Electronic Assembly Manual

ELEC 201: Introduction to Engineering Design

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This manual[1] introduces electronic assembly, provides step-by-step instructions for the assembly of the ELEC 201 RoboBoard, and gives wiring and other information for the electronic hardware used in the course. We assume the reader has no prior electronics background. This document is organized into the following sections:

1. Electronic Assembly Technique
2. RoboBoard Assembly Instructions
3. Battery and Charger System
4. Infrared Beacon
5. Cable and Connector Wiring
6. Sensor Wiring
7. Motor Mounting and Wiring

All of this information, except for Section 2, is also in the Course Notes on the ELEC 201 web site.

[1]Edited 8/02 JFY; printed August 7, 2002.

1 Electronic Assembly Technique

If there are places in life where neatness counts, electronic assembly is certainly one of them. A neatly-built and carefully soldered board will perform well for years; a sloppily- and hastily-assembled board will cause ongoing problems and failures. While building your board your team should switch tasks frequently to avoid fatigue. Mistakes are very easy to make when you are tired, and can be difficult and costly to fix.

The basics of electronic assembly are covered here: proper soldering technique, component mounting technique, and component polarities. Following these instructions and guidelines should make future debugging less frustrating.

1.1 Soldering Technique

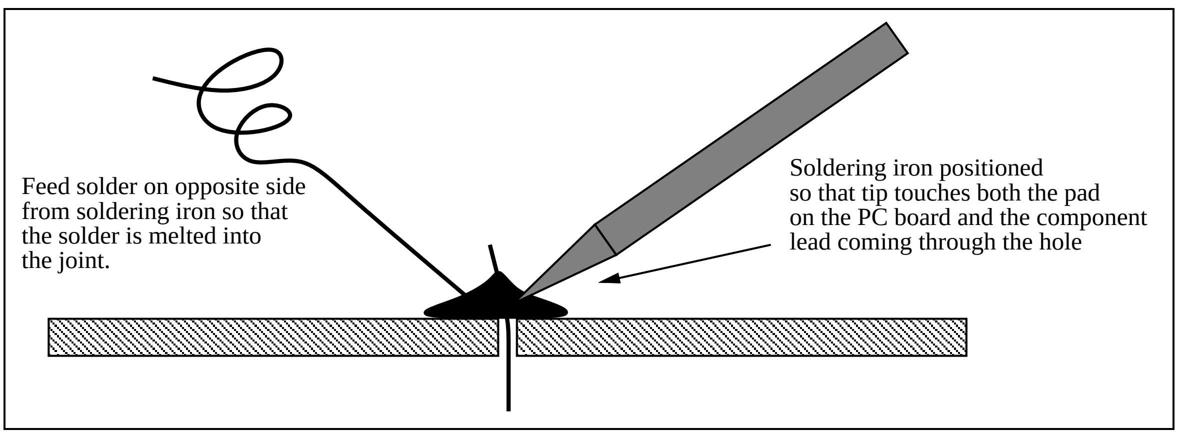


Figure 1: Proper Soldering Technique

Figure 1 shows proper soldering technique: the tip of the soldering iron is inserted into the joint such that it touches both the lead being soldered *and* the surface of the PC board. Use the side of the tip when soldering. The increased surface area will transfer heat more quickly.

Then solder is applied into the joint, *not* to the iron directly. 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. Once solder flows into the joint, lift the soldering iron tip straight up, so that the finished soldered joint appears cone-shaped. This also tends to wipe excess solder along the part of the component lead that will be cut off.

Figure 2 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).

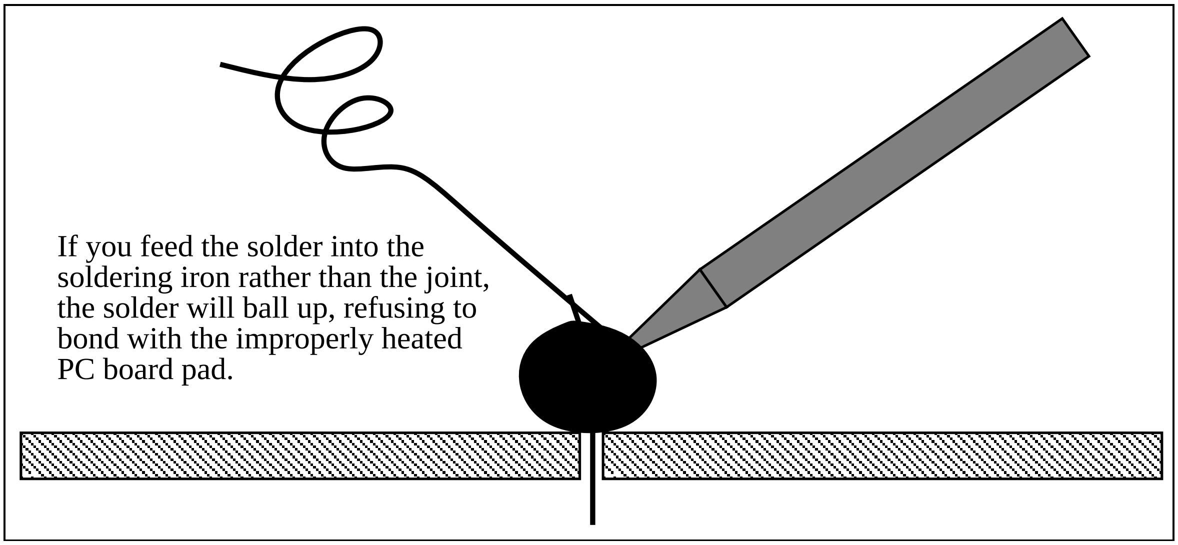


Figure 2: Improper Soldering Technique

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 assembly skills:

1. Keep the soldering iron tip away from everything (including hair) except the point to be soldered. The iron is *extremely* hot and can easily damage parts, cause burns, or even start a fire. The soldering iron should be kept in its holder when not being held.

2. For cleaning off and tinning the tip, a damp sponge should be on hand. Soldering is basically a chemical process, and even a small amount of contaminants can prevent a good joint from being made. "Damp" means wet the sponge and squeeze out all excess moisture.

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 by wiping it on the damp sponge and then immediately melting some fresh solder onto it. Then wipe it on the sponge again. The tip should be shiny and coated with solder.

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

4. The tip of the iron is nickel-plated and therefore should not be filed; this would remove the protective plating on the tip.

5. A *cold solder joint* is a joint containing an air bubble or other impurity that entered as the joint was 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 connections. To fix such a joint, apply the tip (and perhaps a *very* small amount of solder) at the joint until the solder re-melts and flows into the terminal. If a cold solder joint reappears, remove solder with desoldering wick, and re-solder the joint.

6. Do not hold the iron against the joint for longer than 3-4 seconds, since many electronic components can be damaged by prolonged or excessive heat. Too much heat can also cause the traces on the printed circuit board to peel up or even burn off.

   Components that are particularly sensitive to heat damage include diodes, integrated circuits, LEDs, transistors and voltage regulators.

1.2 Desoldering Technique

It takes about ten times as long to desolder a component as it does to solder it in the first place. This is a good reason to be careful when assembling boards. However, errors will inevitably occur, and it is important to know how to fix them. The primary reasons for performing desoldering are removing an incorrectly-placed component, removing a defective component, and removing solder from a cold solder joint to try again with fresh solder.

The most common methods for removing solder are desoldering pumps and desoldering wick. The ELEC 201 lab kit includes a desoldering pump and desoldering wick as standard equipment.

To use the desoldering wick, simply place the wick between the soldering iron and the excess solder, being very careful not to apply heat for too long.

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. This takes a little practice to get right, even for experienced builders.

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 the Teflon tip should not be jammed 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. You may need to open the desoldering pump occasionally and empty out accumulated solder.

1.3 Component Types and Polarity

A variety of electronic components will be in use when assembling the boards. The following section provides a brief introduction to these components – how to properly identify and install these parts when building the boards.

1.3.1 Component Polarity

Polarity refers to the fact that many electronic components are not symmetric electrically. Reversing a polarized component in a circuit will result in very different, often undesired effects. For example, passing current through an LED in one direction (forward biased direction) will cause the LED to light up. Reversing the LED will stop current flow up to a certain, often much higher, voltage. Incorrectly mounted polarized devices will not work, and in some cases will be damaged or may damage other parts of the circuit. The following components are always polarized:

- all diodes (LEDs, standard diodes, zener diodes)
- transistors and voltage regulators
- integrated circuits

Capacitors are an interesting case, because some are polarized while others are not. As a general rule, large capacitors (values 1 μF and greater) are usually polarized, while smaller ones are not.

Resistors are not polarized, meaning it does not matter in which direction electricity flows through them. However, it is usual to mount them so their markings all face the same way to make it easier to work on the circuit. (It is also prettty.) The RoboBoard also contains *resistor single-in-line packages* (SIPs), and these have non-symmetric internal wiring configurations, making them polarized from a mounting point of view.

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

Resistors Individual resistors are small cylindrical devices with color-coded bands indicating their value (how to read color-coding is explained in Figure 10). Most of the resistors in the ELEC 201 kit are rated for $\frac{1}{8}$ watts, which is a very low power rating; hence they are very small devices. A few resistors are much larger: A 1 watt resistor has a large cylindrical shape, while a 5 watt resistor has a large, rectangular package.

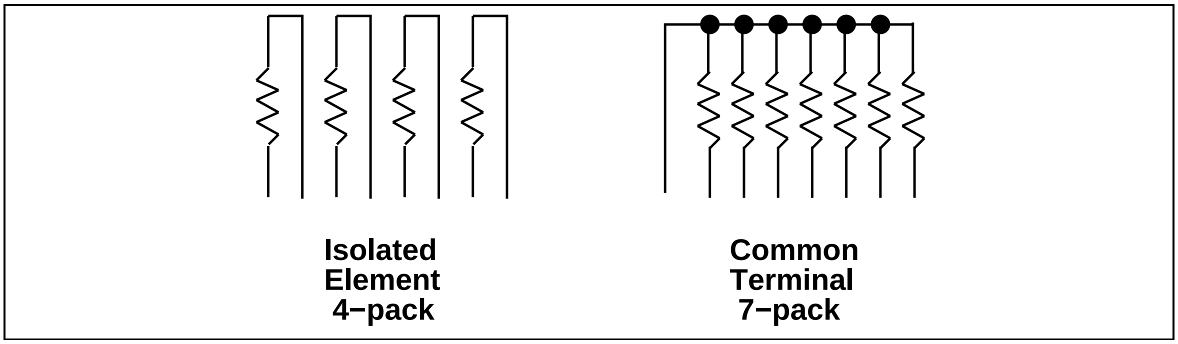


Figure 3: Resistor Pack Internal Wiring

Resistor Packs Resistor packs (or packages) are flat, rectangular packages with four, six, eight, or ten leads. There are two basic types of resistor packs:

Isolated Element. Discrete resistors; usually three, four, or five per package.

Common Terminal. One end of each resistor is tied to a common pin, and the other end is free. The package may contain from three to nine resistors.

Figure 3 illustrates the internal wiring for each style of 8-pin resistor pack.

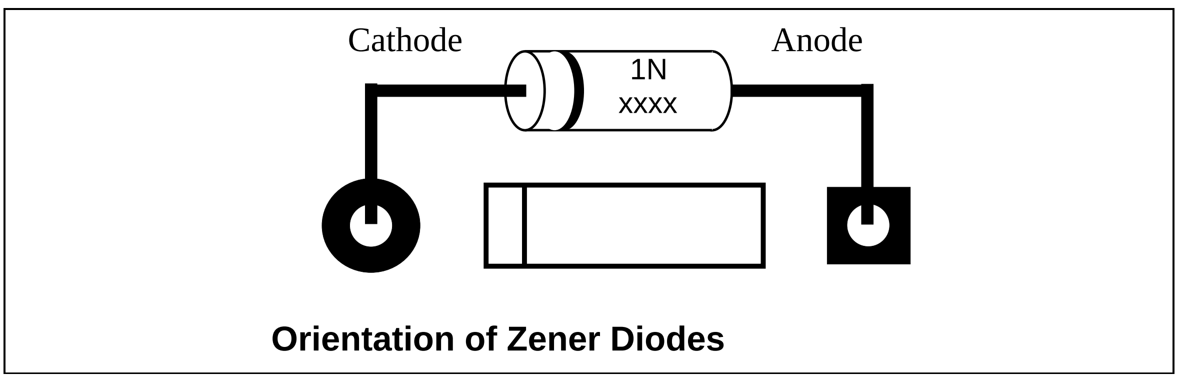


Figure 4: Zener Diode Orientation

All diodes (including the zener diodes and standard diodes used on the RoboBoard) 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. Zener diodes add a twist: at a particular value of reverse polarity voltage (called its "zener," or avalanche voltage), the diode conducts again. This functionality is useful in the design of voltage regulators and (the RoboBoard use) for precise over-voltage protection.

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*, and is always inserted into Pin 2 (the end *opposite* the square pad on the RoboBoard).

Figure 4 shows a the correct orientation of the 1Nxxxx (where "xxxx" is a four digit number denoting the specific diode type) zener diodes used on the RoboBoard and on the battery charger board.

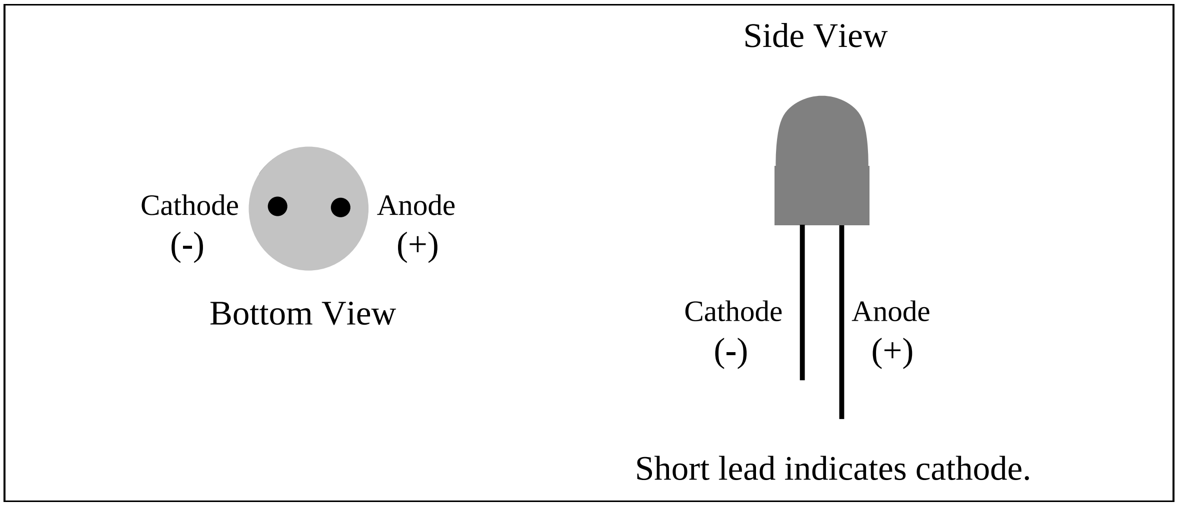


Figure 5: Identifying LED Leads

LEDs *LED* is short for "light-emitting diode." 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. The latter case is the one present in the ELEC 201 kit. Figure 5 shows a typical LED package.

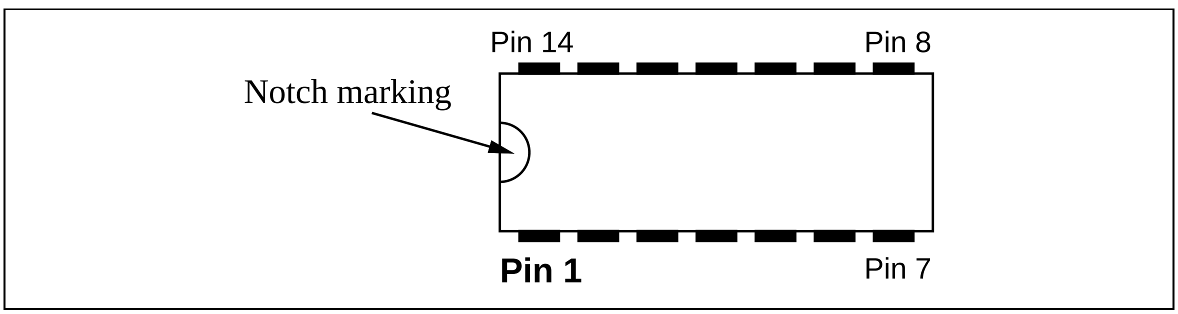


Figure 6: Top View of 14-pin DIP

Integrated Circuits Integrated circuits, or ICs, come in a variety of package styles. Two common types, both of which are used in the RoboBoard design, are called the *DIP* (for dual-inline package), and the *PLCC* (for plastic leadless 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. After pin 1 is identified, pin numbering proceeds sequentially in a counter-clockwise direction around the chip package, when looking from the top.

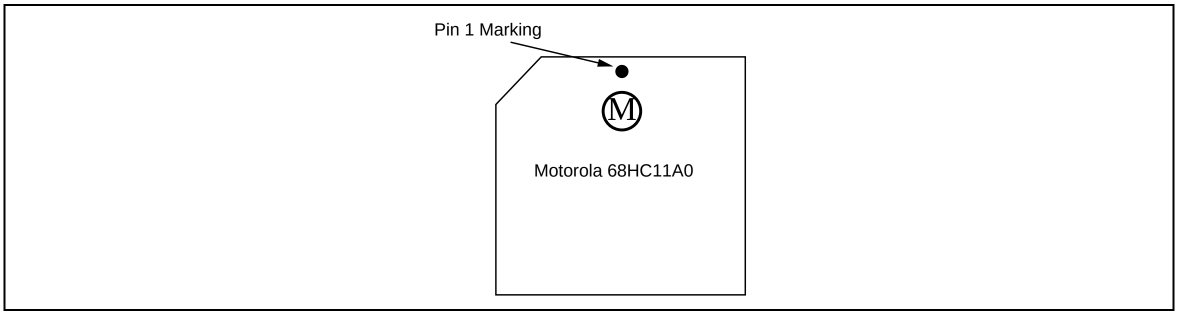


Figure 7: Top View of 52-pin PLCC

Figure 6 shows the typical marking on a DIP package. Figure 7 is a drawing of the PLCC package.

DIP sockets All of the integrated circuits (ICs) on the RoboBoard (except the voltage regulators) are socketed. This means that they are not permanently soldered to the ELEC 201 RoboBoard, but installed in sockets. Components that are socketed can be easily removed if they are damaged or defective. Sockets are also used to avoid the need to solder directly to ICs, reducing the likelihood of heat damage.

Do not place the components into the sockets before you mount the sockets onto the board!

DIP sockets have similar markings to those found on the component that they hold. 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 sockets *are* polarized, however: a PLCC chip can only be inserted into the socket the "correct" way. Of course, this way is only correct if the socket is mounted right in the first place. When assembling the ELEC 201 RoboBoard, a marking printed onto the board indicates the correct orientation of the PLCC socket.

Capacitors Several different kinds of capacitors are made, each having different properties. There are four different types of capacitors in the ELEC 201 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 never 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 very large values (100 μF and up). They are usually polarized except for special cases; all the electrolytics in the ELEC 201 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 capacitors. Unfortunately they are decidedly more expensive. Tantalum capacitors are always polarized.

- **Ceramic.** Most often the smallest capacitors in both size and value. Their values are most often measured in picofarads. Ceramic capacitors are never polarized.

As indicated, some capacitors are polarized and will therefore require special attention when mounting. This is very important.

On the ELEC 201 boards, all polarized capacitor placements are marked with a plus symbol (+). The capacitors themselves 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 (+). The (+) hole is also the hole with the square pad. Some capacitors may not be marked with (+) and (−) symbols. In this case, the positive (+) lead will be marked with a dot or a vertical bar.

Polarized capacitors mounted backwards won't work. In fact, they often **overheat and explode**. They should be mounted carefully. When in doubt, ask.

Inductors The inductors used in the ELEC 201 kit are a miniature coil of wire wound around a small ferrite core. They are about the size of a pencil eraser. Some inductors are coated with epoxy and look a lot like resistors. Others are big bulky coils with iron cores. Inductors usually are not polarized.

Transistors and Voltage Regulators The transistors and voltage regulators used in the ELEC 201 kit are small, three-wire devices. They stand out since they are the only three-wire devices used. Transistors and voltage regulators are polarized.

The table shown in Figure 8 summarizes this discussion with regard to polarity issues.

1.4 Component Mounting

When mounting components, the general rule is to try to mount them as close to the board as possible. The main exceptions are components that must be spaced away from the board before being soldered; some resistors fall into this category.

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 (no light)
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 8: Summary of Polarization Effects

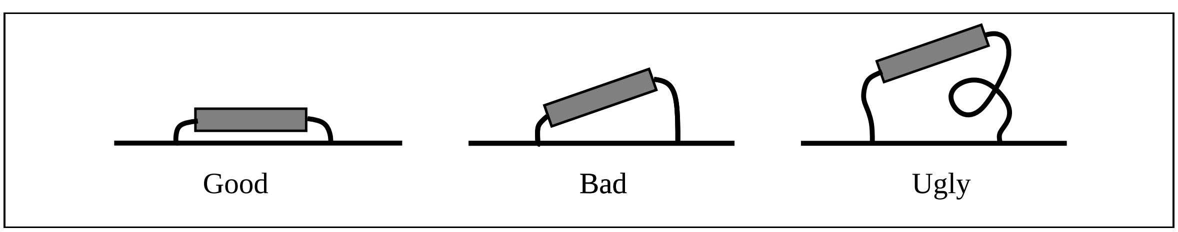


Figure 9: Flat Component Mounting

All LEDs used in the ELEC 201 kit are mounted upright while all resistors are intended to lay flat. See Figure 9 for clarification.

1.5 Component Value Markings

Various electronic components have their values marked on them in different ways. For example, value markings on some resistors are based on a color code (see Figure 10). Other devices, such as transistors and integrated circuits, have their part number printed on the device package. Still others may have several numbers printed on them, some of which are unrelated to their value.

1.5.1 Resistors

The largest resistors – in terms of wattage, not resistive value – simply have their value printed on them.

Other resistors are labeled using a standard *color code*. This color code consists of three value bands (four for a 1% resistor) plus a tolerance band. The first two of the three value bands form the value mantissa. The final value band is the exponent.

It is easiest to locate the tolerance band first. This is a metallic silver-, gold-, or brown-colored band. If it is silver, the resistor has a tolerance of 10%, if gold, the resistor has a tolerance of 5%, and if brown, the resistor has a tolerance of 1%. 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 10 shows the meaning of the colors used in reading resistors.

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 10: Resistor Color Code Table

A few examples should make this clear. (See figure 11 for help)

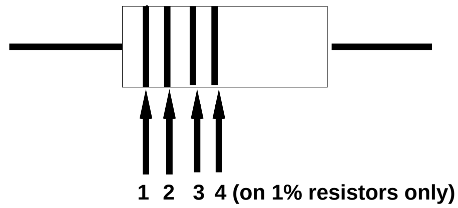


Figure 11: Resistor with Bands

- *brown, black, red*:
  First band: brown-1
  Second band: black-0
  Third band (multiplier value): red-($\times$ 100)
  So have 10 $\times$ 100 = 1,000 ohms, or 1kΩ.

- *yellow, violet, orange*:
  First band: yellow-4
  Second band: violet-7
  Third band: orange-($\times$ 1000)
  So have 47 $\times$ 1000 = 47,000 ohms, or 47kΩ.

- *brown, black, orange*:
  First band: brown-1
  Second band: black-0
  Third band: orange-($\times$ 1000)
  So have 10,000 ohms, or 10kΩ.

- *brown, black, black, red*:
  First band: brown-1
  Second band: black-0
  Third band: black-0
  Fourth band (multiplier value): black-($\times$ 100)
  So have 100 $\times$ 100 = 10,000 ohms, or 10kΩ(for a 1% resistor).

1.5.2 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". Sometimes the "μ" symbol acts as a decimal point; e.g., "$4\mu 7$" 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, and 1,000,000 μF in one Farad.

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.

2 Assembling the ELEC 201 RoboBoard

The ELEC 201 RoboBoard[2] is the heart of the ELEC 201 Robot Controller system. It uses a Motorola 68HC11 family microprocessor coupled with 32K of non-volatile memory. It has outputs to drive six motors, inputs for a variety of sensors, a serial communications port for downloading programs and user interaction, and many other features.

2.1 Assembly Instructions

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

All of the ELEC 201 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. **Correct component placement is absolutely critical. A few minutes spent checking placement and orientation prior to soldering will save hours of debugging and rework later.**

Figure 12 illustrates the component placement on the microprocessor board. The component numbering for parts on the microprocessor board increments in a counter-clockwise fashion around the board for resistors, capacitors, and resistor packs.

Each section of the instructions, or the individual listing of the component contains a reference to the bin in the parts kit where the component can be found. The instruction checklist may be marked off as each step is completed.

1–☐ Get the ELEC 201 V4.1 RoboBoard, and determine which is the "component side." The RoboBoard is the largest of the ELEC 201 boards.

[2]These instructions are for Versions 4.0 and 4.1 of the RoboBoard. Versions 1.0, 1.1, 2.0, and 3.0 of the RoboBoard use different assembly instructions.

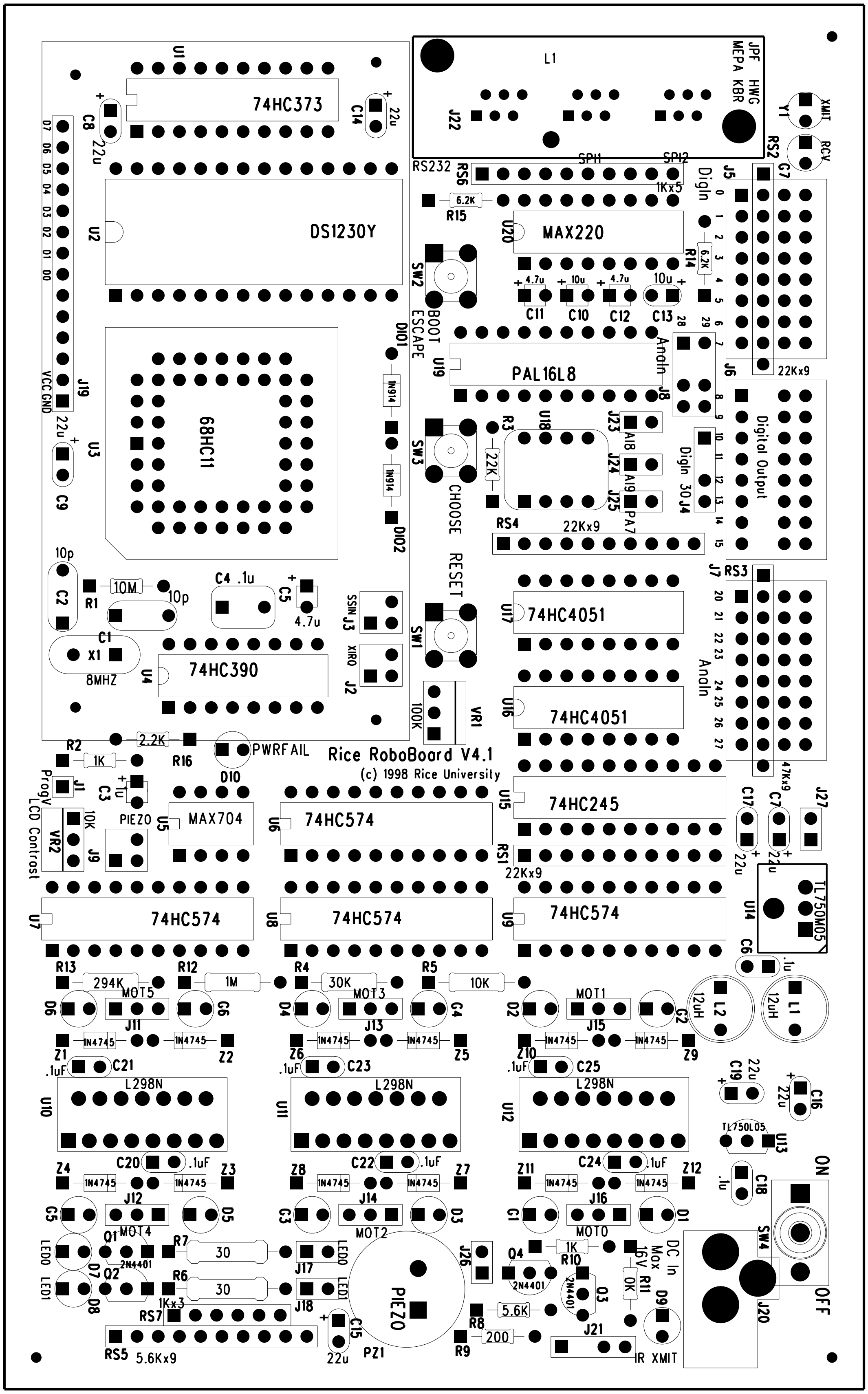


Figure 12: ELEC 201 RoboBoard Component Placement

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 opposite, unprinted side.

Make sure that the components are mounted on the proper side of the board!

2–☐ Measure the resistance between Power and Ground

Using the multimeter set to resistance ("Ω"), touch the red lead to Pin 20 of U19, and the black lead to Pin 10 (refer to Figure 6 if you do not remember the pin numbering scheme.) The value read should be higher than 10 megaohms. If this is not the case, contact your lab assistant *before* proceeding.

If the reading on the multimeter does not change (e.g. the meter reads "O.L"), all is well. However, to ensure that the meter is working properly, connect the probes together. You should get a low resistance reading.

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. In the list that follows, "DIP5" means the DIP socket used for integrated circuit U5.

Note that there are two varieties of 16-pin DIP socket. One type has an integral bypass capacitor and costs about four times as much as the standard variety. None of the 8-pin sockets have integral bypass capacitors.

A caddy-cornering soldering technique technique should be used. After inserting a DIP socket into the board, solder its two opposite-corner pins first. This will hold the chip in place. Look at it carefully to check for correct orientation, and that it is level and down as far as it can go. If not, it is easy to heat one or both pins and adjust the socket. Only when everything is correct, solder the other pins.

If you are sure of your technique, a time-saving method is to place all of the sockets where they belong, then hold a book against the top of the board (and therefore the sockets) while the board is turned over. Then solder two pins on each socket, and check them all before soldering the rest of the pins.

NOTE: U13 and U14 are *not* socketed. They will be installed later.

Bin A

- ○ **DIP1**–20 pins (with bypass capacitor)
- ○ **DIP2**–28 pins (with bypass capacitor)
- ○ **DIP4**–16 pins (with bypass capacitor)
- ○ **DIP5**–8 pins (no bypass capacitor)
- ○ **DIP6**–20 pins (with bypass capacitor)

- ◯ **DIP7**–20 pins (with bypass capacitor)
- ◯ **DIP8**–20 pins (with bypass capacitor)
- ◯ **DIP9**–20 pins (with bypass capacitor)
- ◯ **DIP15**–20 pins (with bypass capacitor)
- ◯ **DIP16**–16 pins (with bypass capacitor)
- ◯ **DIP17**–16 pins (with bypass capacitor)
- ◯ **DIP18**–8 pins (no bypass capacitor)
- ◯ **DIP19**–20 pins (with bypass capacitor)
- ◯ **DIP20**–16 pins (no bypass capacitor)

4–☐ Resistor Packs.

Install the resistor packs. Most of the resistor packs are polarized: the common terminal end is marked with a dot or band. On the ELEC 201 RoboBoard, 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 sometimes more easily seen on the unprinted solder side of the board.)

The "caddy-cornering" technique of soldering the two end terminals first is helpful here also; check the orientation *before* soldering the other pins. **Bin B**

- ◯ **RS1**–22kΩ×9, 10 pins, polarized (marked end goes in the square pad), *marked "101R22K"* or *marked "10R-1-223."*
- ◯ **RS2**–22kΩ×9, 10 pins, polarized, *marked "101R22K"* or *marked "10R-1-223."*
- ◯ **RS3**–47kΩ×9, 10 pins, polarized, *marked "101R47K."*
- ◯ **RS4**–22kΩ×9, 10 pins, polarized, *marked "101R22K"* or *marked "10R-1-223."*
- ◯ **RS5**–5.6kΩ×9, 10 pins, polarized, *marked "101R5.6K."*
- ◯ **RS6**–1kΩ×5, 10 pins, non-polarized (can be mounted either way), *marked "103R1K."*
- ◯ **RS7**–1kΩ×3, 6 pins, non-polarized, *marked "63R1K."*

5–☐ Non-polarized Capacitors. These capacitors may be mounted in either orientation. To keep each component in place while soldering, bend the leads slightly out after inserting into the pad. After installing, solder and clip leads close to the board at the edge of the solder joint. **Always hold the end of the lead being clipped, so that the lead cannot become a projectile.**

Bin E

- ◯ **C1**–10 pF, *marked "10."* **Caution:** The label "C1" on the board is not printed in quite the right place. It is located on an oval with "X1" in the center; *This is not where C1 goes.* You will solder a crystal here later. Look above and slightly to the right of the printed C1 and find another oval with nothing printed in it. Put C1 there. Ask a laboratory assistant if you have any questions.
- ◯ **C2**–10 pF, *marked "10."*
- ◯ **C4**–0.1 μF, *marked "104K 100F" or "104K 100E", or "104K 100G"*
- ◯ **C6**–0.1 μF, *marked "104K." (or "104")*
- ◯ **C18**–0.1 μF, *marked "104K." (or "104")*
- ◯ **C20**–0.1 μF, *marked "104K." (or "104")*
- ◯ **C21**–0.1 μF, *marked "104K." (or "104")*
- ◯ **C22**–0.1 μF, *marked "104K." (or "104")*
- ◯ **C23**–0.1 μF, *marked "104K." (or "104")*
- ◯ **C24**–0.1 μF, *marked "104K." (or "104")*
- ◯ **C25**–0.1 μF, *marked "104K." (or "104")*

6–☐ Microprocessor Socket (U3) (Bin A).

- ◯ Install **PLCC1**, a 52-pin square socket for the 68HC11 (U3). The Pin 1 marking is indicated by the numeral "1" and an arrow in the socket; this marking mounts nearest to **C9** (next to the edge). There should be a beveled notch in the lower-right 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–☐ Male and Female Socket Headers.

To cut sections of header, it is usually best to destroy one unit of header. For example, if you are cutting a 3-long single female strip, count three units and cut through the fourth. After cutting you can trim the excess header with diagonal cutters, or by smoothing with sandpaper.

When mounting the headers, 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.

Both single- and double-wide female header strips are used in the following assembly instructions.

Refer to Figure 13 for placement of these parts.

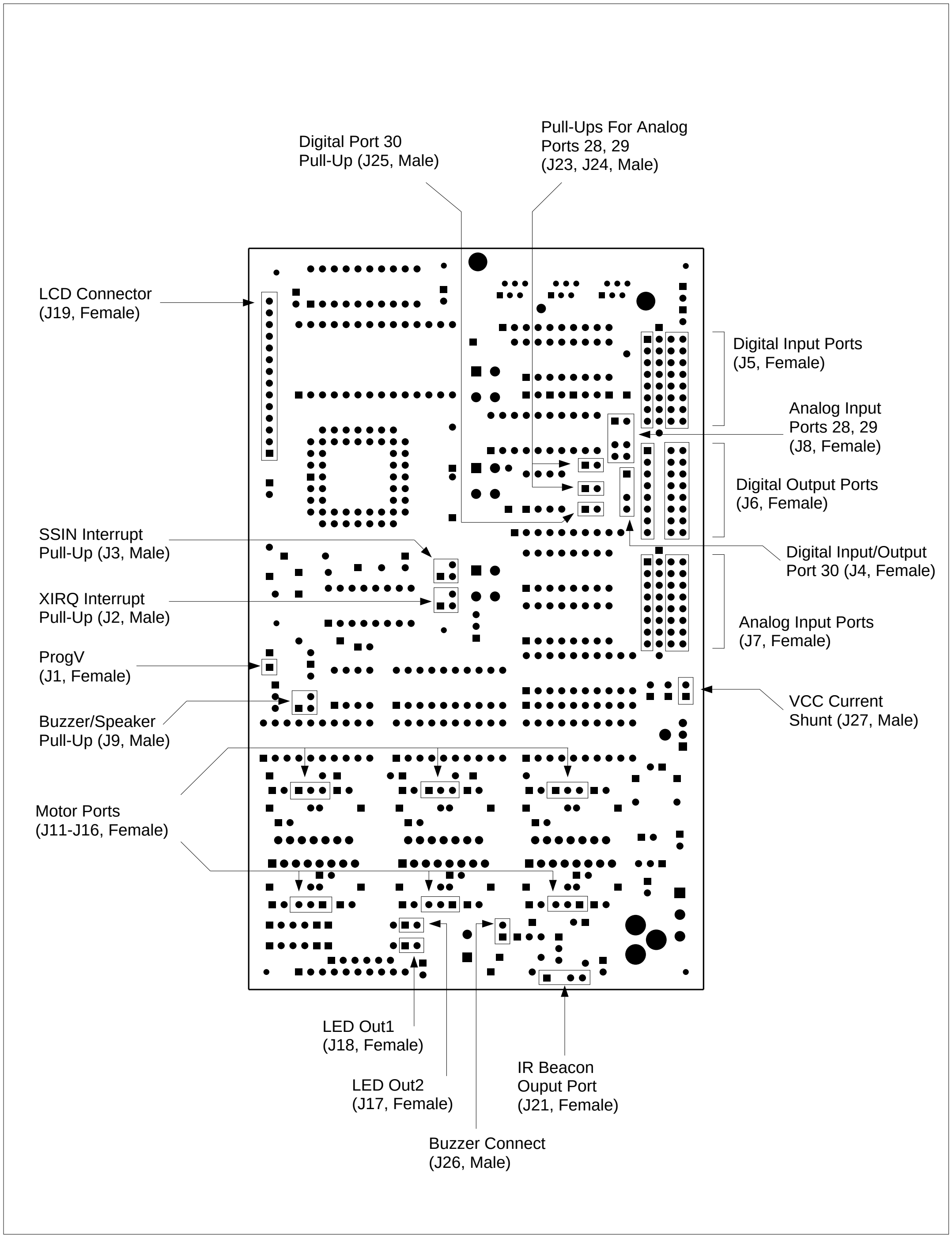


Figure 13: ELEC 201 RoboBoard Header Placement

- ◯ The motor chips have special, pre-cut female header of 7 and 8 pin lengths. Each chip requires one seven pin and one eight pin header. Install the motor mount hardware **(Bin J)** for **U10**, **U11**, and **U12**.
- ◯ Cut three 8-long double female strips, and select three additional pre-cut 8-long single female strips (Bin J). Install the **J5**, **J6**, and **J7** connector blocks. Solder.
- ◯ Cut one 2-long double female strip, and one 2-long single female strip. Install the **J8** connector block. Solder.
- ◯ Cut two 2-long single female strips, and two 1-long single female strips. Install the **J4** and **J21** connector blocks. Solder.
- ◯ Cut three 2-long male strips and three 1-long male strips. They will be installed in groups of three (a triangular pattern of three pins). Install the **J2**, **J3**, and **J9** connector blocks. Solder. The ordering of the two pieces of header is not really important, but it is best to be consistent. For example, put the 1-long strips into pin 1 and the 2-long strips into pins 2 and 3.
- ◯ Cut six 3-long single female strips. Install the **J11**, **J12**, **J13**, **J14**, **J15**, and **J16** connector blocks. Solder.
- ◯ Cut two 2-long single female strips. Install the **J17** and **J18** connector blocks. Solder.
- ◯ Cut five 2-long single male strips. Install the **J23**, **J24**, **J25**, **J26**, and **J27** connector blocks. Solder.
- ◯ Cut one 14-long single female strip. Install the **J19** connector. Solder.
- ◯ Cut one 1-long single female strip. Install the **J1** connector. Solder.

8–☐ LEDs.

LEDs must be mounted so that the *long lead* (the anode) is inserted into the *square* (as opposed to round) pad of the LED footprint.

Be sure to mount LEDs properly as it is very difficult to desolder them without damage if they are mounted backward.

To aid in soldering, bend the leads a little bit after inserting into the board to hold in the LED. **Remember, LEDs are heat-sensitive, so do not hold the soldering iron on the pad too long.** Also, after soldering in one pin of an LED, give it a few seconds to cool down. Check that the recently soldered pad is cool to the touch, *carefully!*, before soldering the other lead. **Bin G**

- ◯ **D1**–red
- ◯ **D2**–red
- ◯ **D3**–red
- ◯ **D4**–red

- ◯ **D5**–red
- ◯ **D6**–red
- ◯ **D7**–red
- ◯ **D8**–red
- ◯ **D9**–red
- ◯ **D10**–red
- ◯ **Y1**–yellow
- ◯ **G1**–green
- ◯ **G2**–green
- ◯ **G3**–green
- ◯ **G4**–green
- ◯ **G5**–green
- ◯ **G6**–green
- ◯ **G7**–green

9–☐ Resistors.

All resistors (except **R6** and **R7**) mount flat against the RoboBoard; try to get the body of the resistor very close to the board. These components are not polarized; however, we suggest that resistors be mounted uniformly – with each resistor's tolerance band closest to the top of the board.

If you have trouble discerning colors, you may wish to have your colleagues handle this task. Actually, it is fairly difficult to read the color bands from $\frac{1}{8}$ watt resistors, even for the trained eye. The blue body of some resistors seem to distort the color of the bands. The best technique is to check the value of each resistor with the Digital Multi-Meter.

After soldering each resistor, check the component side of the joint to ensure that the solder flowed all the way through the joint. If it hasn't, turn the board back over to the solder side, and touch the joint again with the iron briefly– this usually helps. Once the resistor is successfully soldered in place, clip the leads. (Again, be sure to hold each lead while clipping to prevent possibly hazardous projectile wires.)

Make sure that you use 1% resistors where they are called for.

Bin B

- ◯ **R1**–10MΩ, *brown, black, blue* (beige body)
- ◯ **R2**–1kΩ, *brown, black, red* (beige body)
- ◯ **R3**–22kΩ, *red, red, orange* (beige body)
- ◯ **R4**–30.1kΩ, 1% *orange, black, brown, red* (blue body)

- ◯ **R5**–10kΩ, 1% *brown, black, black, red* (blue body)
- ◯ **R6**–30Ω, 1 watt *orange, black, black* (large gray body) NOTE: R6 and R7 should be spaced above the RoboBoard, about as high as the header for **J17** and **J18**.
- ◯ **R7**–30Ω, 1 watt *orange, black, black* (large gray body)
- ◯ **R8**–5.6kΩ, *green, blue, red* (beige body)
- ◯ **R9**–200Ω, *red, black, brown* (beige body)
- ◯ **R10**–1kΩ, *brown, black, red* (beige body)
- ◯ **R11**–0Ω, *use a small piece of wire or a clipped resistor lead.*
- ◯ **R12**–1MΩ, 1% *brown, black, black, yellow* (blue body)
- ◯ **R13**–294KΩ, 1% *red, white, yellow, orange* (blue body)
- ◯ **R14**–6.2kΩ, *blue, red, red* (beige body)
- ◯ **R15**–6.2kΩ, *blue, red, red* (beige body)
- ◯ **R16**–2.2kΩ, *red, red, red* (beige body)

10–☐ Electrolytic and Tantalum Capacitors.

All of these capacitors are polarized. Make sure that the longer lead (marked (+)) on the capacitor goes into the square pad (marked (+)). If the capacitor leads are not marked (+) or (−), a dot or bar will indicate the (+) lead. Be sure on the polarity of these capacitors. The results are pretty spectacular if these are put in backwards.

Bin E

- ◯ **C3**–1 μF, 16 volt tantalum, *marked "1C"*
- ◯ **C5**–4.7 μF, 16 volt tantalum, *marked "4.7", and "16"*
- ◯ **C7**–22 μF, 16 volt tantalum, *marked "22", and "16"*
- ◯ **C8**–22 μF, 16 volt tantalum, *marked "22", and "16"*
- ◯ **C9**–22 μF, 16 volt tantalum, *marked "22", and "16"*
- ◯ **C10**–10 μF, 16 (or 6.3) volt tantalum, *marked "10", and "16" (or 6.3)*
- ◯ **C11**–4.7 μF, 16 volt tantalum , *marked "4.7", and "16"*
- ◯ **C12**–4.7 μF, 16 volt tantalum, *marked "4.7", and "16"*
- ◯ **C13**–10 μF, 16 volt tantalum, *marked "10", and "16"*
- ◯ **C14**–22 μF, 16 volt tantalum, *marked "22", and "16"*
- ◯ **C15**–22 μF, 25 volt tantalum, *marked "22", and "25"*
- ◯ **C16**–22 μF, 25 volt tantalum, *marked "22", and "25"* Note: Insert SW4 (Bin H) into the board before soldering C16 to ensure that C16 does not interfere with the placement of SW4.

- ◯ **C17**–22 μF, 16 volt tantalum, *marked "22", and "16"*
- ◯ **C19**–22 μF, 16 volt tantalum, *marked "22", and "16"*

11–☐ Transistors and Voltage Regulators

Transistors and voltage regulators are polarized. Install them so that their flat edge is above the flat edge of the placement marking. *Transistors and voltage regulators are* very *heat sensitive.* Put your finger (have one of your partners feed solder into the pad for you) on the top to gauge heat while soldering, and wait awhile after soldering each lead to let the device cool down.

Bin D

- ◯ **Q1**–2N4401
- ◯ **Q2**–2N4401
- ◯ **Q3**–2N4401
- ◯ **Q4**–2N4401
- ◯ **U13**–TL750L05 (same package as transistors). This part is extremely heat sensitive, so be careful.
- ◯ **U14**–TL750M05 (the large rectangular version of this device). Install the slip-on heatsink for the TL750M05 regulator (**U14**). First, obtain some thermal compound from your lab assistant. Place a *small* amount of this compound on the metal side of the regulator (facing the board). Then gently press the slip-on heat sink onto the regulator. Guide the regulator pins and heatsink pin into the board until both are snug. Ensure a snug fit, solder and trim the support pin of the heat sink. Solder the regulator pins and trim.

12–☐ 8 MHz Crystal (Bin K)

Crystals are not polarized. Install **X1**, the 8 MHz. crystal.

13–☐ Inductors. (Bin K)

Inductors are not polarized. Install **L1** and **L2**, 12 uH.

- ◯ **L1**–12 uH (may be marked "120K")
- ◯ **L2**–12 uH (may be marked "120K")

14–☐ Switches.

These are slightly rectangular and should only insert easily in the correct orientation.

Bin K

- ◯ **SW1**–miniature pushbutton switch

○ **SW2**–miniature pushbutton switch

○ **SW3**–miniature pushbutton switch

Bin H

○ **SW4**–large slide switch; either orientation works.

15–☐ Variable Resistors. (Bin K)

Orient the variable resistors such that the line on the decal and the dial of the resistor are lined up. *Check carefully for the correct value.*

○ **VR1**, 100kΩ.

○ **VR2**, 10kΩ.

16–☐ Power Receptacle. (Bin H)

Install **J20**, DC power receptacle. When soldering, feed ample amounts of solder into the joint, so that solder completely fills the mounting pads. Try not to melt the receptacle.

17–☐ RJ-11 Top-Entry RJ11 Receptacle. (Bin K)

The top-entry RJ11 phone receptacle needs to be modified before it can be mounted on the RoboBoard. The correct procedure is important. Ask your lab assistant if you have any questions.

Hold the receptacle such that the connecting and mounting pins are pointing downward and the notch is facing you and the row of vertical lines is on the opposite side. Locate the larger triangular mounting pins on your left hand side. The inside mounting pin (the one closest to you) needs to be clipped. Bend this pin outwards to form a right angle. Using the diagonal cutters, clip this mounting pin close to the plastic package.

Install **J22**, the one-position RJ11 receptacle in the space nearest to the center of the board, where it will cover the "J22" mark. The notch should be closest to the edge of the board. Use care in aligning the pins. Be extra careful when inserting not to damage the pins. Solder the mounting pins as well.

18–☐ Piezo beeper. (Bin K)

The beeper is polarized, so mount the Piezo beeper with the long lead in the square pad, and make sure that it is centered on the circular outline.

19–☐ Diodes

Zener diodes are polarized. Install them so that the black band on the diode is in the same orientation as white band marked on the RoboBoard (see Figure 4). *Correct orientation is critical!* If in doubt, ask. Zener diodes *are* *very heat sensitive.* Put your finger on the top to gauge heat while soldering, and wait awhile after soldering each lead to let the device cool down.

Bin J

- ◯ **Z1**–1N4745
- ◯ **Z2**–1N4745
- ◯ **Z3**–1N4745
- ◯ **Z4**–1N4745
- ◯ **Z5**–1N4745
- ◯ **Z6**–1N4745
- ◯ **Z7**–1N4745
- ◯ **Z8**–1N4745
- ◯ **Z9**–1N4745
- ◯ **Z10**–1N4745
- ◯ **Z11**–1N4745
- ◯ **Z12**–1N4745

Two standard diodes are also used on the RoboBoard. **These diodes are polarized** like the zener diodes. Install them with the same orientation as the zeners and with the same care.

Bin G

- ◯ **DIO1**–1N914
- ◯ **DIO2**–1N914

CONGRATULATIONS! You have completed basic assembly of the RoboBoard.

2.2 Final Assembly of the RoboBoard

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 poor electrical connection. Make sure that all of the solder joints are shiny with a silver color. Everyone in your team should check the board, and then ask a lab assistant or the instructor for a final check.

2–☐ Install the eight shunts onto the male headers as follows (see Figure 14 for how pins are numbered):

Bin H

- ◯ **J2** – pin 2 to pin 3 (pin 1 is the square pin)
- ◯ **J3** – pin 1 to pin 3
- ◯ **J9** – pin 1 to pin 3
- ◯ **J23** – pin 1 to pin 2
- ◯ **J24** – pin 1 to pin 2
- ◯ **J25** – pin 1 to pin 2
- ◯ **J26** – pin 1 to pin 2
- ◯ **J27** – pin 1 to pin 2

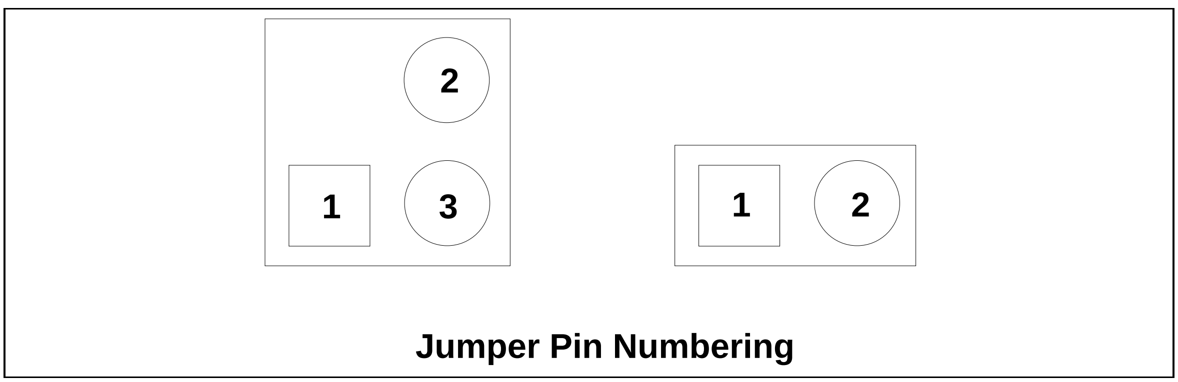


Figure 14: RoboBoard Jumper Pin Numbering

3–☐ Using the multimeter set to resistance ("Ω"), touch the red lead to Pin 20 of U19, and the black lead to Pin 10.

Resistance should increase as the capacitors charge. 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.

4–☐ Ask a lab assistant for a battery and cable, and note their instructions on how to connect it. Connect battery power to the board.

5–☐ Slide the board power switch to "ON".

6–☐ Measure the board voltages. Using the multimeter set to DC Volts ("DC"), touch the red lead to Pin 20 of **U19**, and the black lead to Pin 10. You should read approximately 5.0 volts.

Then touch the red lead to pin 3 of **U13** (pin 3 is in the outside round pad closest to **U12**). You should read approximately 5.0 volts.

7–☐ Slide the board power switch to "OFF".

8–☐ Disconnect the battery.

9–☐ Install the socketed ICs into their sockets on the board. *Be careful not to damage the component leads when installing the chips into their sockets!* Make sure to get the orientation correct (the notched end of the chip should match the notch on the socket and board)—refer to Figure 12 if necessary. **Always touch the board with a part of your body** *before* **bringing the IC in contact with the socket.** This ensures that any static charge that may be present will discharge through you, rather than through the more delicate integrated circuit.

Pushing ICs into sockets can be difficult. It is usually helpful to bend the leads slightly before insertion; ask a lab assistant to show you how. Make sure that all pins of the IC go into the socket, as they sometimes get bent underneath the chip and are difficult to see. If you are having trouble pushing the ICs into the sockets, take the needle nose pliers and *gently* bend the pins inward so the chip will socket easier. Also, make sure to apply even pressure to both sides of the chip so that both sides go into the socket at the same time. It is difficult to put in one side after the other has been inserted.

Again, double-check to ensure correct orientation, because if they are in the wrong orientation when you turn on the power, they are usually destroyed.

- ◯ **U1**–MC74HC373AN (Bin F)
- ◯ **U2**–DS1230Y 32K static RAM (expensive part – use special care) (Bin I)
- ◯ **U3**–68HC11 microprocessor (expensive part – use special care) (Bin I)
- ◯ **U4**–MC74HC390N (Bin I)
- ◯ **U5**–MAX704 (Bin L)
- ◯ **U6**–SN74HC574N (Bin L)
- ◯ **U7**–SN74HC574N
- ◯ **U8**–SN74HC574N
- ◯ **U9**–SN74HC574N
- ◯ **U15**–SN74HC245N (Bin F)
- ◯ **U16**–MC74HC4051N (Bin C)
- ◯ **U17**–MC74HC4051N

- ◯ **U18**–4-pole Dipswitch (Pin one is the pin below the word "ROCKER" so switch 1 will be nearest the microprocessor) (Bin F)
- ◯ **U19**–PAL16L8 (Bin L)
- ◯ **U20**–MAX220CPE (Bin F)
- ◯ **Motor Drivers**

  These devices can only be inserted in one orientation. Insert the three L298N's into the female headers.

  Bin C

  1–☐ **U10**–L298N
  2–☐ **U11**–L298N
  3–☐ **U12**–L298N

- ◯ Have your lab assistant or the instructor examine the board for correct placement, orientation, etc., BEFORE PROCEEDING FURTHER.

2.3 Preliminary Testing

To test the basic functionality of your RoboBoard, borrow an assembled LCD unit from a lab assistant and install it (without screws) into the board. Connect your board to the battery and to the computer as described in the Class Notes on the web. Follow the steps described to load IC, and then test some of the simple IC commands.

2.4 LCD Installation

The LCD display provided in the ELEC 201 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 LCD installation should be performed only after the board has been demonstrated to work properly. It is difficult to debug a board once the LCD display has been bolted on.

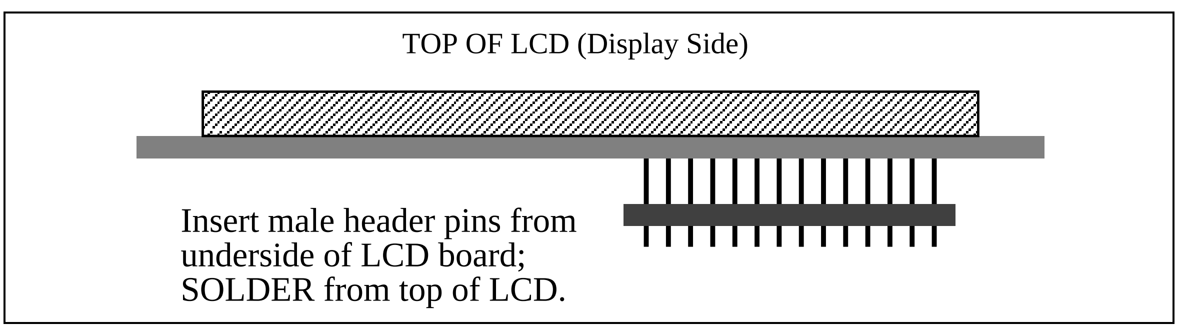


Figure 15: LCD Connector Mounting

The display needs to have a 14-pin male header soldered to its interface. Figure 15 shows how these pins should be installed. You may receive an LCD that is already soldered to a header strip. In that case, you can skip the second and third steps below.

1–☐ Mount four threaded nylon spacers to the RoboBoard with 6-32 nylon screws (do not overtighten!)

2–☐ The LCD mounting holes at the corners need to be drilled larger to fit the mounting screws. If you receive a new display, ask a lab assistant to do this.

3–☐ Cut a 14-long single male LCD header strip; the long pins are 0.31 inches long. Insert the *short* side of the header into **J19**, then mount the LCD as indicated in the figure, putting the top header pins through the holes in the LCD board.

4–☐ Attach the LCD display to the spacers with four more 6-32 nylon screws. The LCD display will now be in correct position and alignment. Solder the 14 header pins to the LCD board. To remove the LCD display, simply remove the four 6-32 nylon screws holding the display to the spacers, and gently pull the LCD display and attached male header away from **J19**. Remember, never overtighten nylon screws. They are much softer than steel.

2.5 Testing the Completed RoboBoard

After you have completed and installed the LCD display, you are ready to test all of the features of your RoboBoard. It is better to ensure that all of your ports work now, rather than to discover later that they are faulty. We have written several programs to do this. One is called *testports.lis*. To download, or install, this program perform the following steps.

1. Make sure that the board has been initialized and that p-code has been downloaded to the board. If you do not know how to do this ask a lab assistant or see the Class Notes on the web page.

2. Start IC.

3. Type `load testports.lis` at the IC prompt. This will load the testports program into the RoboBoard.

4. Using *testports*, check every port on your RoboBoard to see if it is working properly. If this is not the case, consult a lab assistant.

Testports provides instructions for use on the RoboBoard's LCD. If you have any questions about how to use the program, please ask a lab assistant. The program QT.c is another test program that is particularly useful for testing all the motor ports quickly.

2.6 Mounting the RoboBoard

The RoboBoard can be LEGOized by using the threaded axles and a long LEGO beam. LEGOizing the RoboBoard could make it easier to mount to your robot. Figure 16 shows a RoboBoard mounted to a 16-Long LEGO beam. The threaded axles are slipped through the mounting holes on the RoboBoard and one of the holes in the LEGO beam. The threaded axles are then secured using two axle nuts. The side of the board with the LCD display can be mounted on LEGO by using one threaded axle and a 1 inch nylon screw. If you wish to do this, ask your lab assistant for a 1 inch nylon screw.

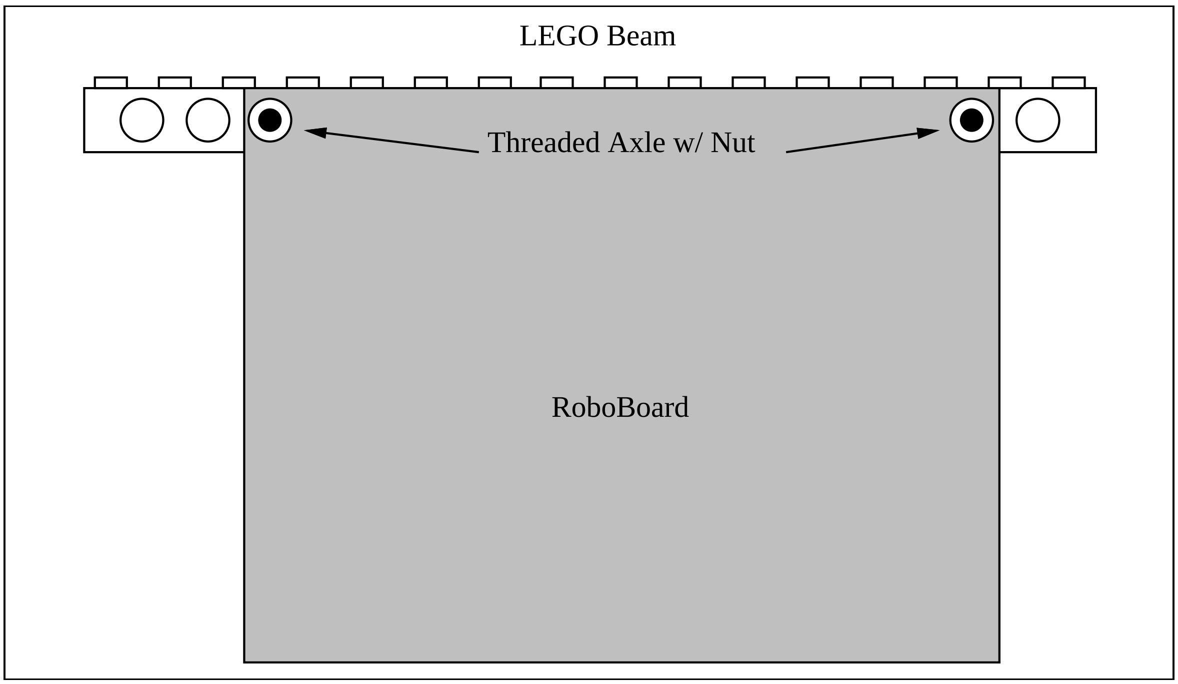


Figure 16: Mounting the RoboBoard on LEGO

2.7 Debugging a Non-working RoboBoard

It is possible that after your best efforts, your RoboBoard is non-functional. This section provides some help to isolating and correcting the cause of the failure. A good working knowledge of the logical design of the RoboBoard and of the function of the various chips is invaluable in finding a fault, so read the chapter of the notes on the ELEC 201 hardware carefully. The steps below will give you additional insight on the operation of the RoboBoard and its components, so read the entire section before starting. Also invaluable is a working RoboBoard, which can provide a comparison for measurements, but most importantly, provides a source of *known-working* chips for substitution. The donor RoboBoard should be loaded with p-code and optionally with a test program like testports. The two different cases of a board that has never worked, and a previously operating board that has failed, are treated separately below. However, there are a few common checks that should be done in any case.

- First, put out the fire. Just kidding, although it has happened. If nothing shows on the display, first check the contrast adjustment pot; also check its value, as it (10KΩ) and the roboknob (100KΩ) are sometimes interchanged.

- More importantly, sometimes a board will act crazy or dead when you turn it on because it is trying to run some (perhaps disfunctional) `main()` program that has been downloaded. It could be waiting for a start light, for example. To avoid this, hold down the CHOOSE button while turning on the power, which bypasses the `main()` function and goes directly to the IC prompt/heartbeat. Also, unfortunately, p-code often gets trashed by an error from a user program and causes problems. Reloading p-code will solve both problems and is a good test. If this doesn't help, or the board is really dead, proceed to the next step.

- Disconnect everything connected to the board.

- Be careful about what you set the board down on. Bench tops are often covered with bits of wire and solder that can short pins. Put the board on a clean piece of paper.

- Measure the battery voltage and polarity.

- Turn on the board and measure the output of the 5 V logic power supply. If the logic supply is low, a bad component or a short is probably drawing too much current. While regulators do fail, they are quite rugged. Note that the regulator will shut off to protect itself if the current draw is too high, in which case the regulator, U14, will be *very* hot, so be careful. A good way to check the regulator is to remove the jumper next to it, J27. This isolates the regulator output from all the components on the board except the filter capacitors C6, C7, and C17. Check them for correct installed polarity and shorts. If the output voltage is still not correct (check right on the pins of the regulator), the regulator is probably bad; replace and recheck. If removing J27 does result in a 5 V output, then the task is to find the component or short that is causing the current draw. Removing all the chips is a good starting point, then proceed, monitoring the current draw at J27, while replacing first the Minimum Functional Chip Set (see below). After that, follow the rest of the steps below as appropriate.

- Measure the output of the 5 V supply, at U13, for the motor chips. If this is low, pull the motor chips and remeasure. If the output is still low or zero, the regulator probably needs to be replaced, as there really is nothing else connected to the output, but check the filter capacitors C18 and C19 as well for correct polarity and shorts.

2.7.1 Failure at Initial Operation

The usual cause of a failure at first startup is an error in construction. So the primary steps involve looking for common errors, and then uncommon errors. First be sure to perform the power supply checks listed above.

- Make sure J27 is in place, or no logic power will get to the board.
- Inspect each chip location carefully to verify that each has the correct chip, that it is oriented properly, and that all pins are actually inserted into the socket (and not bent under the package).
- Check the polarity of all the electrolytic capacitors for correct installation. Installation backwards can cause excess current draw and occasionally sparks, but sometimes no problem will show up for some time.
- Check the polarity of all the zener diodes, both at the motor ports and the data input ports.
- Inspect the soldering for shorts and cold solder joints. In really bad cases, you just have to go over all the joints again and redo them.
- Trim off excess lead length on the solder side of the board with diagonal cutters.

If none of the above helps, go on to the next steps.

2.7.2 Failure of a Previously Working Board

If the source of a problem is not obvious from such information as voltage checks and the nature of the problem, one technique is to pull out chips to get to the minimum working configuration, and then to replace chips sequentially with known-good ones from a working donor board.

The Minimum Functional Chip Set will run the IC logo and heartbeat on the display. The set consists of:

1. The processor, U3, 68HC11.
2. The memory, U2, DS1230Y *loaded with p-code* from a donor board.
3. The 74HC373, U1, memory address latch.
4. The PAL16L8 chip, U19, to provide memory enable on pin 19.
5. The MAX 704, U5, for the reset function on power application.

6. The 74HC245, U15, which senses the Choose button.
7. The LCD, which supplies a status return to the processor.

- Pull all the chips except the Minimum Functional Set above. Use a known-good LCD, and check the contrast pot adjustment.
- Turn on the power; the display should show the IC heartbeat, indicating all the chips are good.
- If "Halted" appears on the display, replace the 74HC245 and try again.
- If nothing appears on the display, start substituting chips from a working donor board. My order is processor, 74HC373, PAL, and MAX 704 (rarely a problem). When you find the problem you can back substitute to verify the bad chip. If you substitute *all* of the Minimum Functional Chip Set from a working donor board, and the voltages are correct, and the board still does not work, you have a big problem: a board fault or a bad on-board component. Fortunately, this is rare, especially if the board has worked previously. Check the solder joints first, and then everything else carefully. Call for help.
- Assuming the board now works minimally, add the next functionality, downloading and digital inputs, by adding the MAX 220, which rarely fails.
- You should now be able to download p-code, robo.lis, and use IC to beep(), etc. Note, if there is no beep, it could be the beeper (jumper in another) or Q4, the driver transistor (check the base drive and output), or a missing jumper J26.
- Digital inputs #0, 1, and 30 should work as they go directly to the processor. Check them from the keyboard; if there is a problem, replace the processor.
- Check digital input ports #2–7. These make use of additional capability of the 74HC245, so if there is a problem, replace it.
- Add *both* the 74HC4051 chips to add the analog input function. U9 supports ports #20–27, and U10 supports ports #28 and 29 plus the roboknob, dip switches, and battery voltage measuring functions. Check all and replace the responsible chip as necessary. Now you can load the program testports.lis for more testing.
- Now add U7, the 74HC574 chip to enable the LED output drivers. Pins 12 and 13 drive the 2N4401 driving transistors, which do burn out if abused. Check the drive at the transistor bases to see if the problem is U7 or the transistor.
- Add IR beacon functionality by installing the 74HC390 chip. This is not necessary for board operation but it checks additional PAL chip functionalities (pin 12). The driver transistor Q3 could also be bad.

- Provide motor port function. First double check the zener diode orientations, then add the three 74HC574 latches; use known-good chips. Add the motor driver chips. Check all the motor ports, both forward and reverse. If nothing works, the problem could be the PAL, which provides enable signals out of pins 16, 17, and 18. Replace the motor driver chips as necessary, and give thanks that they are in sockets in this version of the board. If everything works, you can go back and check the original latches.

- Finally, check the LCD display. Put in the original one, and recheck the contrast adjustment pot. The processor will halt if it does not receive a status signal from the display. Check that the pins *really* insert fully into the socket on the board—a problem if the longer male header was not used. The LCD driver chips are on the LCD board, so replacement of the display is the only option if it is still not working.

And that is all there is, so the RoboBoard should be fully functional at this point. In some cases, and with practice, you can skip some of the steps above if the problem is obviously limited to a particular area, like the motor drivers (a common problem). In that case, just pull the driver chips and the 574 latches and see if everything else works OK. If it does, just substitute latches and motor drivers. For other problems, jump into the sequence above at the appropriate point.

Finally, please destroy and discard all chips found to be bad. Then fill up your donor RoboBoard with new chips as necessary, load it with p-code and testports, and test it, so you will be ready for the next problem.

3 The Battery and Charger System

The ELEC 201 Robot Controller system uses a Panasonic 12 volt lead-acid battery rated for 1.3 ampere-hours of operation. These batteries are rechargeable. The battery is connected to the RoboBoard through the power receptacle J20, just below the power switch.

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 (+) and (−) 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.

3.1 The Battery Charger

The Version 4.1 battery charger is designed to charge one 12 Volt DC battery at a constant charging rate until the battery is fully charged. When the battery is fully charged, the battery charger automatically shuts off. This automatic shut-off feature means that the battery can be left on the charger overnight or longer without risk. A red LED on the board lights up brightly when the battery is charged. You will receive an assembled battery charger board and 12 VDC adapter, but you may need to repair or replace cables. (If you need to build a new charger you will receive additional parts and the assembly instructions.)

3.2 Wiring the Battery Cable

Ask a lab assistant for a battery and cable if you do not already have one. Your battery cable is pre-assembled, but in case you have to repair it, or make a new one, here are instructions.

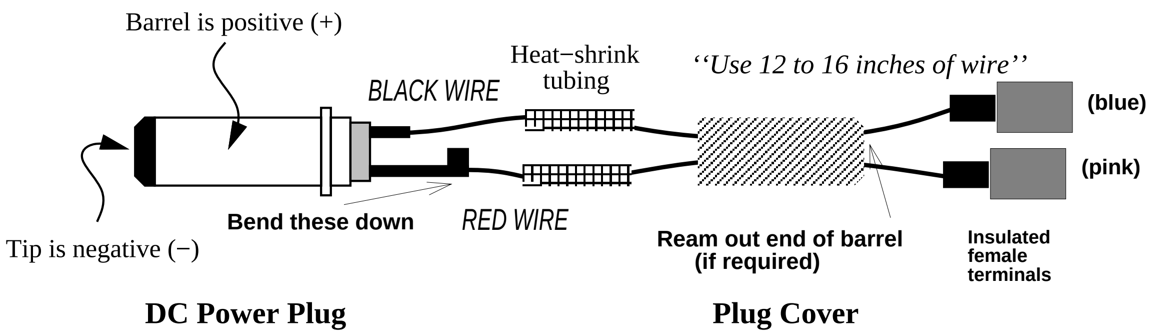


Figure 17: Battery Plug and Cable Wiring Diagram

Figure 17 illustrates how to wire the battery plug and cable assembly.

◯ Cut a 12" to 16" length of the black/red twin cable for use in making the battery cable. Strip and tin the wire ends at both ends of the cable. One end should have about $\frac{1}{4}$ inch of exposed tinned wire; the other end (which will be connected to the power plug) should have about $\frac{1}{4}$ inch exposed. At this end the red wire should be about $\frac{1}{16}$ inch shorter than the black wire.

◯ If your power jack has a hexagonal barrel and a flexible sleeve there is no need to ream the jack. Proceed to the next step. Otherwise, use the reaming tool borrowed from the lab assistant, enlarge the small end of the black annular connector cover. Return the tool to the lab assistant. Slide the cover, reamed end first, onto the tinned leads. Push back about six inches.

◯ Heat-shrink tubing is used on both terminals 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.* Place a $\frac{3}{8}$ inch long piece of heat shrink tubing on each wire before soldering to the power plug. Be sure to keep the heat shrink tubing well away from the point of soldering or it will shrink prematurely.

- ◯ **Proper polarity is important.** The use of red wire to signify the (+) terminal and black wire to signify the (−) terminal is an international standard. Using the "helping hands", position the black wire under the short terminal and solder. Then position the red wire inside the long terminal and bend down the tabs to ensure a good mechanical connection. Solder.

- ◯ After soldering, slide the heat-shrink tubing down over both terminals and shrink.

- ◯ Screw the plug cover onto the plug.

- ◯ Place the pink shielded terminal on the $\frac{1}{4}$ inch of exposed tinned wire of the red lead. Place the blue shielded terminal on the $\frac{1}{4}$ inch of exposed tinned wire of the black lead. Use the crimping tool (borrowed from a lab assistant) to crimp the terminals onto the wire. Use the "red dot" location on the crimping tool, and squeeze the tool until it releases (this takes *a lot* of pressure). *Be sure to return the tool when you are finished!*

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

- ◯ **Make sure to connect the red wire (pink terminal) to the + terminal of the battery.**

3.3 Wiring the 12 VDC Adaptor

You should have a pre-assembled 12 VDC adaptor. Nevertheless, before using your adaptor, use a voltmeter to make absolutely sure that the connections are correct. Plug in the adaptor to a wall outlet, and and set your multimeter to the DC voltage postion. Place the black multimeter probe inside the barrel of the power connector, and the red probe on the outside of the barrel. You should read **positive** voltage. If not, ask a lab assistant to verify the measurement, and then you will need to put on a new plug, following the directions below.

Figure 18 illustrates how to wire the 12 volt DC adaptor and cable assembly. **NOTE: The adaptor may come out of the box with a plug that looks correct, but it probably has opposite polarity from that required.**

- ◯ Examine the 12 Volt DC power adapter. Clip off and discard the existing power plug near the base of the plug (this may have already been done for you). Strip

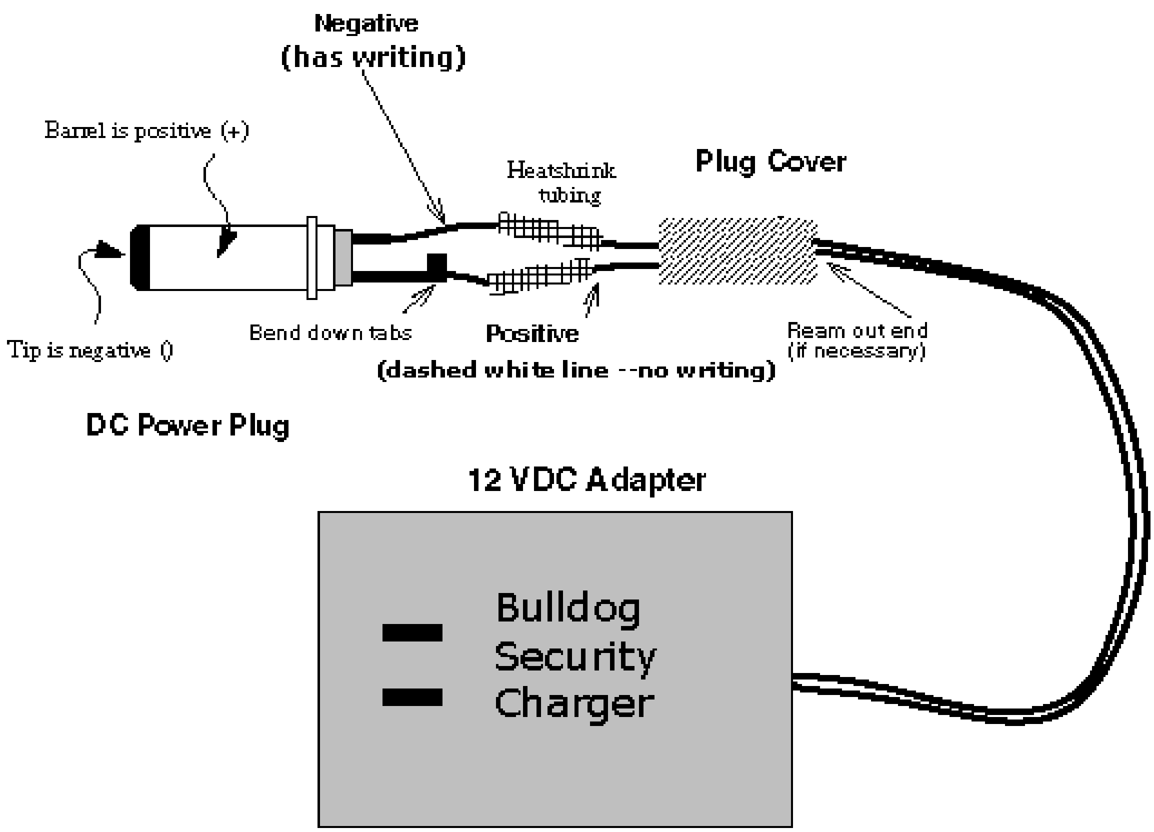


Figure 18: 12 VDC Adaptor Wiring Diagram

$\frac{1}{8}$ inches of insulation from power wires and tin. At this end the non-ribbed wire should be about $\frac{1}{16}$ inch shorter than the black wire.

◯ If your female power jack has a hexagonal barrel and a flexible sleeve there is no need to ream the jack. Proceed to the next step. Otherwise, use the reaming tool borrowed from the lab assistant, enlarge the small end of the black annular connector cover. Return the tool to the lab assistant. Slide the cover, reamed end first, onto the tinned leads. Push back about six inches.

◯ Heat-shrink tubing is used on both terminals 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.* Place a $\frac{3}{8}$ inch long piece of heat shrink tubing on each wire before soldering to the power plug. Be sure to keep the heat shrink tubing well away from the point of soldering or it will shrink prematurely.

◯ We use different models of adapters and the wire markings vary. **Use your volt meter to determine which lead is Positive and which is Negative,** and make a note on the figure, *which may label the wires incorrectly!*

Using the "helping hands", position the **Negative** wire under the short terminal and solder. Then position the **Positive** wire inside the long terminal and bend down the tabs to ensure a good mechanical connection. Solder. *It is essential that this wiring be performed carefully because a short in the power plug will short out the DC adaptor.*

◯ After soldering, slide the heat-shrink tubing down over both terminals and shrink.

◯ Screw the plug cover onto the plug.

◯ *Before using the modified adaptor, use a voltmeter to make absolutely sure that the connections are correct.* Plug in the adaptor to a wall outlet and place the black voltmeter probe inside the barrel of the power connector, and the red lead on the outside of the barrel. You should read **positive** voltage.

4 The Infrared Beacon

The infrared (IR) transmitter board emits modulated infrared light that can be detected by the Sharp GP1U52X IR sensors. The IR board features eight infrared emitting diodes positioned in a circle to generate a 360 degree signal. The diodes are driven by an oscillator circuit (the 74HC390 chip) and a transistor amplifier on the RoboBoard.

The infrared LEDs are wired in series to minimize the current draw from the battery. The board also contains a visible LED, that when lighted, indicates all IR LEDs are transmitting. An unlit LED indicates problems with the board. You will receive an assembled IR transmitter, but you may need to add, repair, or replace the cable and connector. (If you need to build a new IR beacon you will receive additional parts and assembly instructions.)

4.1 Cable and Connector

Use two strands from the rainbow colored ribbon wire; the actual color of the wires is not important. Just pick one color for the positive connection, and the other one for the negative connection. In these instructions we will just call them *pos-color* and *neg-color*, respectively.

- ◯ Cut the 2-conductor piece of ribbon cable to the necessary length for your robot; longer is better than too short. Strip $\frac{1}{4}$" of insulation from the wire on both ends and tin.
- ◯ From *underside* of IR board, insert the pos-color wire into the hole marked (+) and the neg-color wire into the hole marked (−). Solder from the *top* of the board.
- ◯ Mount other end of the wire to outside pins of a four-pin male connector with one pin removed (see Figure 19). The pos-color wire goes to the isolated end-pin (no adjacent pin). Use the guidelines shown in Section 5. Be sure to place heat-shrink tubing on the wires, well away from the connection, *before* soldering. After soldering, slide the heat-shrink tubing down over the pins to make a neat connection. Then apply heat.

The infrared transmitter plugs into the connector labeled IR XMIT on the RoboBoard (see Figure 13), with the positive lead inserted into the end marked (+) on the board.

5 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 board. It also gives instructions for building a cable to connect the RoboBoard to a PC.

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.

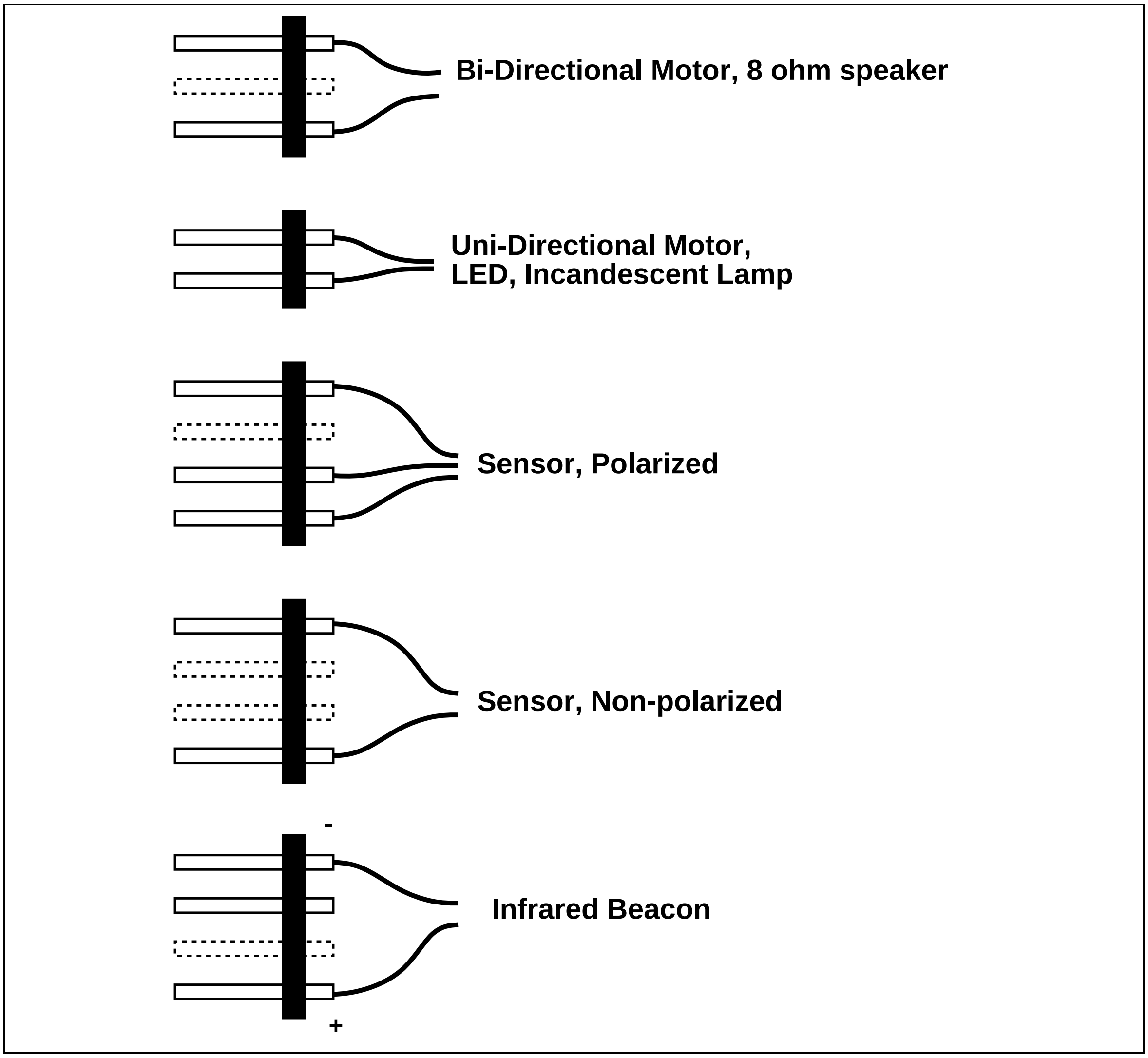


Figure 19: Standard Connector Plug Configurations

Sensors and motors are built with fixed 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 initially.

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.

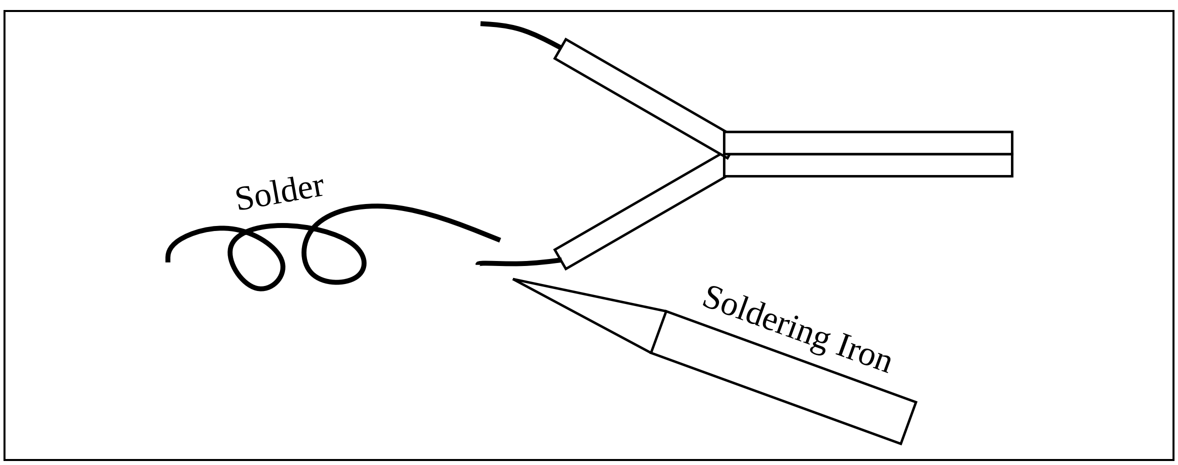
Several different connector styles are used depending on the device that is being connected to the robot. Figure 19 shows the connector configurations used for bidirectional motors, unidirectional motors, sensors, and the infrared beacon.

The ribbon cable provided in the ELEC 201 kit is best for making sensor and motor cables. Use the "helping hands" to hold the connectors while soldering.

Figures 20 through 23 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.

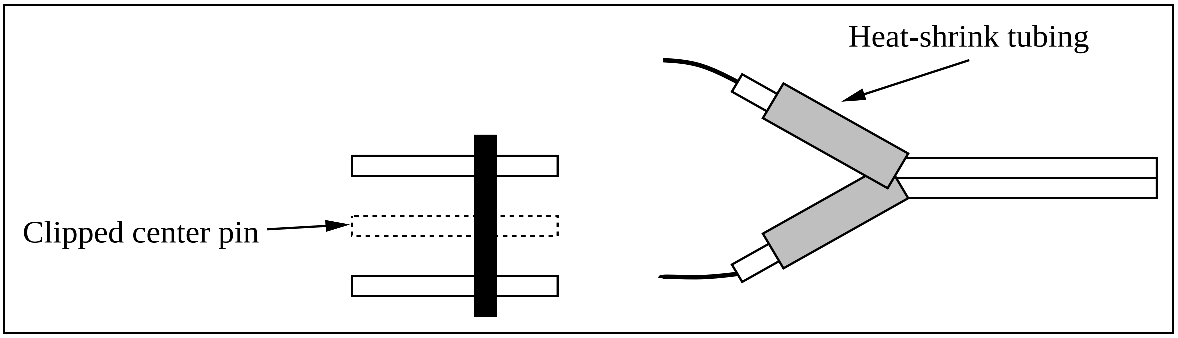
Be sure to place heat-shrink tubing on the wires, well away from the connection, *before* soldering. After soldering, slide the heat-shrink tubing down over the pins to make a neat connection. Then apply heat.

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.



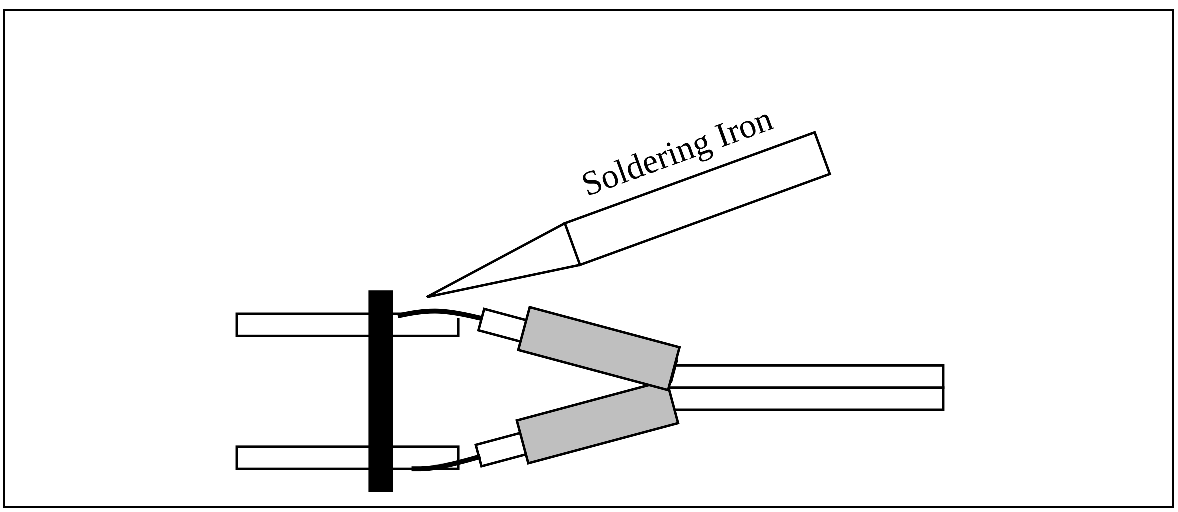
Strip a small amount of insulation off the wire ends. Tin the wire ends by applying a thin coat of solder to them.

Figure 20: Step One of Connector Wiring



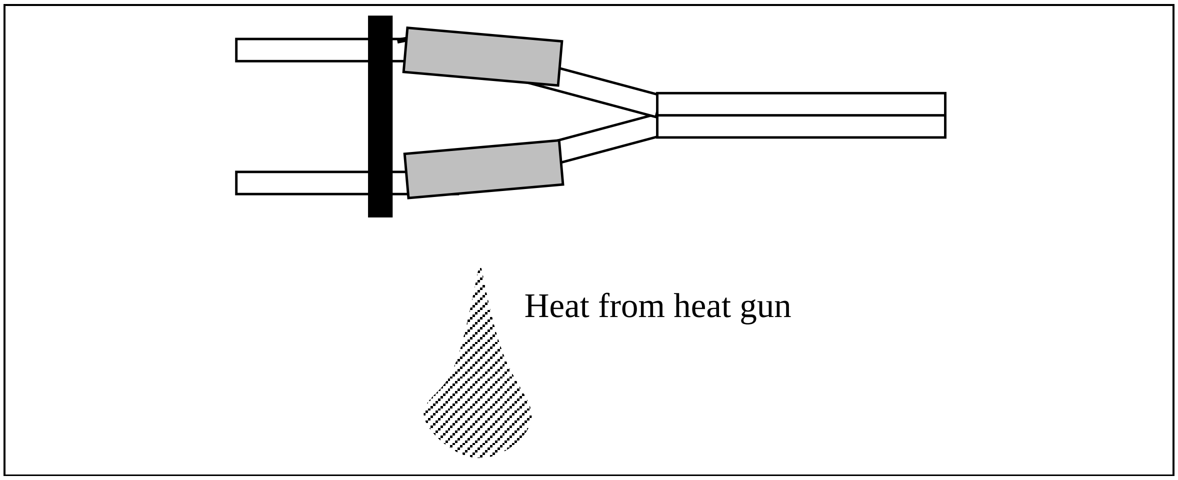
Cut the male connector to size. This example shows a plug that can be used to wire a motor or the infrared transmitter. Cut $\frac{1}{2}$ inch length pieces of heat-shrink tubing, and slide over tinned wires, well away from the point of soldering.

Figure 21: Step Two of Connector Wiring



Using the “helping hands”, hold the connector and wires in place and solder. Clip wires to a little less than the length of the male pins before soldering.

Figure 22: Step Three of Connector Wiring



Slide pieces of heat-shrink tubing over connections. Shrink using heat gun.

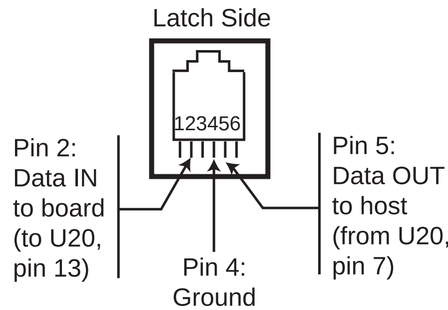
Figure 23: Step Four of Connector Wiring

5.1 Computer Cable Wiring

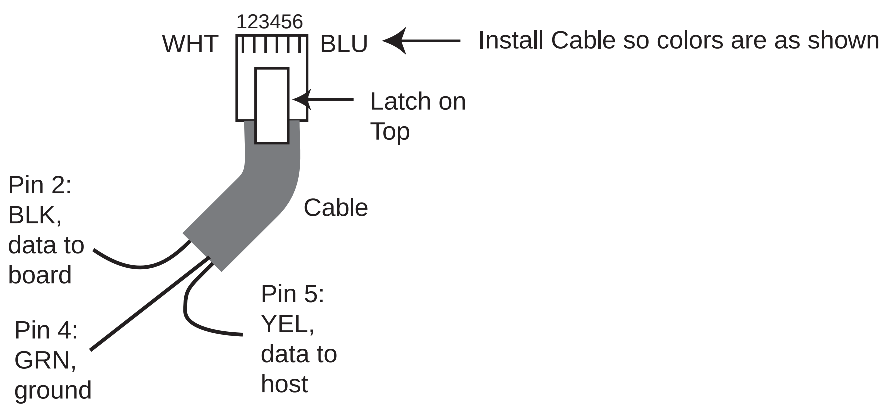
Each of the computers in the ELEC 201 lab has a cable from the serial port to a modular phone plug, known as a RJ-11 plug. You may want to make a similar cable for your own computer. You can obtain the parts from a lab assistant. Refer to Figure 24 for wiring details. New Apple computers require an adapter to provide a standard PC DB-9 serial port.

Rice RoboBoard Connection to PC Host Computer

RoboBoard RJ-11 6-Pin Socket



RJ-11 Plug on Phone Cable



IBM PC DB9 Serial Port: (female connector required)

Terminal #2: YEL: Receive data (to host).
Terminal #3: BLK: Transmit data (to board).
Terminal #5: GRN: Signal Ground.

IBM PC DB25 Serial Port: (female connector required)

Terminal #2: BLK: Transmit data (to board).
Terminal #3: YEL: Receive data (to host).
Terminal #7: GRN: Signal Ground.

Macintosh (Old) Serial Port: DIN-8 Round (male connector)

Terminal #3: BLK: Transmit data (to board).
Terminal #4: GRN: Signal Ground.
Terminal #5: YEL: Receive data (to host).

JFY 9/98

Figure 24: Computer Cable Wiring Diagram

6 Sensor Wiring

Sensors are a critical part of your robot. They provide the information that your control program requires to make navigation, action, and strategy decisions during the game. Poorly mounted or wired sensors are prone to breaking, resulting in no, or worse, incorrect, information to the RoboBoard. Bad sensors are usually a major cause of robot failures. The course notes on the class web site shows many mounting ideas, plus you can look at the robots on display in the lab for ideas (good and bad). However, feel free to experiment and come up with new ideas. Pay particular attention to ruggedness and reliability.

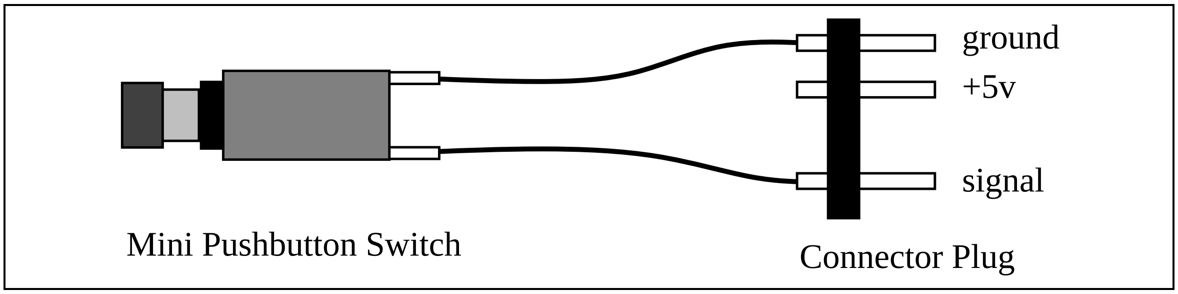
This section shows wiring diagrams for the following sensors:

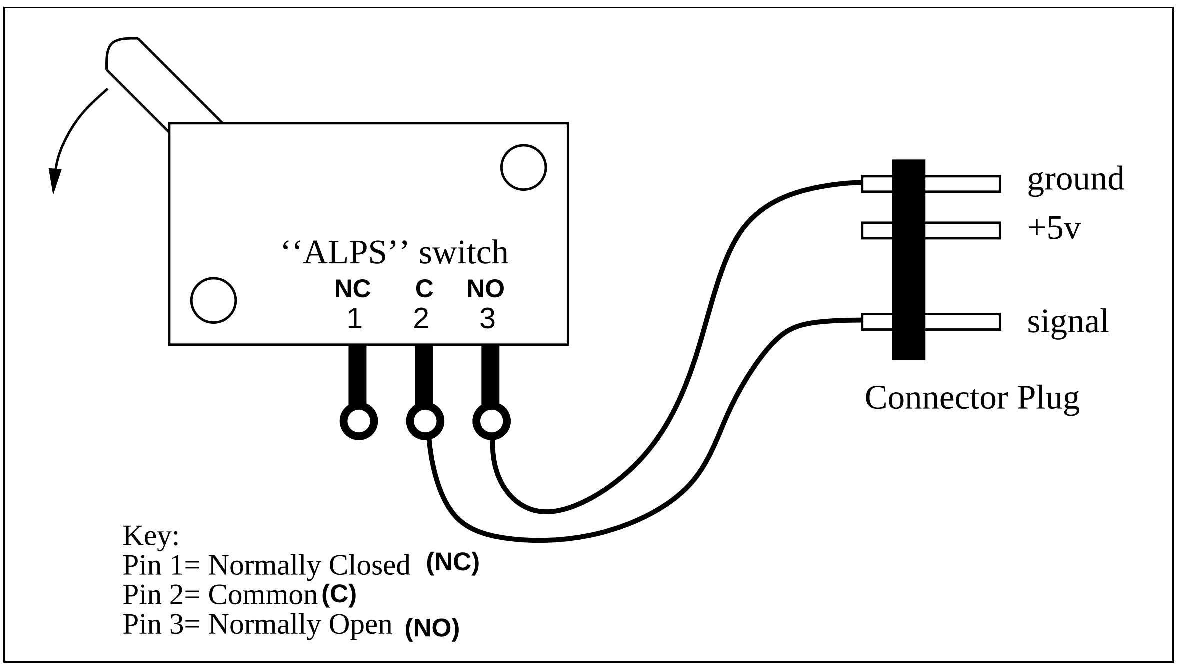
- Touch sensors
- Mercury Tilt Switch
- Photocell light sensor
- Infrared reflectance sensor
- Sharp infrared sensor
- Potentiometer position sensors
- slotted optical switch
- Magnetic Switches

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 found in the Class Notes. Examples of correctly wired sensors are available for your inspection. As a general rule, do not wire a sensor until it is needed. This will conserve material, and will result in cable lengths appropriate for your robot.

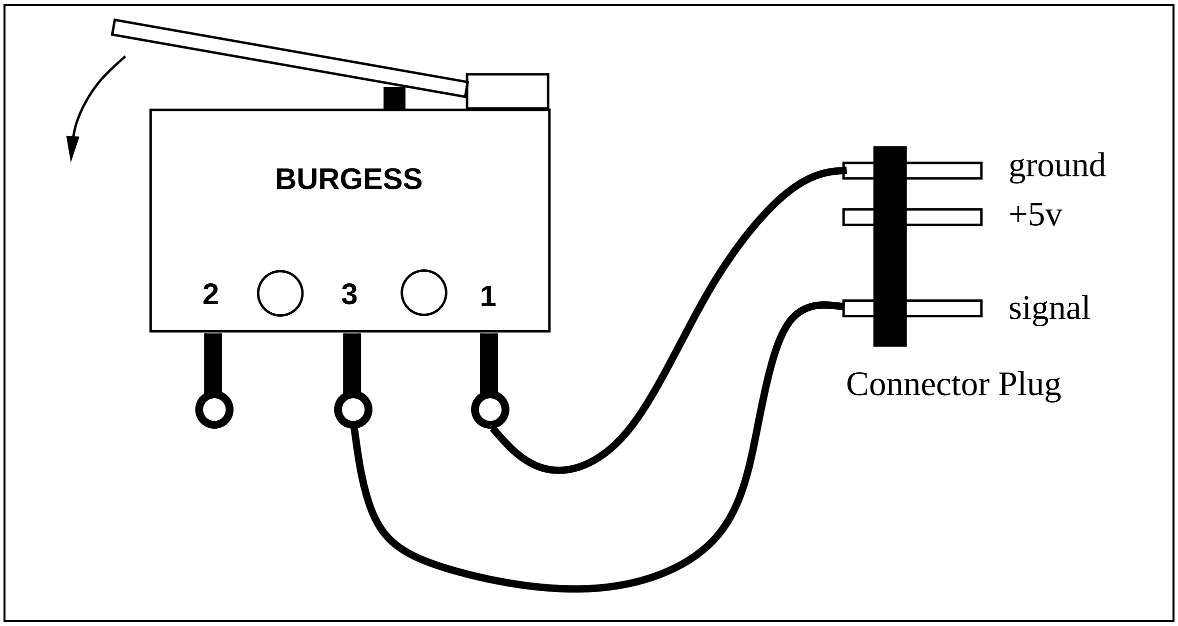
6.1 Touch Sensors

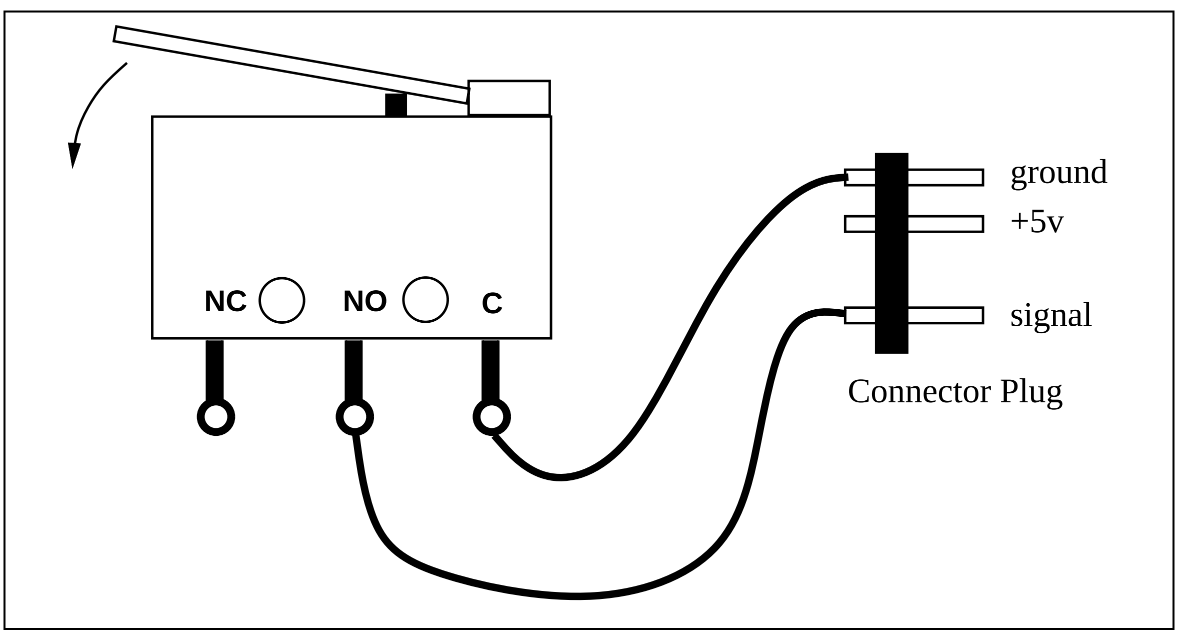
Several switches in the ELEC 201 kit may be used to make touch sensors. Diagrams for the white "ALPS" switch, the small red push-button switch, the Burgess lever switch, the lever switch, the mock roller switch, and the roller switch are shown.

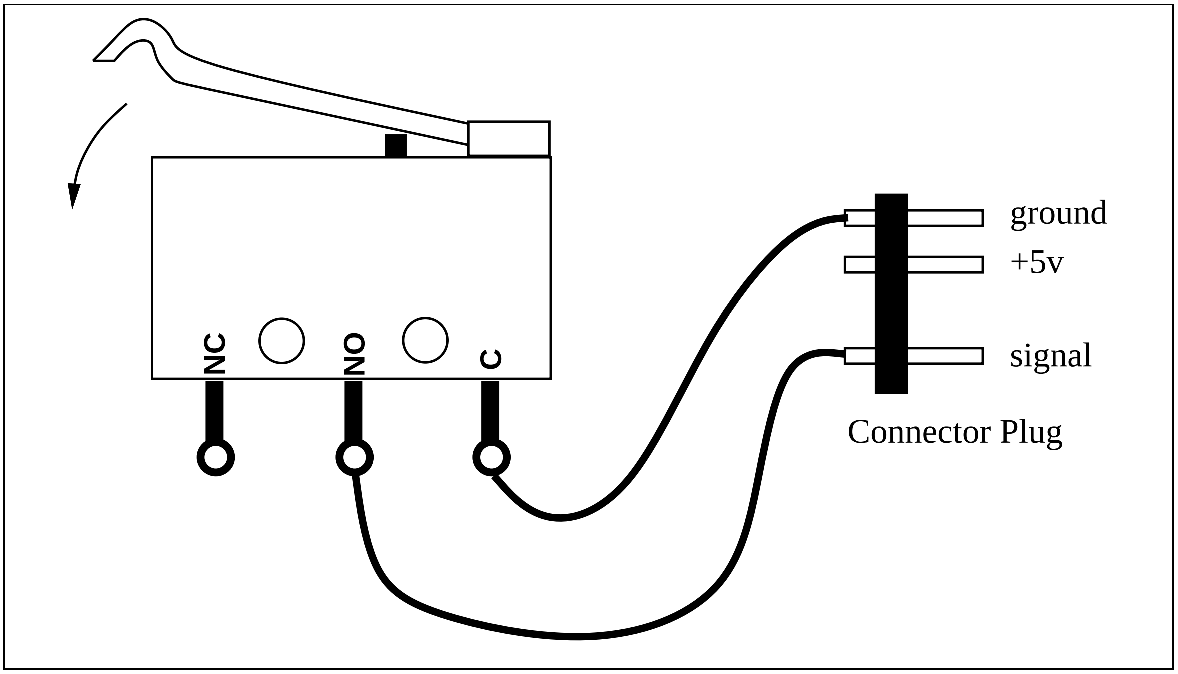


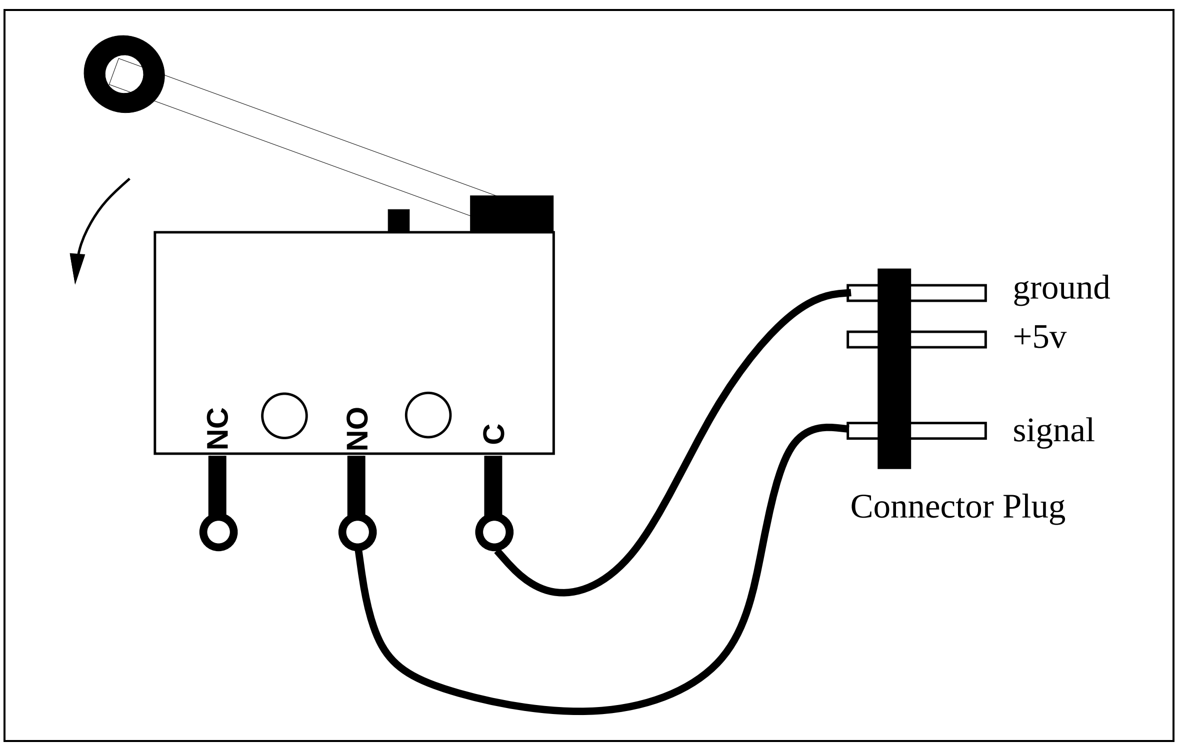


Touch switches should be wired in a normally open configuration, so that the signal line is brought to ground only when the switch is depressed.


BURGESS
2
3
1
ground
+5v
signal
Connector Plug

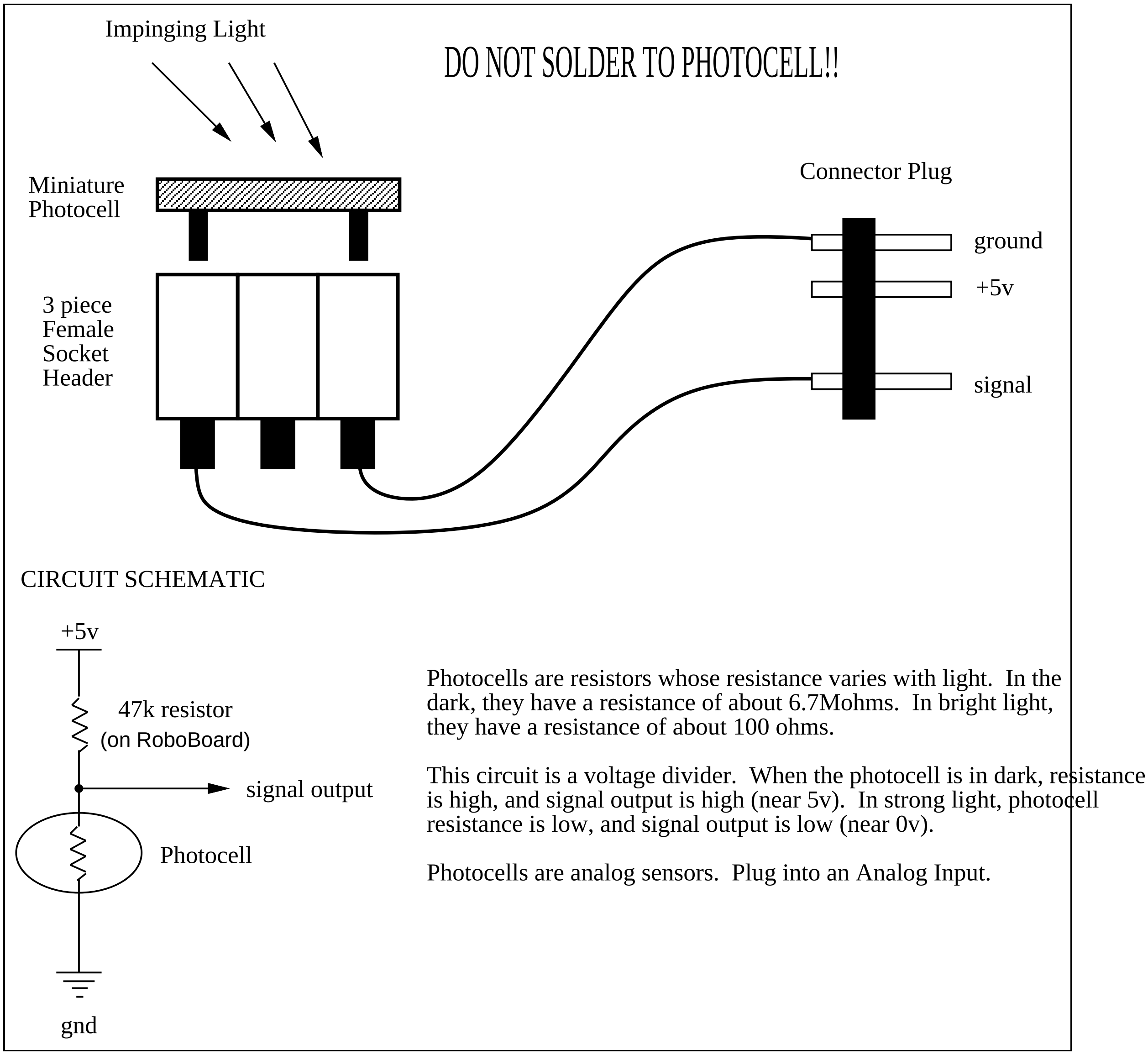

NC
NO
C
ground
+5v
signal
Connector Plug


NC
NO
C
ground
+5v
signal
Connector Plug


NC
NO
C
ground
+5v
signal
Connector Plug

6.2 Photocell Light Sensor

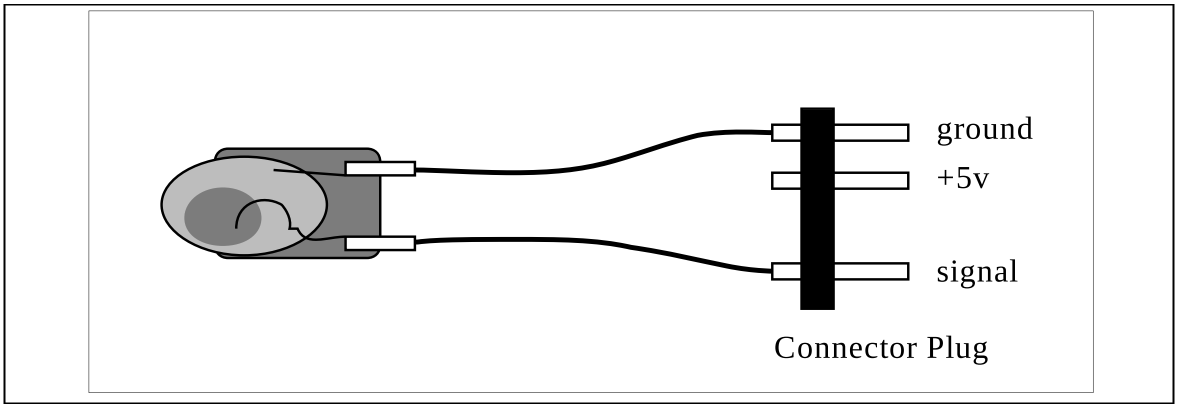
The photocell is a special type of resistor whose resistance varies in proportion to the impinging light. The more light hitting the photocell, the lower its resistance.



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

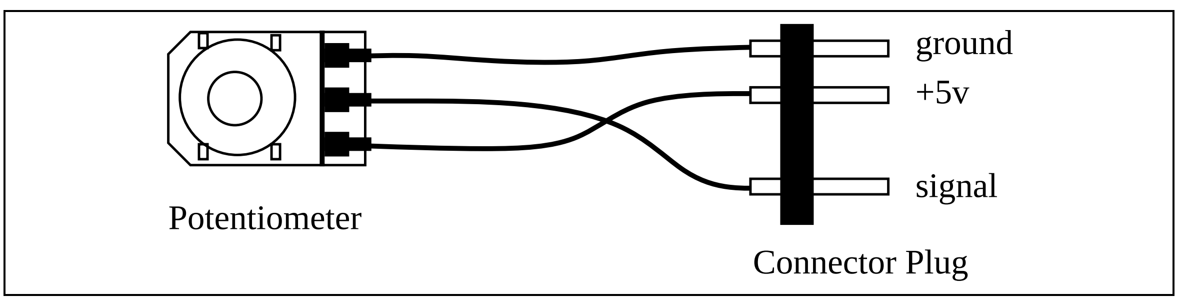
6.3 Mercury Tilt Switch

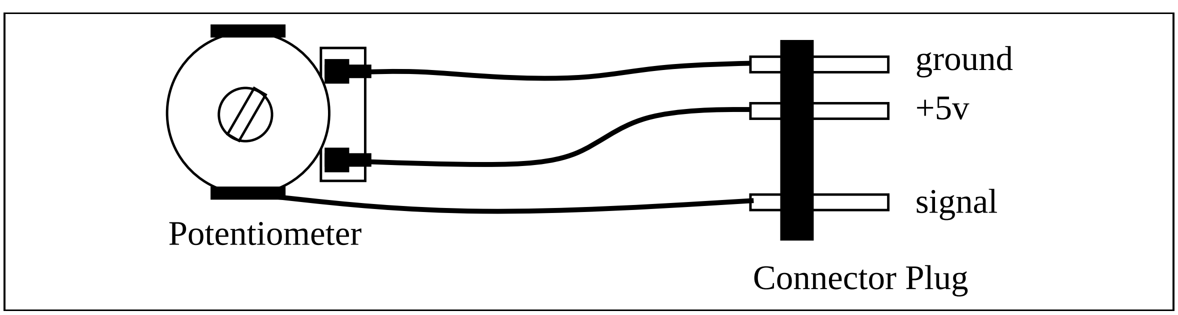
Assemble the Mercury Tilt Switch according to the diagram below. Be sure to apply heat-shrink to both ends.



6.4 Potentiometer

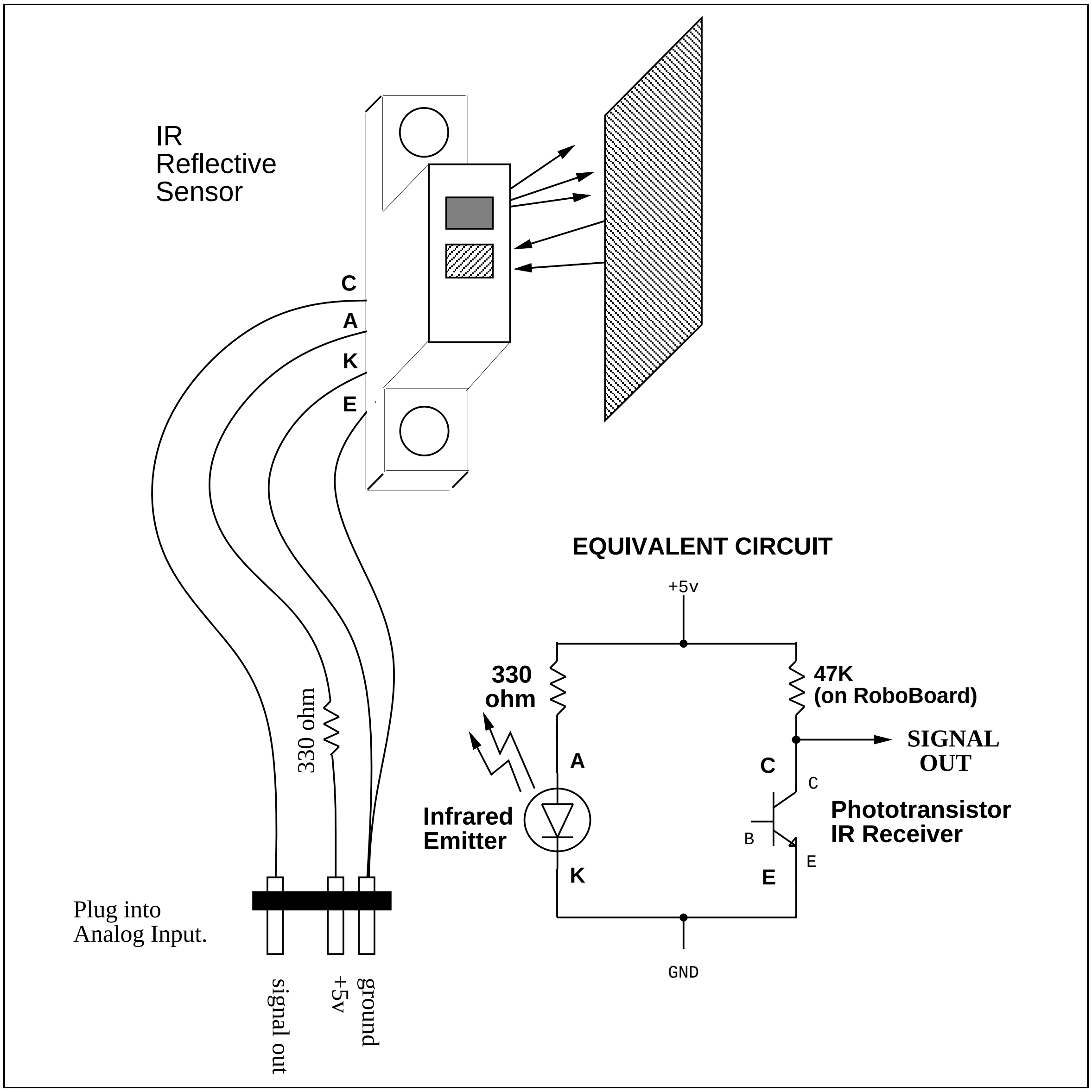
The potentiometer can be used as a rudimentary rotary position sensor. The first diagram deals with shafted potentiometers. The second deals with slotted potentiometers.





6.5 Infrared Reflectance Sensor

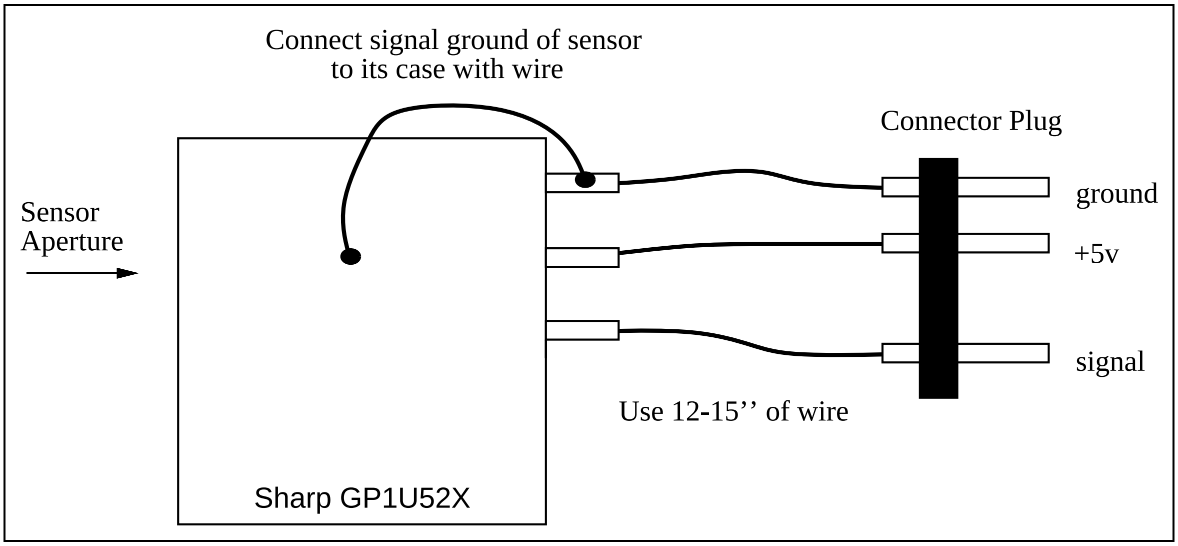
IR reflectance sensors contain a matched infrared transmitter and infrared receiver pair. These devices work by measuring the amount of light that is reflected into the receiver. Because the receiver also responds to ambient light, the device works best when well shielded from ambient light, and when the distance between the sensor and the reflective surface is small (less than 5mm). IR reflectance sensors are used primarily to detect white and black surfaces. As you would imagine, white surfaces generally reflect well, while black surfaces reflect poorly.



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.

6.6 Sharp Infrared Sensor

The Sharp GP1U52X sensor detects infrared light 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.

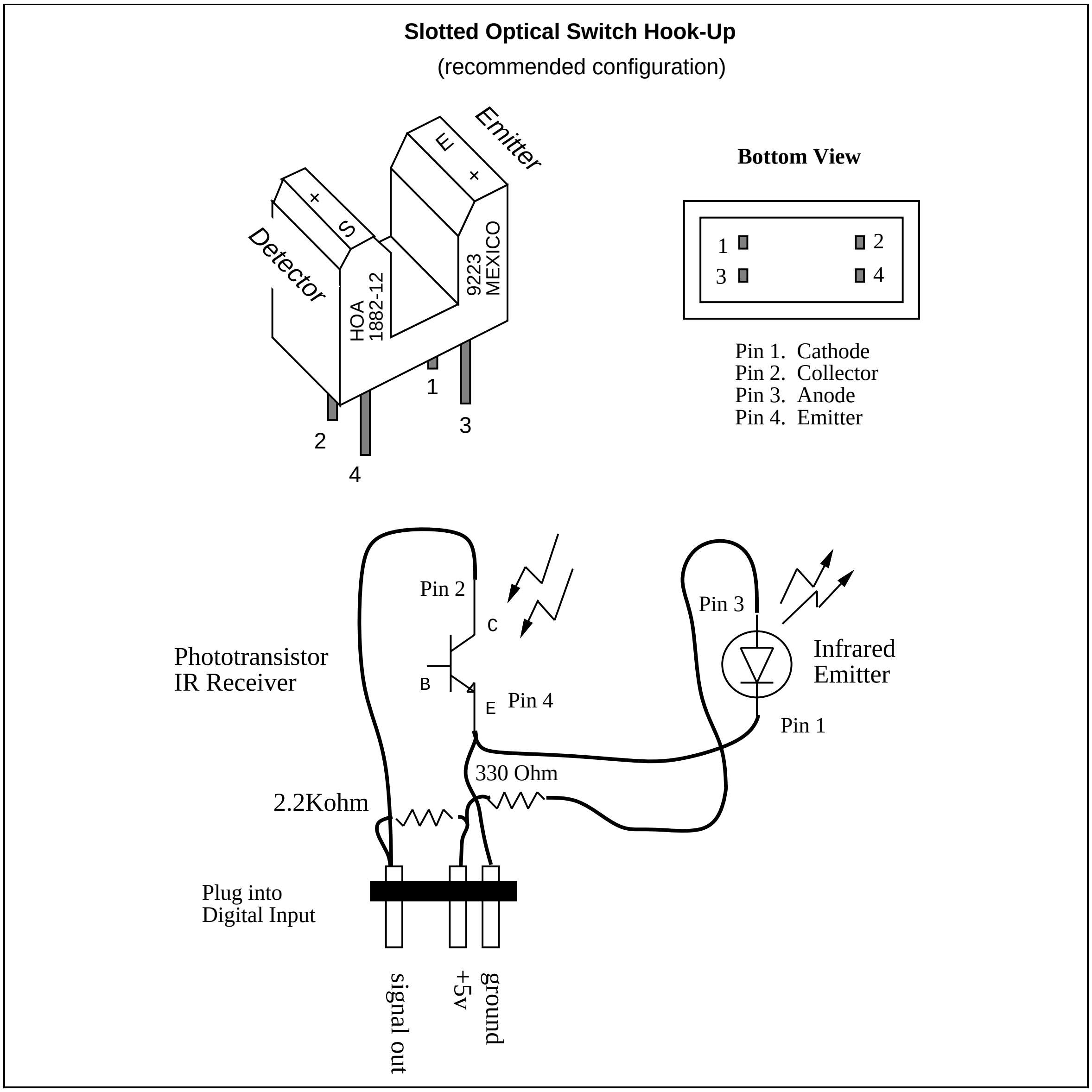


The metal case of the sensor must be wired to circuit ground, as indicated in the diagram. This makes the metal case act as a Faraday cage, protecting the sensor from electromagnetic noise.

An explanation of the infrared system, and use of the Sharp sensor is given in the Class Notes.

6.7 Slotted Optical Switch

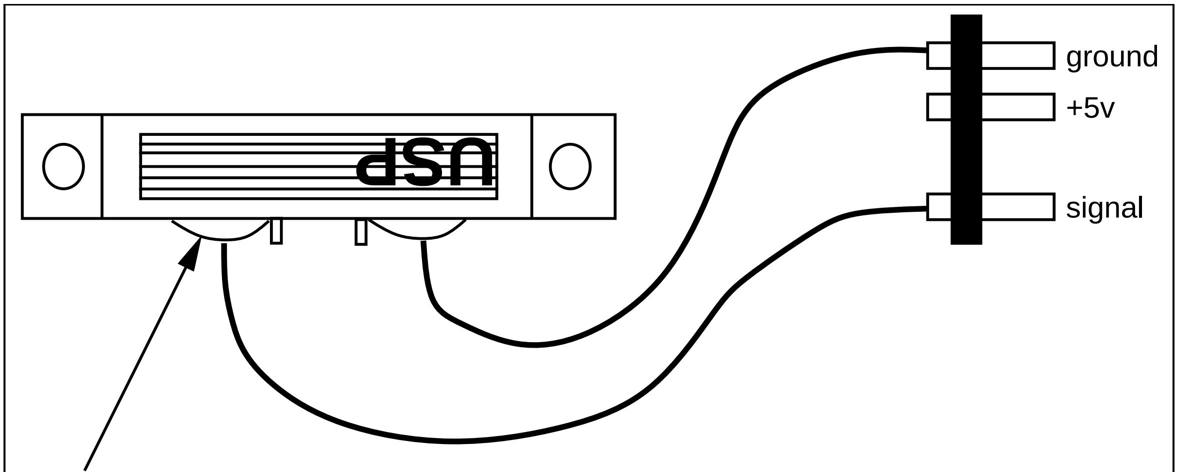
Like the IR reflective sensor, the slotted optical switch contains a matched infrared transmitter and infrared receiver. The slotted optical switch also works by measuring the amount of light transmitted from the transmitter to the receiver, but in this case the transmission is direct, rather than reflected. Best results are again achieved when ambient light is shielded from the device. We recommend that you examine the sample before attempting to wire a slotted optical switch.



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. Generally, however, the slotted switch is used as a digital sensor, with the two states Blocked and Unblocked.

6.8 Magnetic Switches

These magnetic switches are used as window sensors in home security systems. The switch will close when it comes within 1" of its companion magnet.



To attach wires to screw terminals, loosen screws, place stripped and tinned wire under screws and tighten the screws. No soldering is required.

7 Motor Mounting and Wiring

Several types of motors are available, but they all are either round, or oblate (round with two flat sides). See the course notes on the class web site for the different motor's characteristics and for instructions on how to mount them to LEGO pieces. It is important to get the motor aligned correctly so that the gears will mesh properly, with minimum friction.

In addition to mounting the motor on a LEGO piece, you must also attach a gear to the shaft. You will find some motors in the lab that use heat shrink tubing and glue to attach an eight-tooth gear to the motor shaft. We now use a method that is more reliable and more versatile. We attach a small section of LEGO axle to the shaft, and then any gear (and other parts) can be easily attached. Since the adapter will go through a beam hole, you can attach it before mounting the motor; in fact this is the best procedure. The same technique is used for all the motors, but you must use the correct adapter piece because the motor shafts have different diameters.

7.1 LEGOizing Motor Shafts

- ◯ Score the motor shaft slightly with sandpaper, *taking great care not to get sand inside the motor*. Point the motor shaft-down, grip it with a piece of sandpaper near the motor, and pull down away from the motor, so you are putting scratches along the length of the shaft. Repeat several times.

◯ Clean the shaft with alcohol. Scoring and cleaning are especially important if you are re-working an old motor, so that the shaft is clean and the glue will adhere.

◯ Obtain the correct motor-axle adapter piece. This is a piece of LEGO axle with a hole drilled through the center. The motor shaft is a *snug* fit in the hole. Different motors have different shaft diameters, so there are multiple adapters. *Be sure to use the correct one!*

◯ Put a drop of instant glue (Loctite 409) on the end of the motor shaft; spread it around the shaft circumference. Only about 4mm or 3/16 inch of the shaft end needs to be coated.

◯ It's best to have two people for the final step. Have your partner hold the motor on the bench with the shaft pointing up; place it on a LEGO beam so you will not bend the contacts or put pressure on the shaft. Your partner should also hold a LEGO beam so the motor shaft goes through a hole and the beam is flat against the brass motor bearing. This will indicate how far to push the adapter onto the shaft.

◯ Hold the adapter with needle nose pliers, and put it on the motor shaft. You will have to tap it with a small hammer, or screwdriver handle, etc. Drive it down until it just clears the beam mounting guide.

◯ Remove the beam, and give the glue a few minutes to dry.

7.2 Wiring a Cable and Plug to a Motor

◯ Motor cables should be constructed with two strands of ribbon cable wire. Cut an 8-inch to 12-inch length of the wire.

◯ 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 should be wired for bidirectional use, as shown in Figure 19.

For the following steps, cut three-long strips of male socket header as needed.

◯ Using the connector plug wiring technique shown in Figure 20 through Figure 23, wire the motor plug. Polarity does not matter since the plug may be inserted into a motor power jack in either orientation. However, placing a tag of tape on one of the wires just above the header, or marking one side of the plug with paint, will keep the motor orientation consistent. Even though the motors will operate when plugged in backwards, labeling the motor leads means your robot really will go forward when you tell it to, and not backwards.