Chapter 4

Assembly Manual

This chapter presents an introduction to electronic assembly followed by step-by-step instructions for assembling the 6.270 hardware. The instructions assume no prior background in electronics. The order of the assembly should help you get into the soldering mode, and will give you practice at soldering some of the bulky items before soldering the delicate devices.

Instructions are provided for the following boards and devices:

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

If your team has more than one soldering iron, you can assemble some of the boards in parallel.

The reasons for having the teams build the boards are two fold. First it gives you an opportunity to learn about the components and how to solder. The second reason is to get you familiar with the boards and how they operate. As you read through the assembly sections, a brief description of the functionality will be given so that you become familiar with the system.

4.1 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 holder that is attached to the Microprocessor Board. These are used to run the microprocessor and some sensors. They are also used to keep the program and data in the RAM when the board is switched off.

These batteries should power the microprocessor board for about thirty hours of operation before needing to be replaced. The board should not be left on inadvertently because the batteries will be drained. When the board is off, you should not remove the AA batteries, or else the RAM will be erased. These batteries will last longer if the motor batteries are also plugged into the board.

The second set of batteries plug 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 it could cause a microprocessor circuit to 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. These batteries can be used to start a motorcycle, or maybe even a car. *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. These batteries however, have been reinforced very well and should not explode, but will burn you if they are shorted.

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. This means that you cannot alter the electrical configuration, but you can modify the physical configuration. You can also use the battery casings that were donated by Gates Batteries to hold your batteries. It is important that you take care in assembling the battery packs because the batteries are charged in their initial state. You should assemble the batteries first so that there are no inadvertent shorts that can cause the batteries to overheat.

4.1.1 Battery Pack Construction

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

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. One battery pack can be used to operate the robot while the other is being charged (charging takes about 10 hours). There are reasons for which you may want your design to have batteries in different locations.

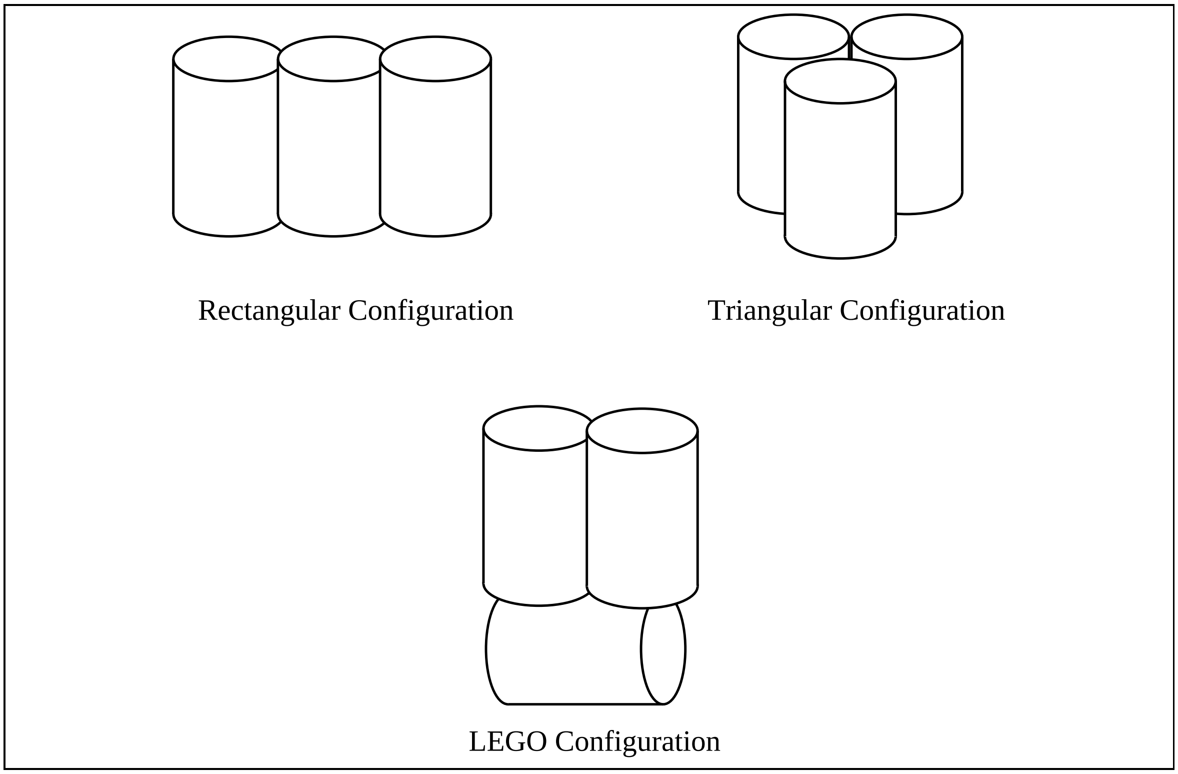


Figure 4.1: Three Battery Pack Configurations

Two obvious alternatives for battery pack construction are depicted in Figure 4.1: a rectangular configuration and a triangular one. Another possibility is a LEGO configuration shown in Figure 4.1 which can be mounted on a $6x8$ LEGO plate. Other configurations may be explored.

Wiring the Battery Cable

Figure 4.2 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.

- ○ $\frac{1}{16}''$ 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

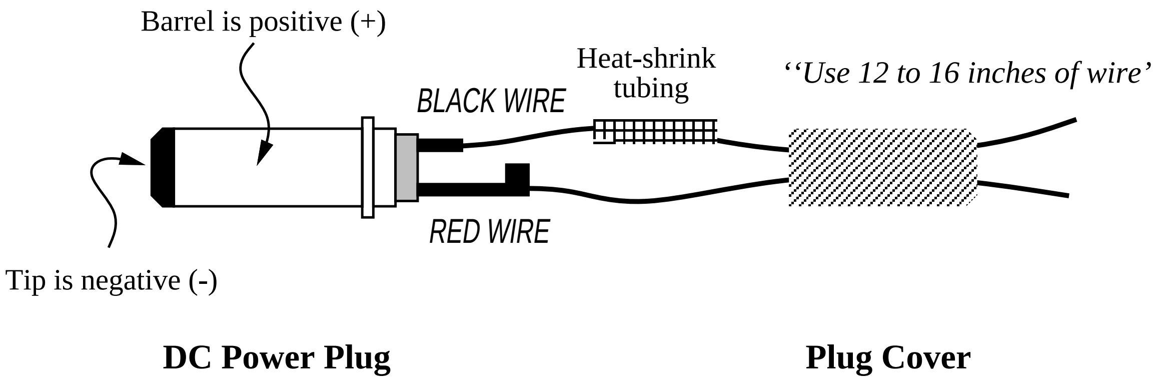


Figure 4.2: Battery Plug and Cable Wiring Diagram

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 4.3. 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. Incorrect wiring will cause the wire to get hot and catch on fire.*

After the battery pack is wired, an overall configuration (as suggested in Figure 4.1 can be selected. The battery pack may be held in the desired configuration using a variety of materials, including rubber bands, cable ties, hot glue, and/or electrical

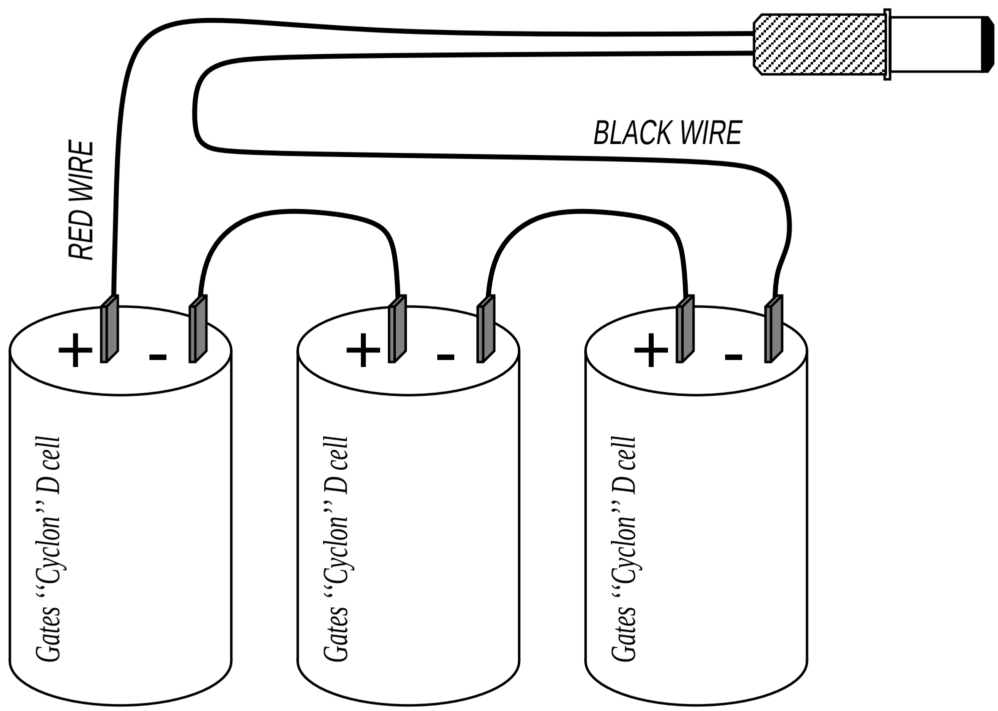


Figure 4.3: Battery Pack Wiring Diagram

tape. The terminal of the batteries can be bent and hot glued so they do not inadvertently get shorted. Do not put too much hot glue, or else the battery will not be able to breathe. There must be a pathway for the gases in the battery to escape or else too much pressure builds up in the casing and may cause an explosion.

4.1.2 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. In this configuration, the power is supplied to the battery through the larger valued resistor (15Ω). The batteries are charged with a constant current of about 400 milliamps.

  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. The batteries are being charged at a constant current of about 800 milliamps.

  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.

  Is is better to charge the batteries at the slower rate if possible. When high currents are being passed through the batteries, they tend to heat up. The batteries do not accept charge very well at higher temperatures.

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.

Assembly Instructions

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.

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

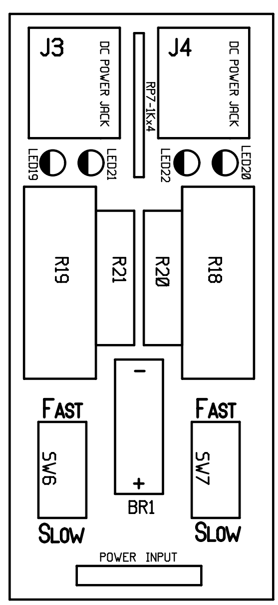


Figure 4.4: Battery Charger Component Placement

Figure 4.4 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 in white. You should always solder on the solder side of the board, which does not have white writing.

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 Pack.**

Install **RP7**, 1.2kΩ×4, 8 pins, *Blue single in-line pin. 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.**

These LEDs are the LEDs which are in bin with a yellow LED. There is another compartment with just red LEDs do not mix these two up. The red LEDs in the upper right hand compartment are not low power LEDs. You need to use the low powered LEDs in this section.Mount LEDs so that the short lead is inserted in the shaded half of the placement marking. Make sure to push the LEDs all the way through and mount them as close to the board as possible.

- ◯ **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. This resistor is marked by a big white square outline on the component side.
- ◯ **R19**–7.5Ω, 5 watts. This resistor is marked by a big white square outline on the component side.
- ◯ **R20**–15Ω, 2 watts, *brown, green, black*
- ◯ **R21**–15Ω, 2 watts, *brown, green, black*

6–☐ **Slide Switches.**

◯ **SW6**–miniature SPDT slide switch

◯ **SW7**–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 any connectors on the DC side of the adapter. Measure the voltage across the wires and make sure that the voltage is above 12VDC when the adapter is plugged into the wall. 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–☐ Check Out

You can test the battery charger in the lab using a voltmeter. Plug the charger into the wall socket and measure the voltage between positive and negative of the bridge rectifier. Make sure that the polarity is correct. Plug the battery pack into each of the jacks, and make sure the red LED is on when the switch is on FAST and the green LED is on when the switch is on SLOW. You should check it out with a TA if you are unsure.

10–☐ 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.

4.2 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 motors are driven through a diode which provides a .6 volt drop, but the motor drivers may drop up to 1.2 volts and reduce your motor output.

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

The simplicity of the Motor Switch Board will give the inexperienced solderer an opportunity to get some practice before committing to the bigger boards. A second member in the group should begin to assemble a motor to test the Motor Switch Board.

4.2.1 Assembly Instructions

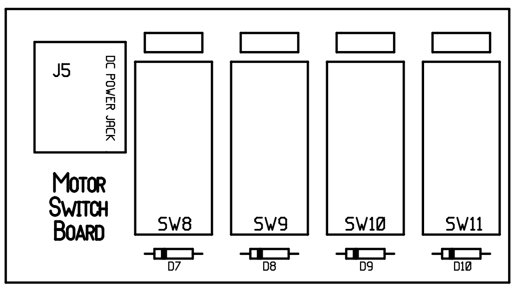


Figure 4.5: Motor Switch Board Component Placement

Figure 4.5 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.

2–☐ Diodes.

These diodes have black epoxy bodies. Polarity matters: Install the diodes with the banded end as marked on the circuit board. These diodes can be mounted in the horizontal position.

- ◯ **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.

To cut socket headers to length, repeatedly score between two pins using an exacto knife. Score on both sides of one division and then snap or cut the strip carefully with the diagonal cutters 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. These are often difficult to cut without some past experience, so don't hesitate to ask a TA if you have any trouble. You only have a limited number of the female header so do not waste them because they are very expensive and we do not have too many extra.

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

4.3 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 up to 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 4.6 is a component placement guide for the Expansion Board.

Assembling the expansion board is the next step before taking on the task of soldering the microprocessor board. It is important that good soldering technique be developed before moving on to the microprocessor board.

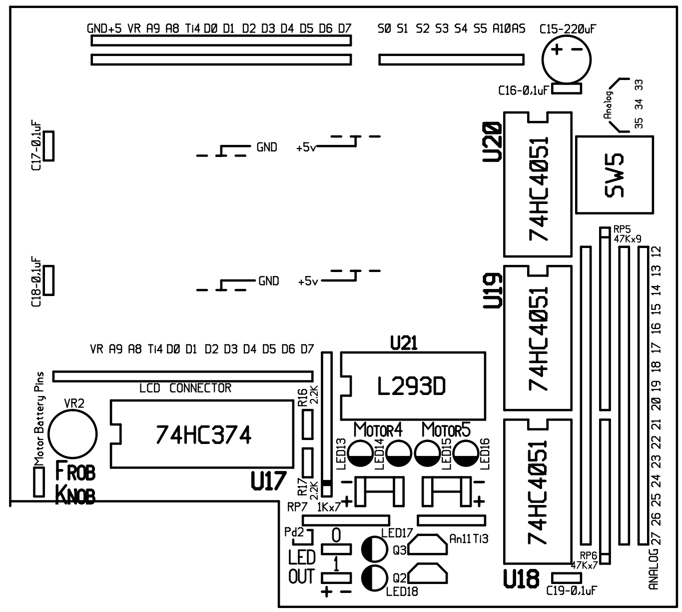


Figure 4.6: Expansion Board Component Placement

4.3.1 Assembling the Expansion Board

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

The side that has white component markings is the component side. The reverse is the solder side.

2–☐ Resistor Pack.

These resistor pack are all polarized resistor packs where the common terminal end is marked with a 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 shaded hole.*

The "caddy-cornering" technique of soldering the two end terminals first is helpful here. Solder one end of the terminals before soldering the remaining pins. Adjust the component such that it is straight and the pins are oriented properly, and then solder the other end of the resistor pack. After the resistor pack is straight and aligned, solder the middle pins. This will allow you to align the resistor pack and make it straight before all the pins are fastened.

○ **RP5**, 47k$\Omega\times$9, 10 pins, polarized, *marked "E47KΩ."* The marked end of the resistor pack goes through the shaded square hole.

○ **RP6**, 47k$\Omega\times$7, 8 pins, polarized, *marked "E47KΩ."* Mount on the component side so that the marked end of the resistor pack goes through the shaded square hole.

RP5 and RP6 are pull up resistors for the analog inputs. These are used so that the inputs to the analog ports don't float. They are also used as part of a resistor divider in some of the sensors used.

○ **RP7**, 1k$\Omega\times$7, 8 pins, polarized, *marked "E1KΩ."* Mount so that marked end of resistor pack goes in square hole on board.

3–☐ 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.

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. You may need to apply heat to the corner pins to press the socket down if it is not flush with the board.

○ **DIP21**–16 pins. The socket used for this DIP is different from the other sockets. The pins are more rounded, and the sockets are circular holes. The other sockets have more rectangular socket holes. These are gold plated sockets and are used for a better conduction pathway to the motor outputs.

○ **DIP17**–20 pins

○ **DIP18**–16 pins

○ **DIP19**–16 pins

○ **DIP20**–16 pins

4–☐ LEDs.

These LEDs are low powered 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, indicates motor 4 in reverse direction.

○ **LED14**–green, indicates motor 4 in forward direction.

○ **LED15**–red, indicates motor 5 in reverse direction.

- ◯ **LED16**–green, indicates motor 5 in forward direction.
- ◯ **LED17**–red, indicates LED out 1 is on.
- ◯ **LED18**–red, indicates LED out 0 is on.

5–☐ Trimpot.

Install **VR2**, 50kΩ, this is the FROB KNOB. The three pins of the potentiometer are polarized. They should look like they form a triangle. The triangle should correspond to the triangle of pins on the board.

6–☐ Resistors.

These resistors must be mounted in the upright position due to the tight spacing.

- ◯ **R16**, 2.2kΩ, *red, red, red.*
- ◯ **R17**, 2.2kΩ, *red, red, red.*

7–☐ Capacitors.

- ◯ **C16**–0.1μF, non-polarized
- ◯ **C17**–0.1μF, non-polarized
- ◯ **C18**–0.1μF, non-polarized
- ◯ **C19**–0.1μF, non-polarized

8–☐ Male Header Pins.

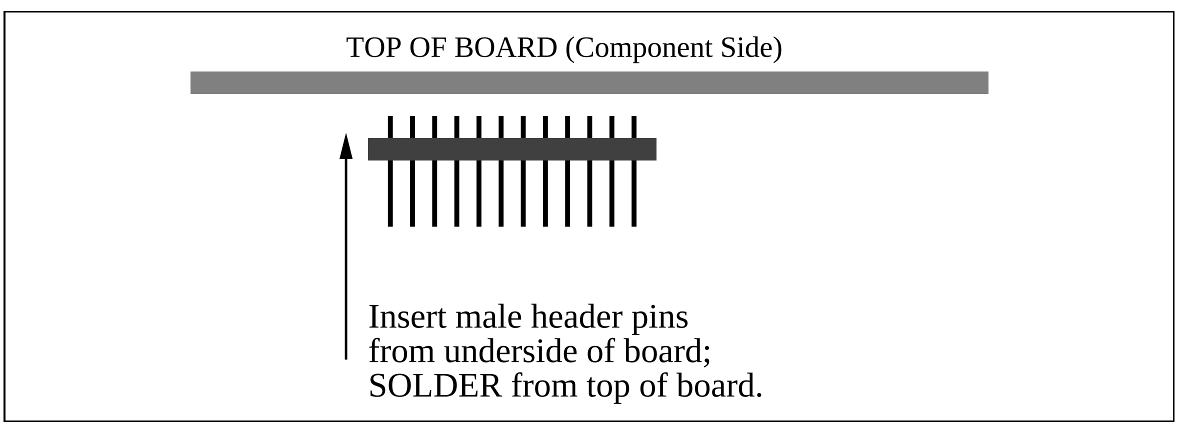


Figure 4.7: Mounting Method for Male Header Pins

The following steps deal with the interface pins which 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 4.7). 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 4.8 for pin placement.

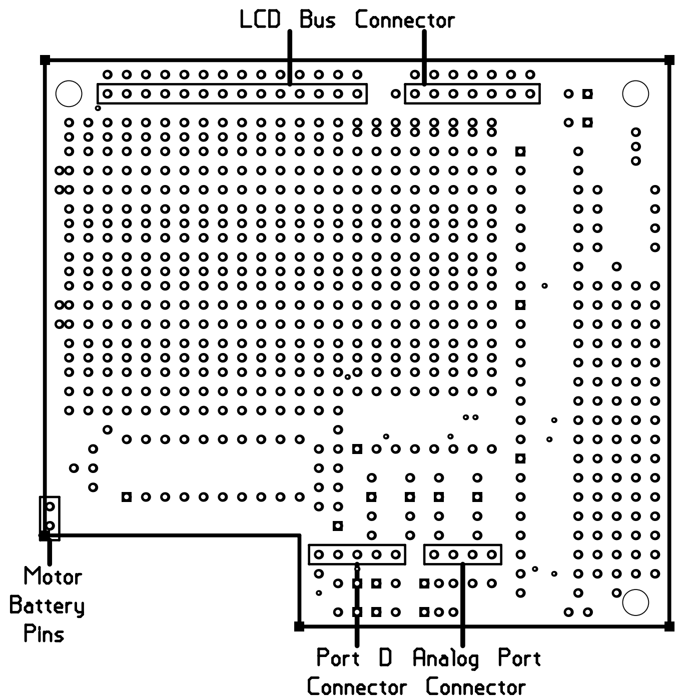


Figure 4.8: Expansion Board Male Header Pin Placement

- ◯ **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

9–☐ Transistors.

Install transistors **Q2** and **Q3** (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.

These transistors look identical to the DS1233 Econo Reset chip. Be sure you have the MPS2222A transistors and not the DS1233, or your board will not work.

10–☐ **C15**–220μF, *polarized.* Be sure to mount with correct polarity.

Leave some spacing between the board and the capacitor so the capacitor can be bent over. Before soldering the capacitor bend it sideways so it points to the left side of the board, and then solder.

11–☐ **Female socket headers.**

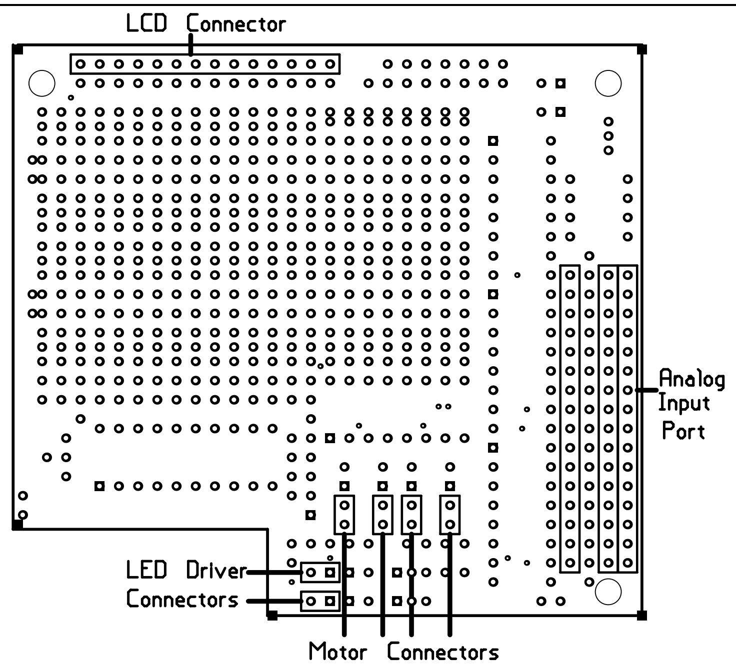


Figure 4.9: Expansion Board Female Header Mounting

Refer to Figure 4.9 to be sure of placement of these parts.

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 (so that the male header connects all three strips, perpendicular to the length of the female strips) into the socket to hold them at proper horizontal and vertical placement before soldering.

◯ Cut three 16-long strips. Before installing the Female header, make sure that the resistor packs RP5 and RP6 are correctly installed. Once the female header is in place, it is nearly impossible to replace the resistor packs. Install the **Analog Input Port**. A male header strip can be used at each end to align the vertical and horizontal placement of the female header. 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 4.9, at the top edge of the board.
- ◯ Cut six 2-long strips. Install **Motor Connectors** and **LED Driver Connectors**.

12–☐ DIP Switches.

Install **SW5**, 4-position DIP switch. Install so that numbers are on the outside edge of the board.

4.3.2 Testing the Expansion Board

As with the Microprocessor Board, run through the following checklist before mounting the chips into the Expansion Board.

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

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. This is the output latch used for controlling motor 4 and 5, and the two LED outputs. There are two additional outputs that can be jumpered to.
- ◯ **U18**–74HC4051. This is the analog muliplexer that controls analog outputs 20-27. It feeds the signal to analog 9.
- ◯ **U19**–74HC4051. This is the analog multiplexer that controls analog outputs 12-19. It feed the signal to analog 8.

- ◯ **U20**–74HC4051. This is the analog muliplexer that contols the Frob Knob, the DIP switches, and analog 33-35. It feeds the signal to analog 10.
- ◯ **U21**–L293D. Slide gold heat sink onto chip before installing in socket. The diagram for the mounting is shown in figure 4.10. The gold heat sink slides right onto the chip.

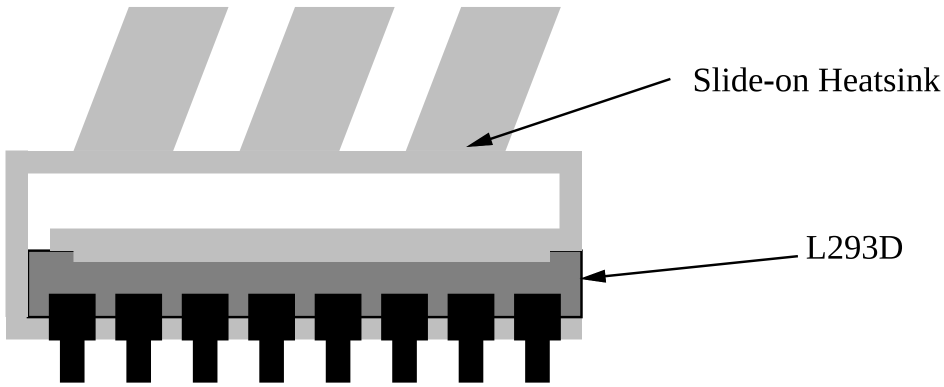


Figure 4.10: Motor Chip Stacking Technique

4.4 The LCD Display

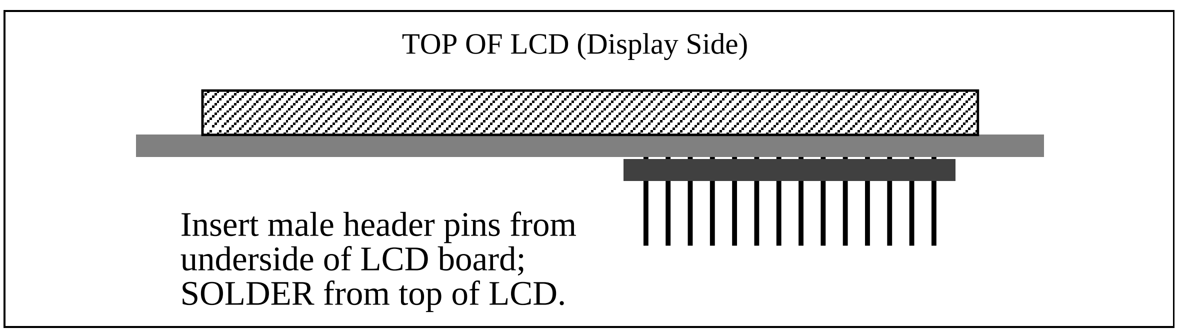


Figure 4.11: LCD Connector Mounting

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 4.11 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.

4.5 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.

4.5.1 Assembling the Microprocessor Board

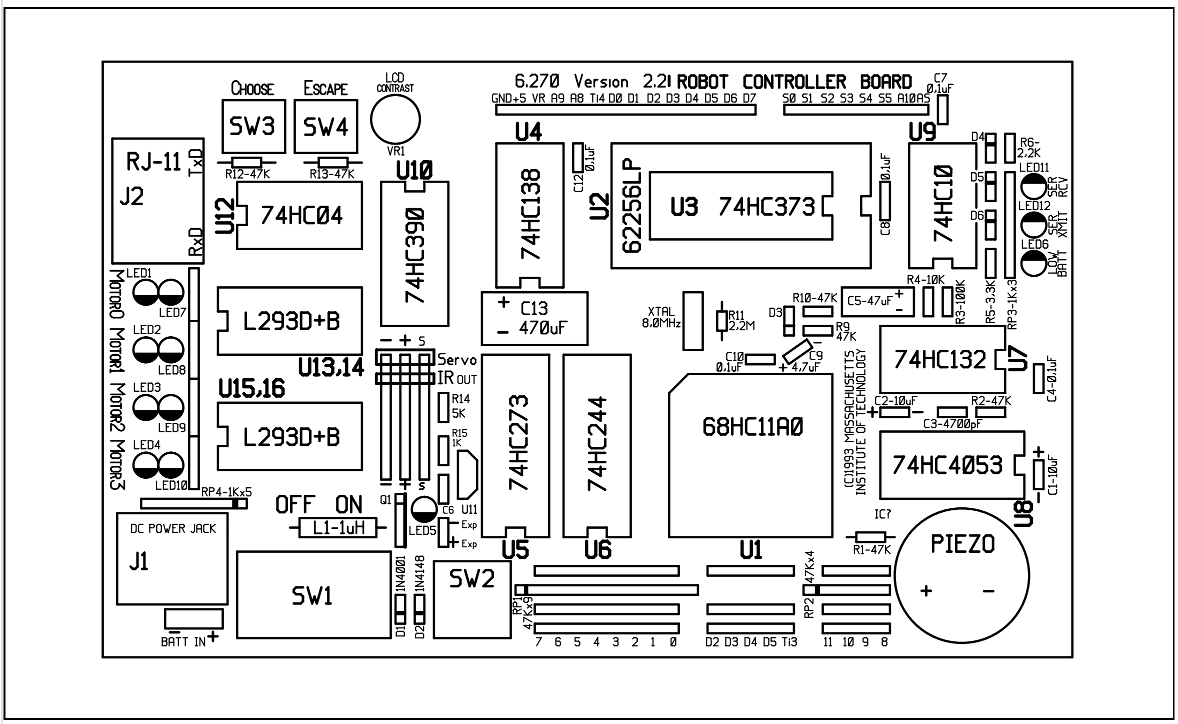


Figure 4.12: 6.270 Microprocessor Board Component Placement

Figure 4.12 illustrates the component placement on the microprocessor board.

In addition to checking off the boxes and circles after completion of a component, it may be helpful to fill in the component location in Figure 4.12.

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–☐ **Flat Resistors**

Begin by installing the resistors that lie flat along the board. Try to get the body of the resistor very close to the board.

3–☐ **R1**–47kΩ, *yellow, violet, orange,* flat mounting, lower right corner.

4–☐ **R11**–2.2MΩ, *red, red, green,* flat mounting, next to oscillator.

5–☐ **R12**–47kΩ, *yellow, violet, orange,* flat mounting, top left corner under SW3.

6–☐ **R13**–47kΩ, *yellow, violet, orange,* flat mounting, top left corner under SW4.

7–☐ **Non-polarized Capacitors.**

Next install the non-polarized capacitors. These are the smallest components on the board. After installing, solder and clip leads close to the board.

- ○ **C3**–4700 pF, *marked "472."*, above U8.
- ○ **C4**–0.1 μF, *marked "104."*, right edge next to U7.
- ○ **C6**–0.1 μF, *marked "104."*, above SW2.
- ○ **C7**–0.1 μF, *marked "104."*, top right corner above U9.
- ○ **C8**–0.1 μF, *marked "104."*, between U9 and U2.
- ○ **C10**–0.1 μF, *marked "104."*, just above 6811.
- ○ **C12**–0.1 μF, *marked "104."*, left of U2.

8–☐ **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 discernible on the unprinted solder side of the board.)

The "caddy-cornering" technique of soldering the two end terminals first is helpful here. Solder the two ends of the terminals before soldering the middle pins. This will allow you to align the resistor pack and make it straight before all the pins are fastened.

- ◯ **RP1**–47kΩ×9, 10 pins, polarized, *marked "E47KΩ."*, located at the bottom of the board.
- ◯ **RP2**–47kΩ×5, 6 pins, polarized, *marked "E47KΩ."*, located at the bottom of the board. You must cut off one pin which is the farthest from the marked end before mounting the component.

  RP1 and RP2 are pull-up resistors for the digital inputs and the analog inputs. Only the analog 10 and 11 pull-up resistors are connected. Since analog 8 and 9 are multiplexed inputs, a pull-up resistor is connected to each of the multiplexed inputs. If you use the analogs without the expansion board, you must jumper the pull-ups to analog 8 and 9.
- ◯ **RP3**–1kΩ×3, 6 pins, non-polarized, *marked "V1KΩ,"* top right corner.
- ◯ **RP4**–1kΩ×5, 6 pins, polarized, *marked "E1KΩ,"* bottom left corner.

9–☐ 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 socket for integrated circuit U4.

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.

The socket used for the first two DIPs are different from the other sockets. The pins are more rounded, and the sockets are circular holes. The other sockets have more rectangular socket holes. These are gold plated sockets and are used for a better conduction pathway to the motor outputs.

- ◯ **DIP13/14**–16 pins. There is only one socket for these two ICs. (Use the gold plated sockets)
- ◯ **DIP15/16**–16 pins. There is only one socket for these two ICs. (Use the gold plated sockets)
- ◯ **DIP4**–16 pins
- ◯ **DIP5**–20 pins
- ◯ **DIP6**–20 pins

- ◯ **DIP7**–14 pins
- ◯ **DIP8**–16 pins
- ◯ **DIP9**–14 pins
- ◯ **DIP10**–16 pins
- ◯ **DIP12**–14 pins

10–☐ 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.

11–☐ Ceramic Resonator.

Install **XTAL1**, 8 Mhz. ceramic resonator. This is a heat sensitive device and the soldering iron should not be in contact with any given pin for more than about eight seconds.

12–☐ Inductor.

Install **L1**, 1 uH, located below the OFF and ON markings on the board. The inductor looks like a miniature coil of wire wound about a thin plastic core. It is about the size of a resistor.

13–☐ 28-pin Socket.

You must first cut out the bar across the middle of the socket. Do this carefully by scoring the bar and then cutting it with wire cutters. Install on top of **U3**, with the notch marking as indicated. Solder.

14–☐ LEDs.

These LEDs draw less current than other LEDs in you kit. If you put the wrong LEDs in, your batteries will die out much faster than you expect.

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, indicates motor 0 in reverse direction.
- ◯ **LED2**–red, indicates motor 1 in reverse direction.
- ◯ **LED3**–red, indicates motor 2 in reverse direction.
- ◯ **LED4**–red, indicates motor 3 in reverse direction.
- ◯ **LED5**–red, indicates IR emitters are on.
- ◯ **LED6**–red, indicates Low Battery.
- ◯ **LED7**–green, Indicates motor 0 in forward direction.
- ◯ **LED8**–green, Indicates motor 1 in forward direction.
- ◯ **LED9**–green, Indicates motor 2 in forward direction.
- ◯ **LED10**–green, Indicates motor 3 in forward direction.
- ◯ **LED11**–green, Indicates serial receive.
- ◯ **LED12**–yellow, Indicates serial transmit, and is off when the board is in download mode.

15–☐ Resistors.

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

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.

- ◯ **R2**–47kΩ, *yellow, violet, orange,* upright mounting, above U8.
- ◯ **R3**–100kΩ, *brown, black, yellow,* upright mounting, right side above U7.
- ◯ **R4**–10kΩ, *brown, black, orange,* upright mounting, right side above U7.
- ◯ **R5**–3.3kΩ, *orange, orange, red,* upright mounting, right side of U9.
- ◯ **R6**–2.2kΩ, *red, red, red,* upright mounting, top right corner.
- ◯ **R9**–47kΩ, *yellow, violet, orange,* upright mounting, above 6811.
- ◯ **R10**–47kΩ, *yellow, violet, orange,* upright mounting, above 6811.
- ◯ **R14**–4.7kΩ, *yellow, violet, red,* upright mounting, center underneath IR out. Mislabeled "5k" on silkscreen.
- ◯ **R15**–1kΩ, *brown, black, red,* upright mounting, under R14.

16–☐ Polarized Capacitors.

All of these capacitors are polarized. Make sure that the lead marked (+) on the capacitor goes into the hole that is marked (+). Some of the tantalum capacitors are not marked. If the capacitor leads are not marked (+) or (−), the lead marked with a dot or bar is the (+) lead. Be careful. The electrolytic capacitors have a bar with a minus sign in them, and these are the negative terminals.

- ◯ **C1**–10 μF Tantalum, right side of U8.
- ◯ **C2**–10 μF Tantalum, above U8.
- ◯ **C5**–47 μF Electrolytic, above U7. Fold capacitor flat to the board before soldering.
- ◯ **C9**–4.7 μF Tantalum, above 6811.
- ◯ **C13**–470 μF Electrolytic. Fold capacitor flat to the board before soldering. You will need to extend the capacitor into the space next to the oscillator. This is a tight squeeze between the oscillator and the IC sockets.

17–☐ 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, right of SW1. This diode has a black epoxy body and fairly thick leads.
- ◯ **D2**–1N4148, left of SW2. This is a glass-body diode.
- ◯ **D3**–1N4148, under U2.
- ◯ **D4**–1N4148, next to U9.
- ◯ **D5**–1N4148, next to U9.
- ◯ **D6**–1N4148, next to U9.

18–☐ Female Socket Headers.

To cut socket headers to length, repeatedly score between two pins using the utility 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

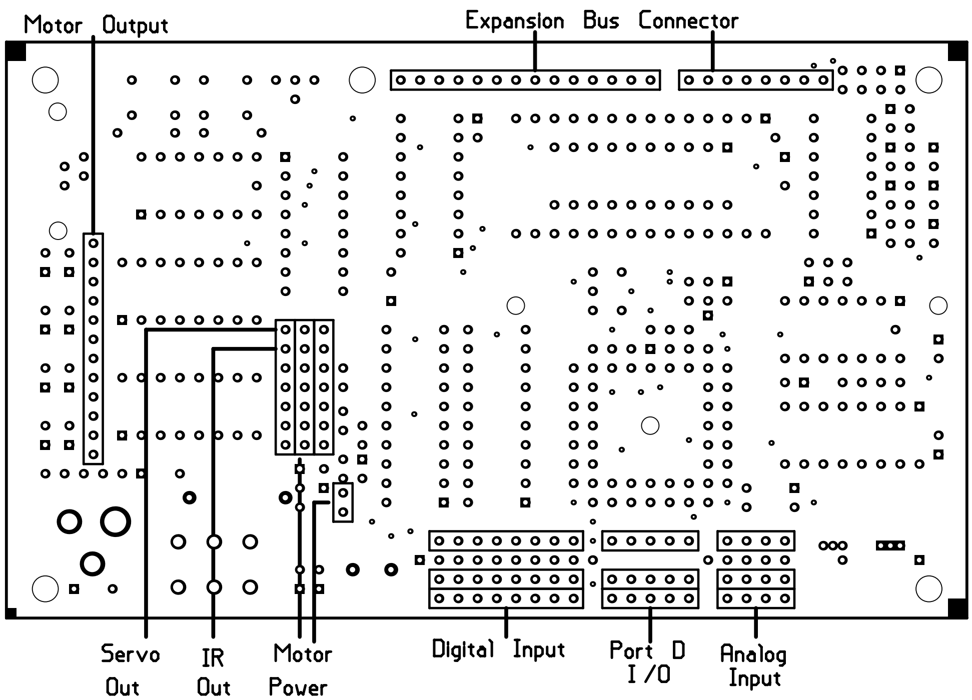


Figure 4.13: 6.270 Microprocessor Board Header Placement

header into the socket to hold them at proper horizontal and vertical placement before soldering.

Refer to Figure 4.13 for placement of these parts.

- ◯ Cut three 8-long strips, Install the **Digital Input** connector block. Before placing these header, make sure that RP1 is properly aligned. Once the female header is in place, removal of RP1 is nearly impossible, You may wish to solder all three strips simultaneously. The male pins can be put across the three strips at each end to make sure the female strips are aligned properly. Solder.
- ◯ Cut three 5-long strips. Install the **Port D I/O** connector block. You may wish to solder all three strips simultaneously. The male pins can be put across the three strips at each end to make sure the female strips are aligned properly. Solder.
- ◯ Use three 4-long strips. Install the **Analog Input** connector block. Before placing these header, make sure that RP2 is properly aligned. Once the female header is in place, removal of RP2 is nearly impossible, You may wish to solder all three strips simultaneously. The male pins can be put across the three strips at each end to make sure the female strips are aligned properly. Solder.
- ◯ Cut one 12-long strip. Install the **Motor Output** connectors. Solder.
- ◯ Cut one 8-long and one 14-long strip. Install the **Expansion Bus** connector. Solder.
- ◯ Cut three 7-long strips. Install the **Motor Power** connector. Solder.
- ◯ Cut one 2-long strip. Install the **Expansion power** connectors. Solder.

19–☐ PLCC Socket

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.

20–☐ Switches.

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

◯ **SW3**–miniature pushbutton switch. The switch is polarized and will fit snugly in one direction and not the other. Do not bend the leads too much, or force the switch in.

◯ **SW4**–miniature pushbutton switch. The switch is polarized and will fit snugly in one direction and not the other. Do not bend the leads too much, or force the switch in.

21–☐ Trimpot.

Install **VR1**, 50kΩ.

22–☐ U11. Reset Power Regulator – DS1233

This component looks like a transitor and is located with the expansion board IC's in your parts bin. DS1233 goes here with the rounded part towards the PLCC socket, as shown on the silk screen on the board.

This part looks a lot like the MPS2222A transistors. Be sure you install the DS1233 here, or your board will not work.

23–☐ Transistor

Install **TIP120** such that the metal backing is facing the expansion port power connector and the plastic is facing the DC power jack. This is a tight squeeze. Fold the transistor to the left so it lies flat above the inductor (L1). It is important that the heat sink on the transistor does not touch the edge of the Expansion Board.

24–☐ Piggy-Backing the L293 Chips.

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 4.14. 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 close as is possible, so that both press firmly against the heat sink. Be careful not to apply too much heat to the IC. Soldering the opposite corners will help secure the ICs in place and will make soldering the remaining pins easier.

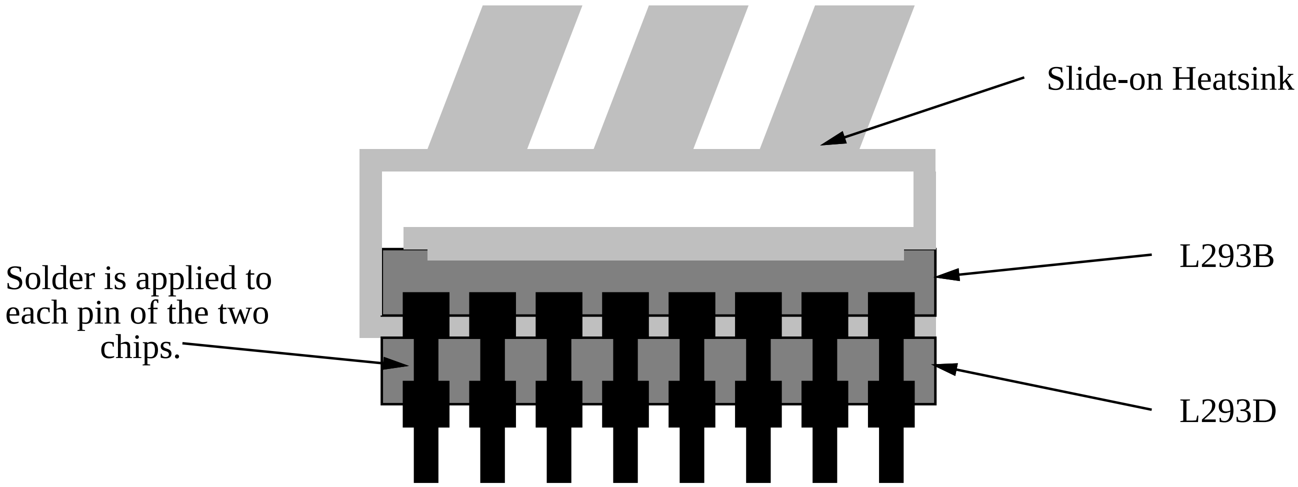


Figure 4.14: Motor Chip Stacking Technique

Repeat for the other pair of motor driver chips.

By piggy-backing the two chips, there is a parallel circuit for the motor current to flow through, so the amount of current that can be delivered to the motor is almost doubled to about 1.2 Amps.

25–☐ Power Jack.

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

26–☐ Phone Jack.

Install **J2**, modular phone jack. The phone jack is polarized, and should pace outward.

27–☐ Piezo Beeper.

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

28–☐ Battery pack.

- ◯ Clip connector on the battery pack and about 1/2" 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.

4.5.2 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 greater than 0. *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 slightly. 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 4.12 if necessary. Remove the 4AA batteries before installing the ICs.

- ◯ **U1**–68HC11A0 microprocessor. The brains of the board. A 68HC11A1 microprocessor may be substituted.
- ◯ **U2**–62256LP 32K static RAM where the memory is stored.

- ○ **U3**–74HC373 (already soldered to board). This is the latch that is used to access the memory locations.
- ○ **U4**–74HC138. This is the address decoder for memory mapping input and output latches
- ○ **U5**–74HC273. This is the output latch to the motors 1-4. Upon power up, the latch is cleared so all the motors are turned off when the board is turned on.
- ○ **U6**–74HC244. This is the tristate input latch which drives the bus for reading the digital inputs.
- ○ **U7**–74HC132. Schmitt trigger used for the serial communications with the downloading machine.
- ○ **U8**–74HC4053. Used to switch the RS232 TxD.
- ○ **U9**–74HC10. 3-input NAND used in the low-battery indicator.
- ○ **U10**–74HC390. Dual decade counter that divides the 2MHz clock to a 40kHz signal used in the IR emitters.
- ○ **U12**–74HC04. An inverter through which the motor outputs to the L293 are inverted. Because the L293s draws less processor current when all the inputs are high than when all the inputs are low the outputs are inverted so that when all the motors are off, all the inputs to the 293 are high. Another inverter is used to invert the signals in the IR circuitry.
- ○ **U13,14**–L293D + L293B motor driver assembly with heatsink
- ○ **U15,16**–L293D + L293B motor driver assembly with heatsink

4.5.3 Board Checkoff

You now have the components in place to check your board. Follow the instructions to check off your board. If there are any problems along the way, check the debug section (*In Works*), or find someone to help you.

1–☐ Turn the board off, and plug in the AA batteries. You should also plug the motor batteries into the board. When the motor batteries are not plugged in, the motor chips draw power from the processor batteries, and therefore reduce the lifetime of your AA cells. To extend the lifetime of your AA cells, always have your motor batteries plugged in.

2–☐ Attach the expansion board on top of the microprocessor board. Be careful not to bend any pins, and make sure that all the pins go in the correct sockets. Then put the LCD on the expansion board.

3–☐ When you turn on the board, the yellow light should be on. To get the board into download mode, you must turn the board off, and while holding down the escape button, turn the board on. The yellow light should flicker, and then be off. If this does not happen, check the debug section under startup. When the yellow light is off, the board is in download mode.

4–☐ When you hit the big red reset button, the yellow light should come on permanently. If the yellow light does not come on, then check the debug section under startup.

5–☐ In order for your board to work, the pcode must be loaded into the board. You need to do this only when there are new revisions of the pcode and when the RAM memory has been corrupted.

There are two types of downloading. The first download mode is the mode where the microprocessor load the pcode. This is done using the **init_bd** command. When the yellow LED is off, the processor is ready to accept new assembly code.

To download the pcode to the board you must:

- Plug the serial cable into the board. The green LED should be on whenever the board is connected to the host computer. If the green LED is not on, check the debug section on serial problems.
- Turn on the board. (SW1)
- Hold down the "CHOOSE" button (SW3) while pressing the red reset button (SW2). Release the reset button. Watch for the yellow serial transmit light to extinguish. Release the "CHOOSE" button. Your board is now in pcode download mode.
- You need to download the pcode to the board. The command to download will be different, depending on the machine you are using. On the Athena workstations you must **add 6.270** and then type **init_bd** at the prompt. The yellow LED must be off for downloading to occur.
- You should get the following response when downloading the pcode:

```
6811 .s19 file downloader.  Version 6.1  16-Nov-91  rsargent@athena.mit.edu
Downloading 256 byte bootstrap (229 data)
```

  and a bunch of dots should appear on the monitor and the yellow and green LEDs should begin to flicker. This flickering lets you know that there is communication between the board and the host computer. If the response is a different, check the debug section, on downloading or serial problems.

- Once the pcode is loaded into the board, press the reset button, and the board should beep and on the LCD should be the message:

  ```
  Interactive C
  V 2.71 1/4/93
  ```

  or something similar. You may need to adjust your LCD contrast to see the messages on the LCD. Do this by turning the variable resistor VR1.

The second download mode is through IC when you download your code or the IC libraries. The yellow light must be on for this download to occur. When you press reset, the yellow light should come on.

6–☐ When the pcode is loaded into the board, you can use the IC program. This can be done by simply typing **ic** at the prompt when the board is connected to the host computer. The IC program will download several libraries to the board.

7–☐ The next step is to use the test program to make sure that all the outputs and inputs are working. Before you do this, you must build a simple digital sensor for testing the input ports.

8–☐ After you are in the IC program, you will need to load the test code into the board. To do this, at the **C>** prompt type **load testboard.c** to load in the test code. This program is designed to help you become familiar with the board, and where things are located.

9–☐ The following tests will be performed:

- Check Motor Outputs.
- Check Digital Inputs.
- Check Analog Inputs.
- Check Dip Switches.
- Check Frob Knob.
- Check LED outputs.

You can advance through the menu by using the ESC button and the CHOOSE BUTTON. To advance to the next test push the ESC button. When checking the analog and digital ports push the CHOOSE button to advance the port number.

10–☐ You should test each of the digital and analog ports using a digital switch. The analog readings for an open switch should be around 255 since the inputs are connected to a pull up resistor. When the switch is closed, the analog reading should yield a low number below 50. The digital ports should show a 1 when the switch is closed and a zero when it is opened.

4.5.4 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 strips of double sticky tape to attach the AA battery pack to board. Make sure that the wire in the AA holder does not come in contact with any of the protruding leads on the underside of the board. Many problems can occur is the wire in the battery pack shorts adjacent leads on the board.

After the Microprocessor Board, the Expansion Board, and the LCD 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.

You should then bring your boards to one of the organizers or a TA to get it checked off. The checkoff procedure will require that you have some knowledge of the location of the ports and we expect you to try out the test code before checkoff.

4.6 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 a divide by 50 counter (the 74HC390 chip) and a power transistor (TIP120) 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.

4.6.1 Assembly Instructions

Figure 4.15 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.

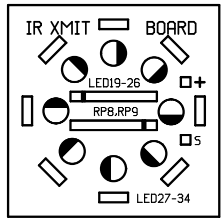


Figure 4.15: Infrared Transmitter Component Placement

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. These resistor packs are blue, and have 6 pins, but you will need to cut off one of the pins. Do this carfully. Do not cut the resistor pack, just the last pin labeled with a 6.

- ○ **RP8**–33Ω×4
- ○ **RP9**–33Ω×4

2–☐ Visible LEDs.

The visible LEDs used on the infrared transmitter board have *red lenses*. They should look similar to the low powered LEDs. These will be in the parts bin in the upper right hand bin. *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.

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

- ○ **LED23**–red lens, red element
- ○ **LED24**–red lens, red element
- ○ **LED25**–red lens, red element
- ○ **LED26**–red lens, red element
- ○ **LED27**–red lens, red element
- ○ **LED28**–red lens, red element
- ○ **LED29**–red lens, red element
- ○ **LED30**–red 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 red wire to the middle pins of a three-pin male connector and the black wire to one of the outside pins. Use guideline shown in Section 4.7.

The infrared transmitter plugs into the connector labelled IR OUT on the Microprocessor Board (see Figure 4.13), with the red lead inserted into middle (power) strip and the black lead plugged into the right hand (signal) strip. The transistor acts as a switch between the signal lead of the IR emitter and ground so no current may flow when the signal to the base of the transitor is off. If the connector is plugged in backwards, the IR LED will always be on, and the transmitter will get very hot.

4.7 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.

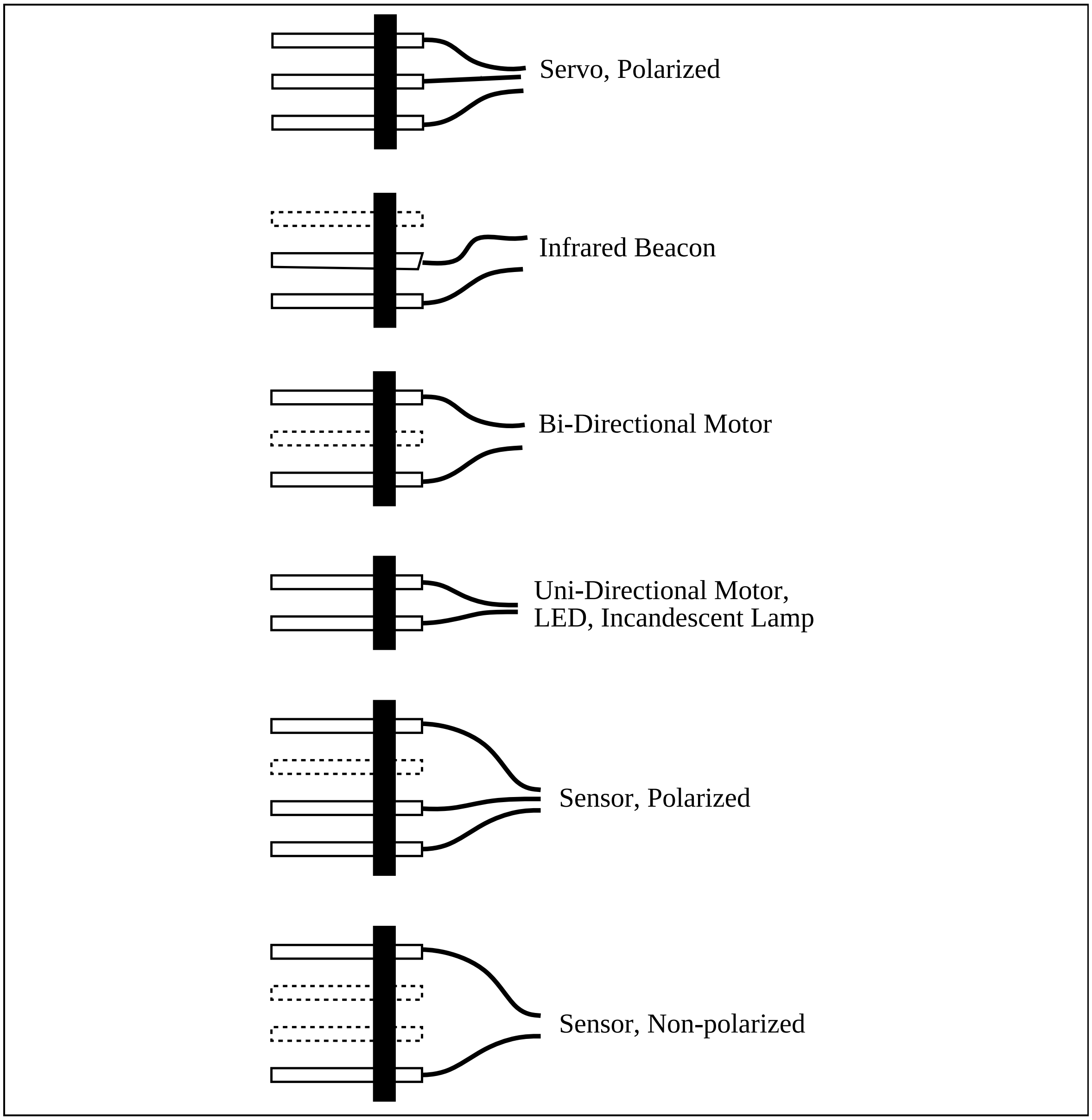
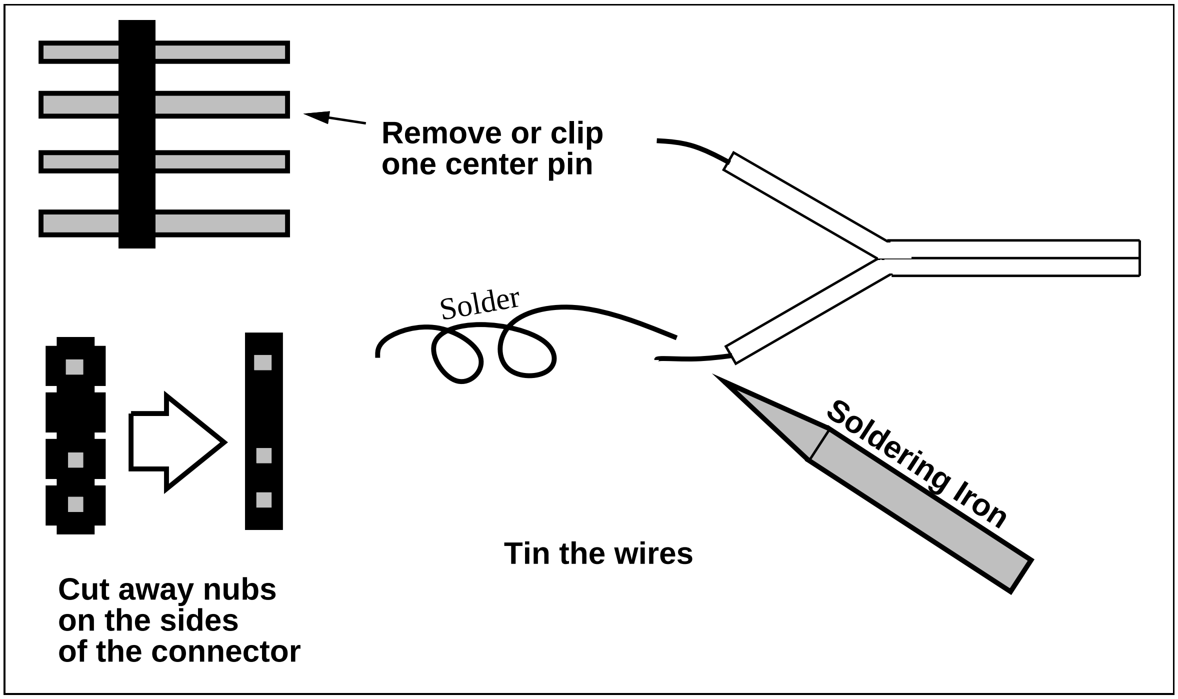
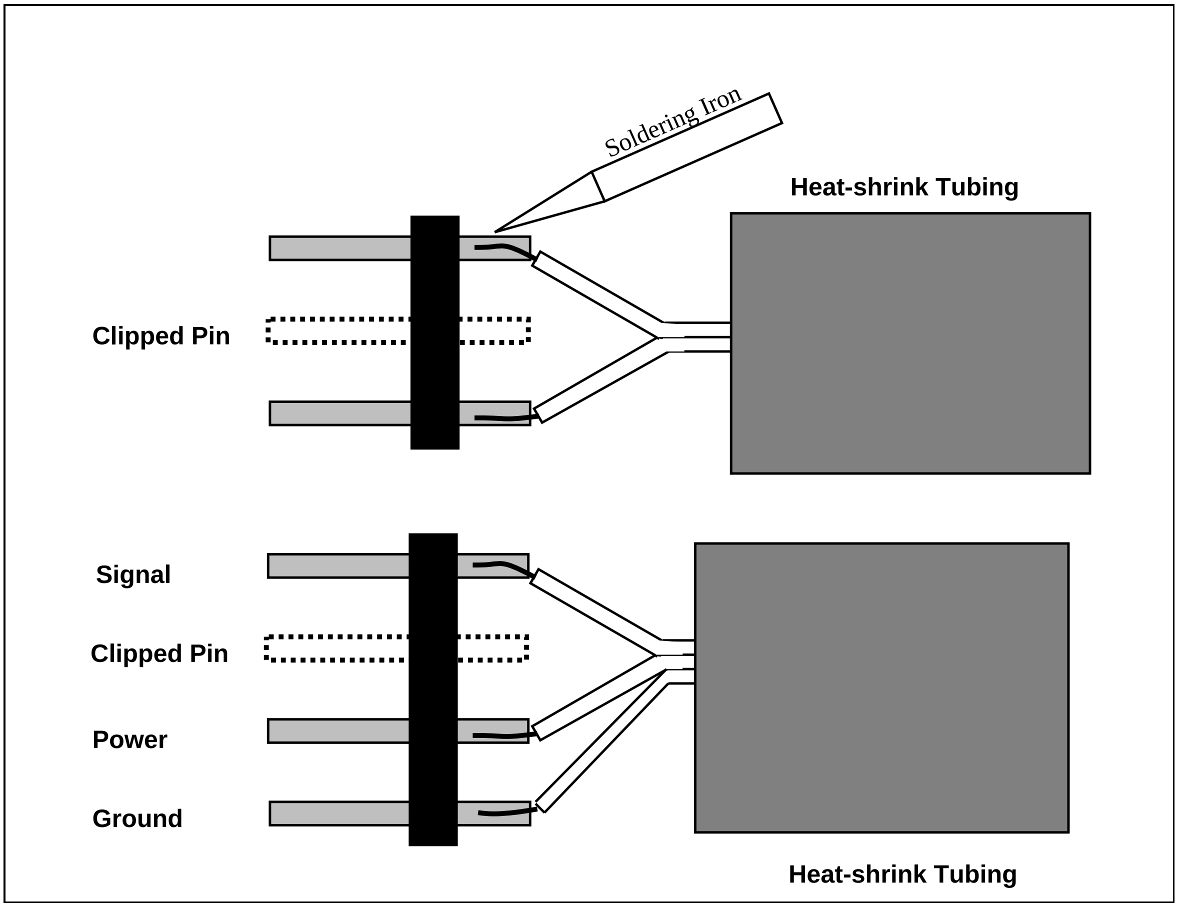


Figure 4.16: Standard Connector Plug Configurations



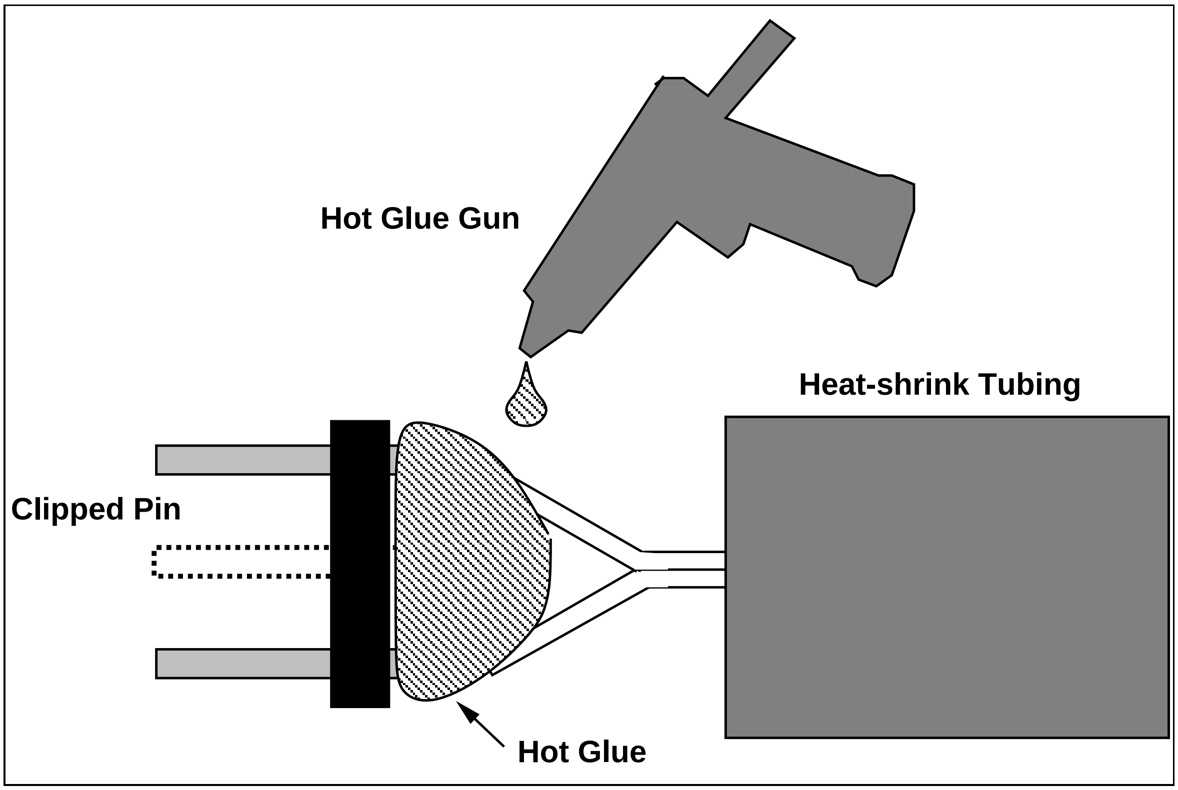
Strip a small amount of insulation off the wire ends. Tin the wire ends by applying a thin coat of solder to them.

Figure 4.17: Step One of Connector Wiring



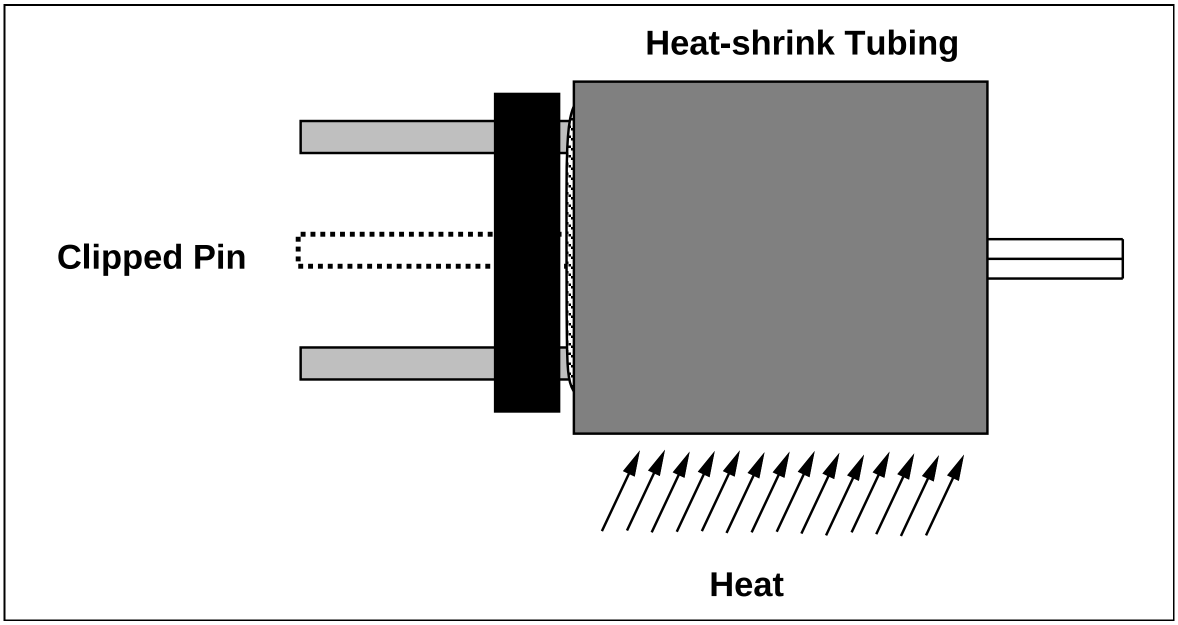
Cut the male connector to size.This example shows a plug that can be used to wire a motor and the bottom a polarized sensor. Cut $\frac{1}{2}$ inch length pieces of 1/4" heat-shrink tubing. Solder the wires to the connector, being careful not to let the heat from the soldering iron shrink the tubing.

Figure 4.18: Step Two of Connector Wiring



Use hot glue to strengthen and insulate the connection. Be careful not to use too much glue, or else the connector will be too fat. While the glue is cooling off, you should slide the heat shrink tubing over the glue and flatten the glue while it is till soft.

Figure 4.19: Step Three of Connector Wiring



Slide a piece of heat-shrink tubing over connections. Shrink using heat gun, flame from a match or lighter, or the side of a soldering iron. A heat gun provides by far the best results, and you may want to come to lab to use one.

Figure 4.20: Step Four of Connector Wiring

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 4.16 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 4.17 through 4.20 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. Too much glue or heat shrink tubing will make the connector fat, and later you will not be able to connect several connectors side by side. You will want to keep the connectors small and sturdy.

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.

4.8 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.

4.8.1 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 axle 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 a lego axle be installed on the motor shaft. In general, this is the most useful motor configuration. You will probably mount an eight-tooth LEGO gear on the shaft. Other possibilities include mounting a LEGO pulley wheel or a larger diameter gear on the axle.

Attaching a Shaft 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.

- ◯ You should give one of the organizers a small piece of LEGO axle so that we can drill a hole in it. The hole in the axle will be the size of the motor shaft. The axle should fit snugly over the motor shaft.

- ◯ Place a drop of super glue around the outer area of the motor shaft, farthest away from the motor housing as shown in Figure 4.21. *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.

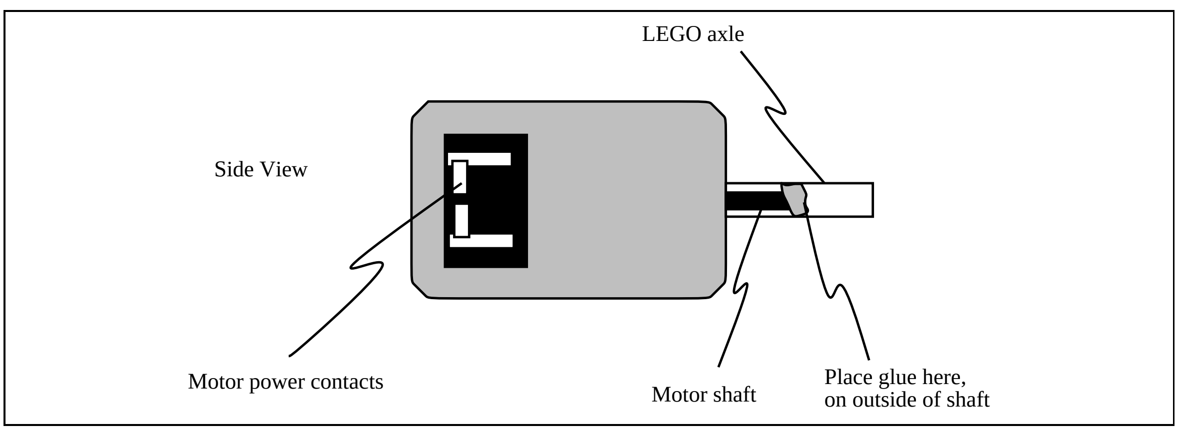


Figure 4.21: Motor Housing with Tubing

- ◯ *This is the most crucial step.* Slide the axle over the motor shaft and wipe off any excess glue with a paper napkin. Make sure that the glue does not get into the motor housing assembly.

Attaching the Polaroid Motor to a LEGO Base

The purpose of this step is to 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 4.22. 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.

- ○ Assemble the jig as shown in Figure 4.22. A second 2×4 plate will mounted to the motor.
- ○ Cut off the LEGO nubs from the second 2×4 plate that will be connected to the motor. Place a piece of double-sided sticky tape on the plate.
- ○ 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. Remove the paper from the tape and secure the motor onto the tape.
- ○ With a second 2×4 plate, cut off the bottom ridges so that it is a flat piece with just the nubs, or use a 2×4 piece of grey plate. Attach a piece of double-sided sticky tape to the bottom of the piece.
- ○ Make a second jig as shown in figure 4.23 out of four 2×4 bricks, two 2×4 plates, and two 6×8 plates that sandwich the motor in place.
- ○ Attach the piece to the motor such that the motor can be locked into place when another piece is attached across the top of the motor. It is probably a good idea to lock in your motors in a similar fashion when building your machine.

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.

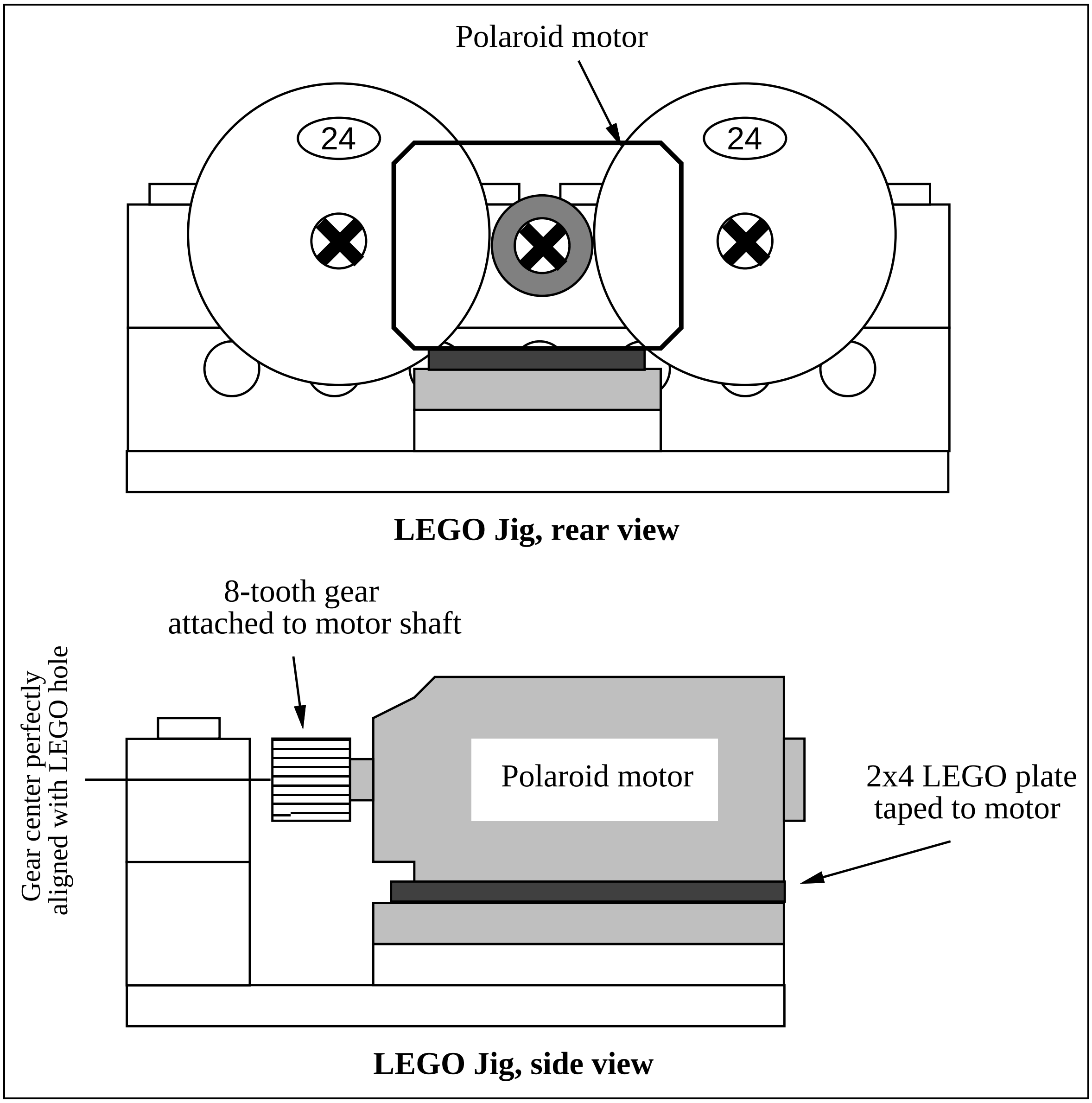


Figure 4.22: LEGO Jig for Mounting Polaroid Motor

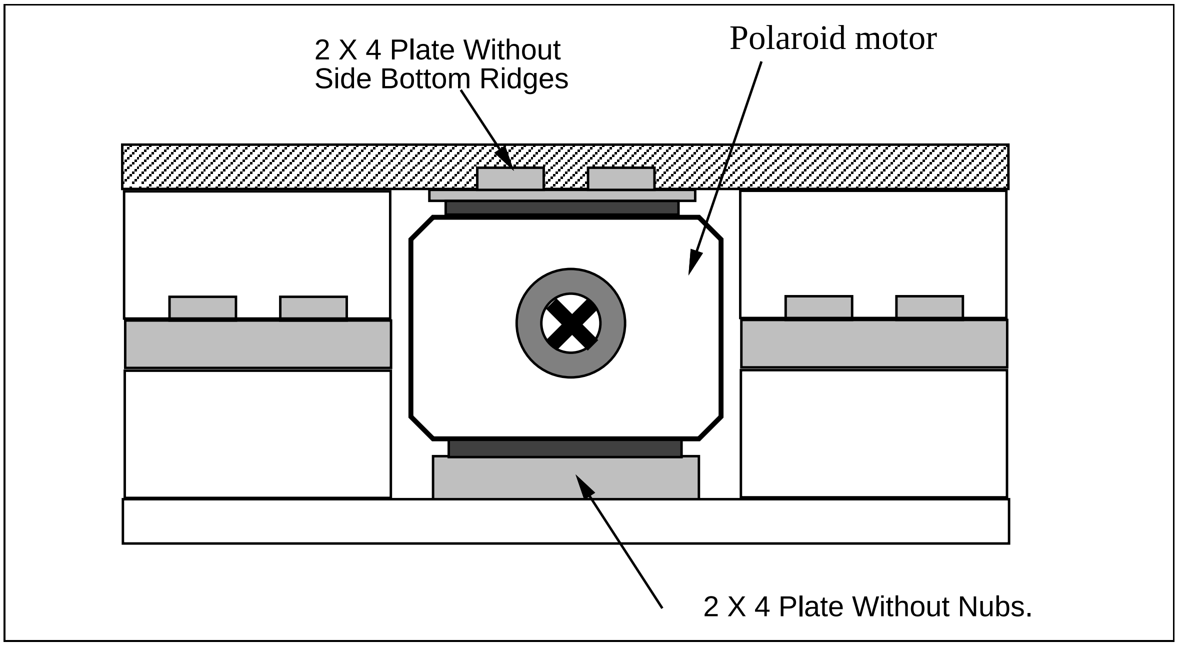


Figure 4.23: LEGO Jig for Mounting Polaroid Motor

- ◯ Motor plugs may be wired for bidirectional or unidirectional use, as shown in Figure 4.16. (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 4.17 through Figure 4.20, wire the motor plug. Polarity does not matter since the plug may be inserted into a motor power jack in either orientation.

4.8.2 Servo Motor

Figure 4.24 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.

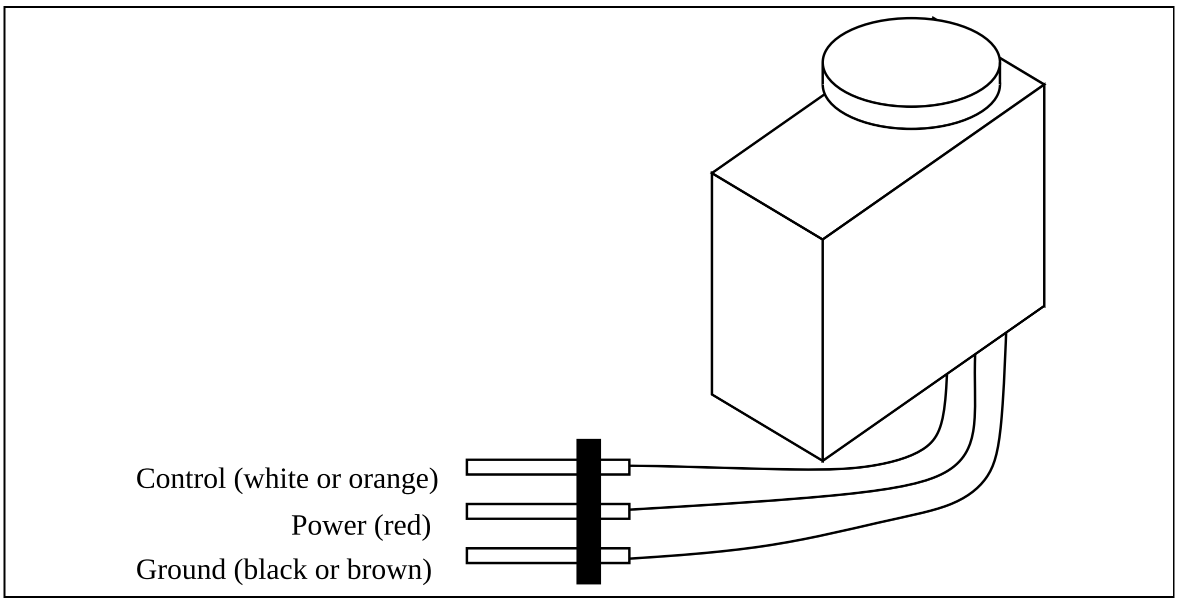


Figure 4.24: Servo Motor and Integral Connector Plug