◯ Get an 8-tooth LEGO gear. It has two inside surfaces: a beveled surface and a flat surface. The gear will slide on easier when the beveled side is placed on first. Push the gear in all the way. It should fit without slippage. The gear should not be wobbly.

- ◯ Using a hot glue gun, glue the outer edge of the tubing to the gear by placing the glue into the inside of the gear.

- ◯ After the glue has dried, remove the gear from the shaft. The tubing should come off with it and should be inside the gear. Cut off any excess tubing (tubing that is longer than the gear) from the side that mounts onto the motor.

- ◯ *This is the most crucial step.* Place $\frac{1}{2}$ drop to 1 drop of super glue into the center of the tubing and push the gear back onto the shaft. Too much glue can ruin the motor. Place the motor with the gear facing down to let the excess super glue dry away from the motor housing.

Attaching the Polaroid Motor to a LEGO Base

The purpose of this step is to permanently affix the motor to LEGO parts so that it will mesh properly with gear mechanisms built from other LEGO pieces.

To make sure that the motor is mounted properly, it will be placed on a platform in the correct orientation to mesh with other LEGO gears.

This platform or jig is shown in Figure 1.32. It is constructed from two 2×8 beams, one 6×8 flat plate, one 2×4 plate, two 24-tooth gears, and two axles.

The motor is placed on a 2×4 flat plate and mounted so that its 8-tooth gear is nestled between the two 24-tooth gears at the proper horizontal and vertical LEGO spacing.

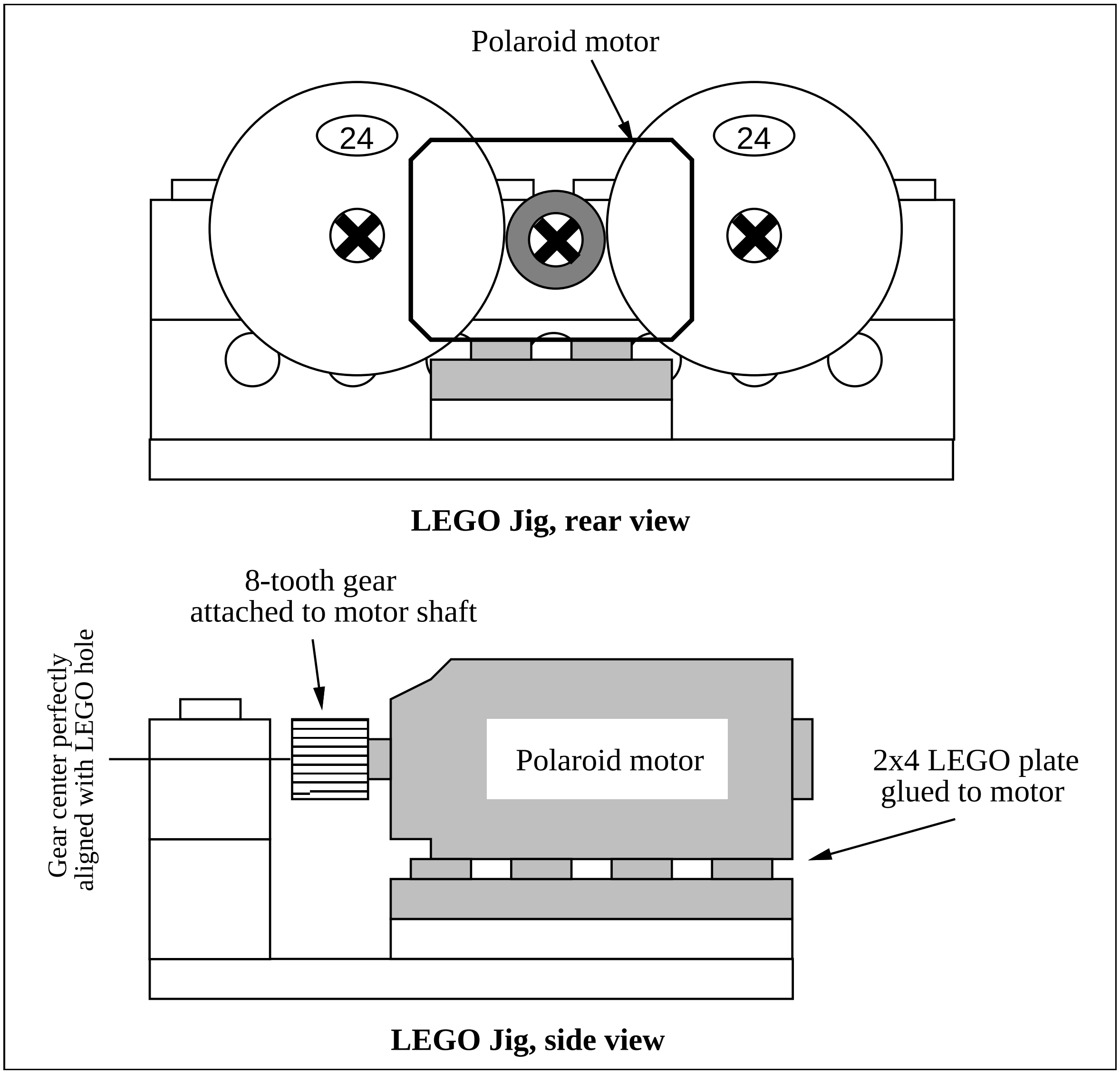


Figure 1.32: LEGO Jig for Mounting Polaroid Motor

- ◯ Assemble the jig as shown in Figure 1.32. A second 2×4 plate will mounted to the motor.
- ◯ Mix some epoxy and place it on the top connectors of the base plate. Put enough to hold the motor.

- ◯ One face of the motor has two notched openings. Place the motor on the 2×4 plate such that the notches are facing up. This is to prevent the epoxy from getting into the motor.

- ◯ Position the motor on its plate so that the 8-tooth gear is meshed between the two 24-tooth gears, and the center line of the motor shaft is parallel with the axles of the 24-tooth gears.

- ◯ Wait five to fifteen minutes for the epoxy to harden.

Wiring a Cable and Plug to the Polaroid Motor

- ◯ Motor cables may be constructed with either two strands of ribbon cable wire or the twisted pair red/black cable. Cut an 8 inch to 12 inch length of whichever wire is preferable.

- ◯ Strip and tin both ends of the wire.

- ◯ On the side of the motor there should be two metal lead/pads. Solder one wire lead to each pad. After proper soldering, hot glue may be used to hold the wire to the side of the motor for a stress relief.

- ◯ Motor plugs may be wired for bidirectional or unidirectional use, as shown in Figure 1.26. (For most purposes, motors will need to be operated bidirectionally.)

  Cut a two- or three-long strip of male socket headers as will be needed.

- ◯ Using the connector plug wiring technique shown in Figure 1.27 through Figure 1.30, wire the motor plug. Polarity does not matter since the plug may be inserted into a motor power jack in either orientation.

1.10.2 Servo Motor

Figure 1.33 illustrates a typical servo motor similar to the one provided in the 6.270 kit. The servo motor has a short cable that terminates in a three-lead connector, as illustrated. The functions of these lead are power, ground, and the control signal.

Figure 1.34 illustrates the cable that should be built to interface the servo motor to the 6.270 board. As indicated in the diagram, the servo cable plugs into the PWR OUT port located on the Microprocessor Board, and the PORT D2 signal located on either the Microprocessor Board or the Expansion Board.

The adapter cable should be made as long as needed.

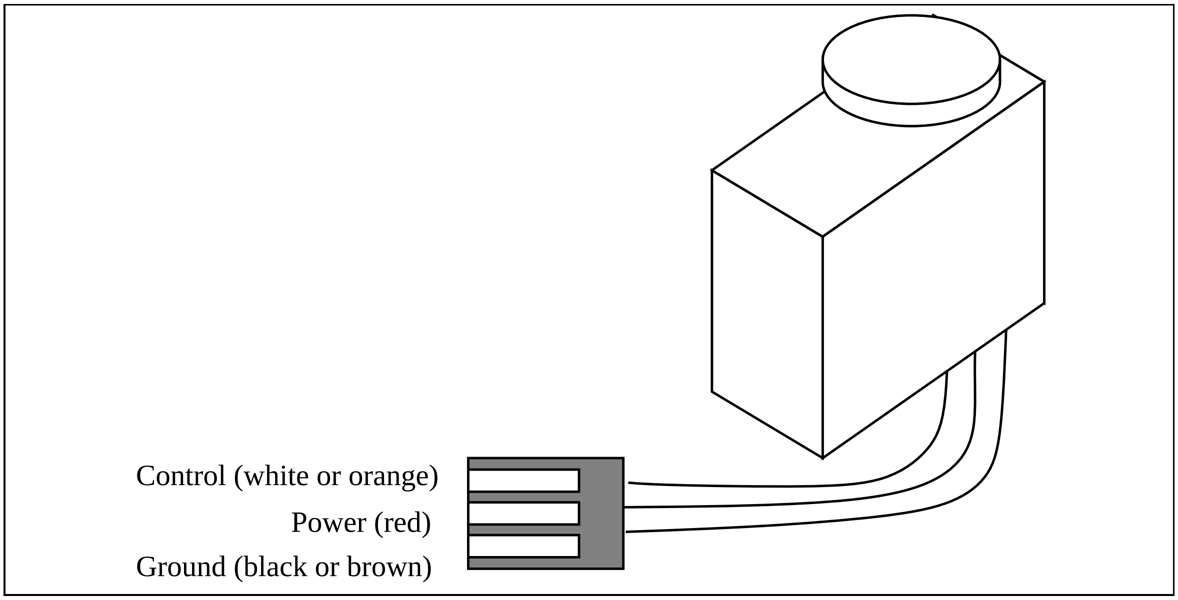


Figure 1.33: Servo Motor and Integral Connector Plug

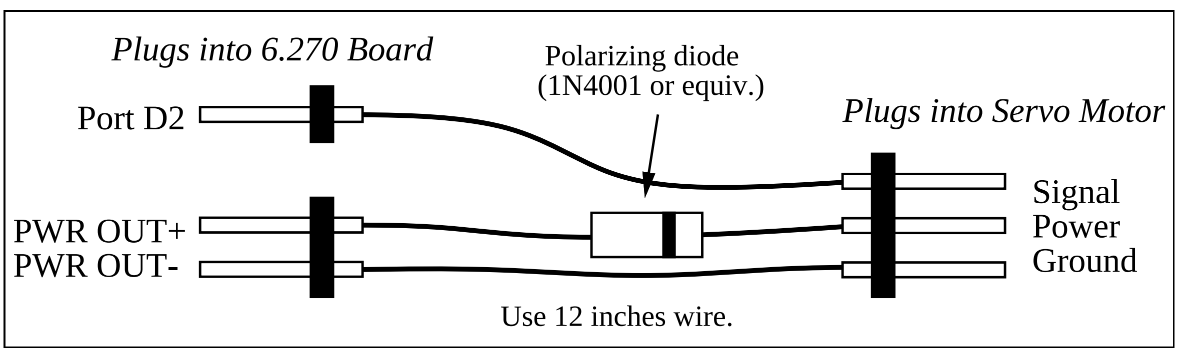


Figure 1.34: Servo Motor Cable Wiring Diagram

1.11 Computer Cable Wiring

The double-headed modular plug cable supplied in the 6.270 kit is used to connect the board with VAXstation 3100 and DECstation 3100 computers. This cable has a normal modular plug on one end (this end plugs into the board) and a off-center-keyed plug on the other end (this end plugs into the computer).

This section provides directions for building a cable to interface the 6.270 board with a VAXstation 2000 computer. The following parts are used:

- length of modular cord with plug attached to one end
- DB-9 female computer connector
- DB-9 connector housing

When building the cable adapter, be careful to follow the wiring directions precisely. Refer to Figure 1.35 as needed.

- ○ Begin by cutting the spade lug connectors from the modular plug cable. Strip a bit of insulation from the ends of the four wires and tin the wire ends.

  The cable provided in the kit is about 15 feet long. It may be cut to a shorter length if desired.

- ○ Thread the wire ends through the metal housing as indicated in Figure 1.35.
- ○ Tie a knot in the end of the cable about one to two inches from the free wire ends. This knot will act as a stress relief when the cable is pulled.
- ○ Connect the wire leads to the three terminals of the DB-9 connector as indicated in the diagram.

  Note: Make sure that the wiring of the modular cable you are using matches the diagram; e.g., that the black wire is on the left when looking down on the modular plug as in the diagram. *If the black wire is on the right, reverse the wiring of the black and yellow connections.*

- ○ Install the connector assembly in the plastic plug housing (this is not pictured in the diagram). The two screw handles must be installed before the housing is snapped together.
- ○ Snap the housing together and the job is done. The one-inch long aluminum tube may be discarded; it may not be used as a kit part.

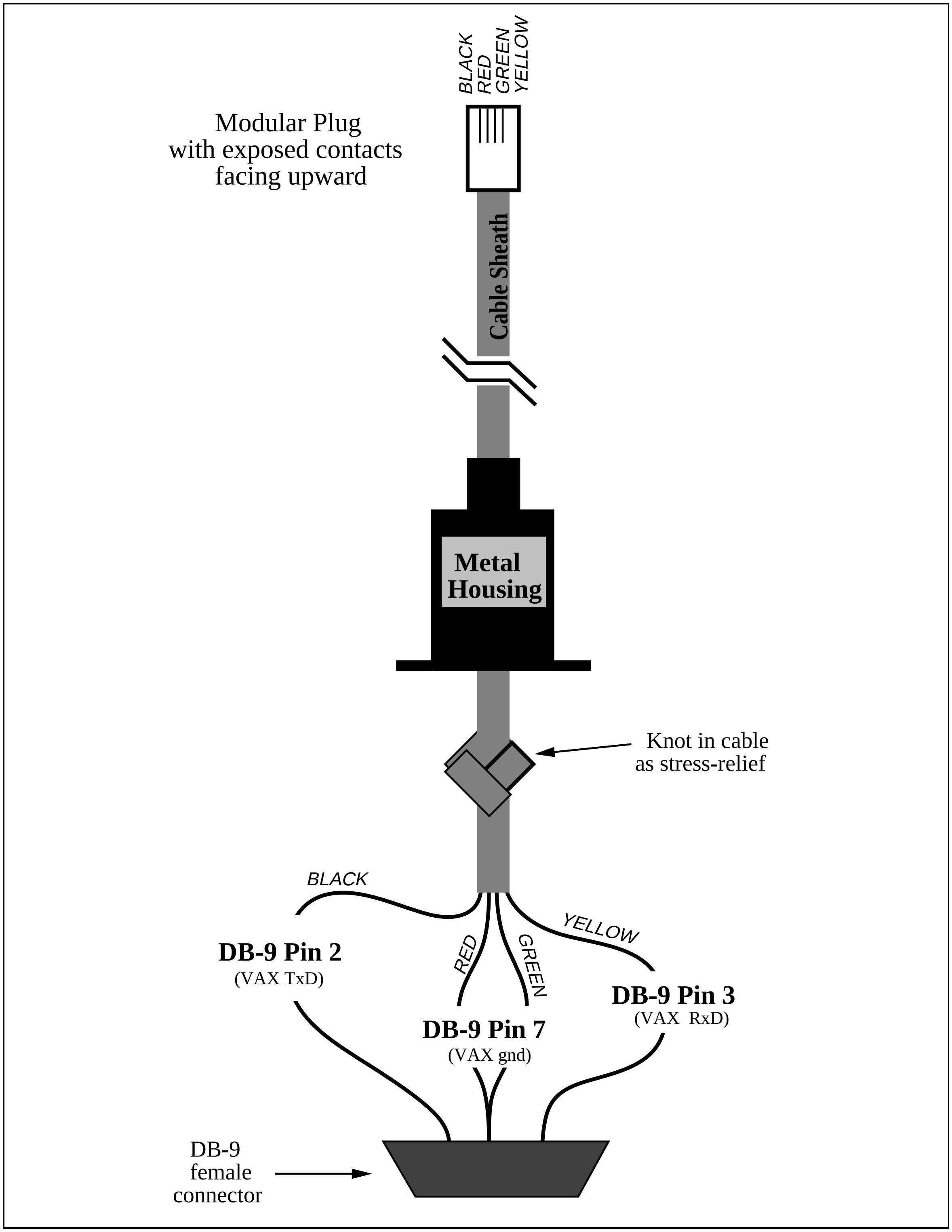


Figure 1.35: VAXstation 2000 Computer Cable Wiring Diagram