

during the Lab exercises for this course.

Additionally, the power supply has a built in Voltage and Current meter. There is a switch which connects these meters to either the +6V supply or to the +20V supply. Note, both the 0-6V output and the 0-20V output are active all of the time – the meter selection switch on the power supply only changes the output to which the internal meter is connected. However, these meters are imprecise and should not be relied upon -- instead use the **Digital Multimeter**.

Digital Multi-meter (DMM)

The other piece of equipment is a digital multimeter (DMM). It can be used as a voltmeter, measuring the voltage between two points. It can also act as an ammeter, which measures current flow through a wire. Finally, it can act as an ohmmeter, which measures the value of a resistor. To measure volts or ohms connect the black lead to the common banana jack (“LO” jack on the far right) and the red lead to the upper right banana jack and set the DMM to either DC volts or ohms (Ω 2 Wire). Note, when the DMM is set to measure voltage, it has an extremely high input resistance. That is, little or no current will flow through the DMM regardless of the voltage that is applied across the leads. This also means that when it is not connected to a circuit voltages induced by electric fields in the air can result in a nonzero voltage reading on the meter. Do not worry, this is normal and does not indicate a fault with the DMM. To measure current connect the black lead to the common banana jack (“LO” on the far right) and connect the red lead to the lower right banana jack and set the DMM to DC Amps (shift-DC I on the HP34401A). Note, to change from measuring voltage to measuring current you must both change the red lead on the DMM and change the mode setting on the DMM.

The Protoboard

For a circuit to work properly, all of its elements must be firmly attached with conducting material. On the robot, the element leads, the copper on the PC board, and the solder accomplish this. However, in this course, you will be testing parts of the circuit before you install them on the robot PC board. It is impractical to solder the elements together before placing them in the robot. Consequently, a protoboard is necessary. The protoboard is a white plastic rectangle with a grid of small holes in it. You plug your chips and your wires and your power supply connections into the little holes. A diagram of how the wires are connected inside the protoboard is shown in Fig. 2.1. The protoboard has holes which can firmly secure element leads that are plugged into it. The holes are grouped beneath the surface by conducting materials. When two leads are put into holes of the same group, those leads are electri-

cally connected. Lines on Fig. 2.1 show how the holes are connected under the surface.

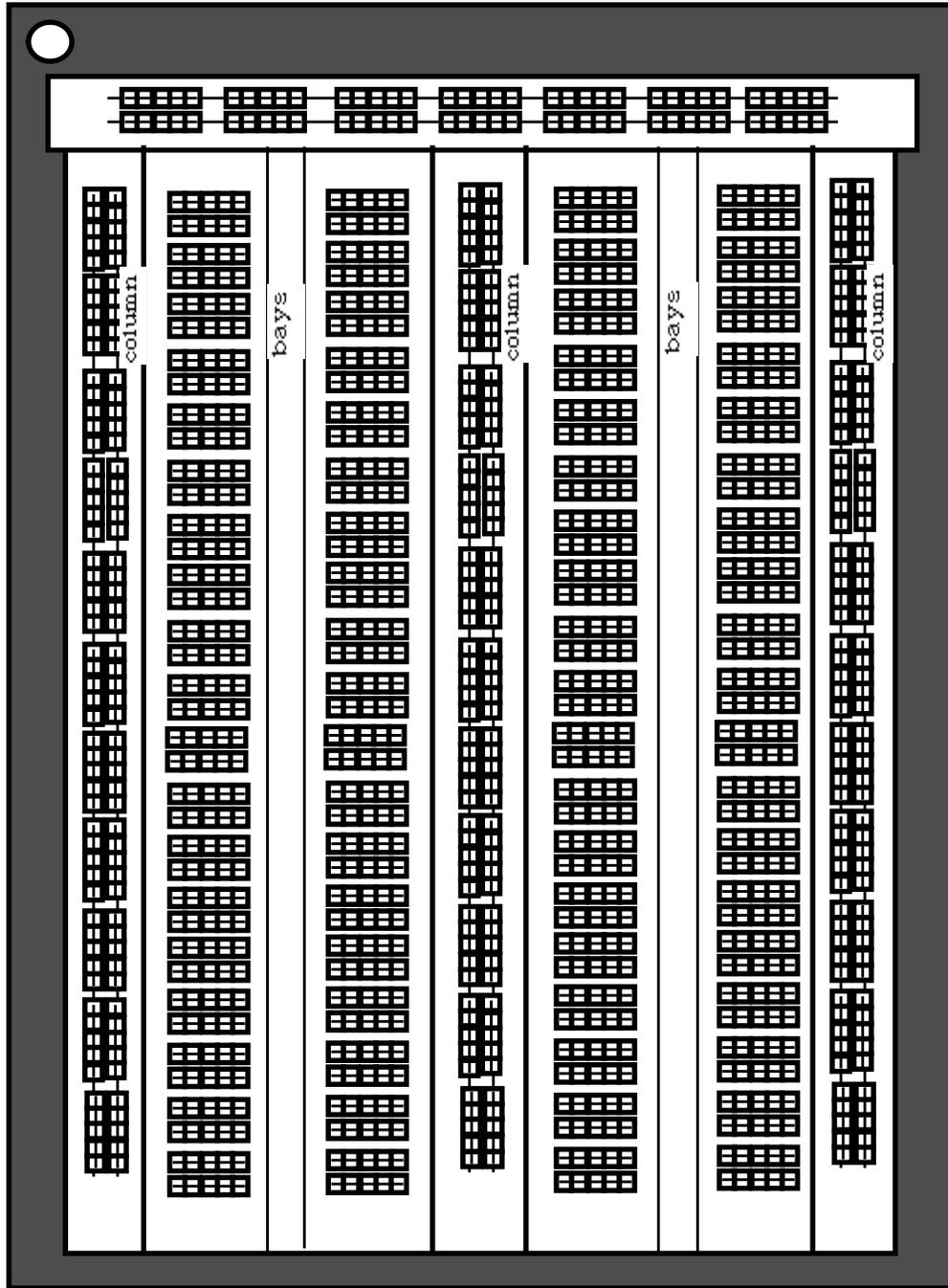


Figure 2.1 Layout of the protoboard and the wiring inside the board.

Why does the protoboard have regions labeled “columns” and “bays”? Because you need to do two different things when you

build circuits: (1) plug in the electronic components - they go in the bays, and (2) get power and common throughout the circuit. These voltages get wired to the columns. The way you typically wire up the power and common is shown in Fig. 2.2 and Fig. 2.3. Note that this puts a vertical strip of power holes to the right of each bay, and it puts a vertical strip of common holes to the left of each bay. This is the whole idea: make it easy to find a power hole and a common hole no matter where an IC or component is in the bays.

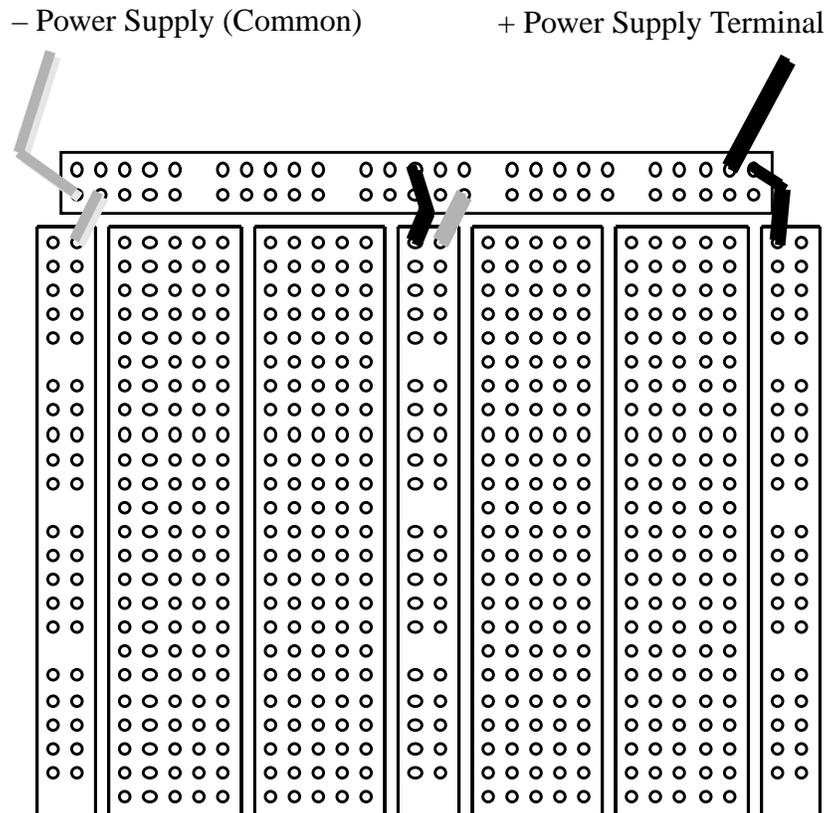


Figure 2.2 Typical protoboard power supply connections.

Wires

In general you should use, #22 gauge, #24 gauge, or #26 gauge solid hook-up wire to connect the components on your protoboard together. To create a connection, cut the wire to the desired length, strip the ends off with a wire cutter being careful not to nick the metal part of the wire with the wire cutters. Finally, insert the stripped ends of the wire into the holes in your protoboard to make connections as shown in Fig. 2.4.

A few helpful rules about wires:

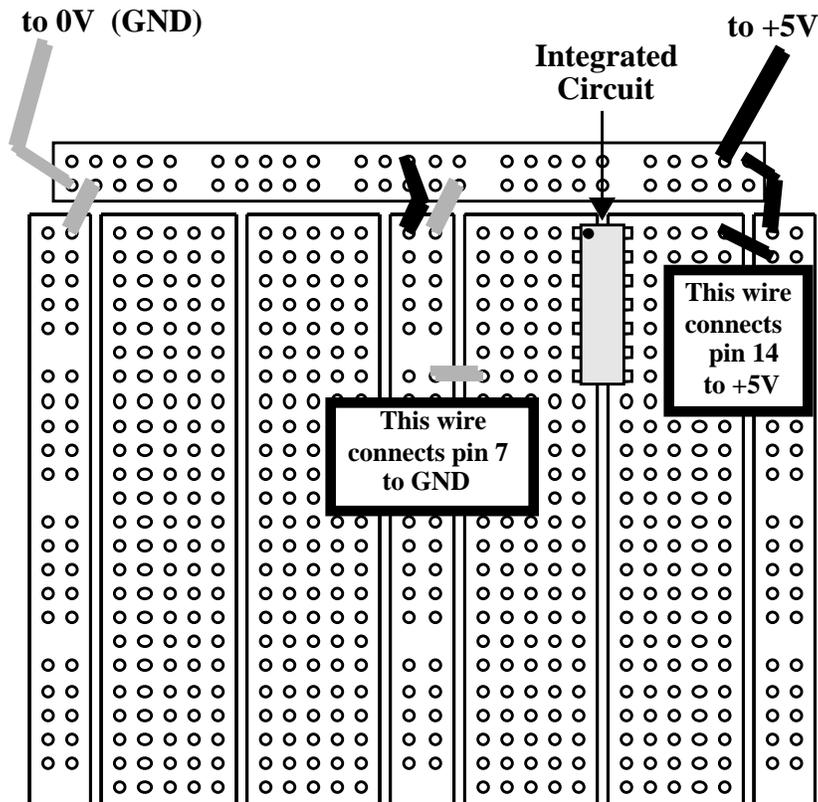


Figure 2.3 Power supply connections to components in the bay on a protoboard.

- Cut them to the right length. It's tough to debug your circuit if even the short connections have a lot of extra wire sticking up in the air. You should cut the wire to the needed run length plus 1".
- Cut off enough insulation to get a good connection. This should be about 1/2" on each end of bare wire. Don't cut off too much insulation or two wires can rub up against each other and make a connection you did not plan.
- Keep inserted wires flat if you can. Don't wire over the top of ICs if you can avoid it—it makes it really hard to remove that IC without yanking out all of the wires.
- If there are a lot of colors of wire in the box, try to color code wires of the same type (like power or ground, or inputs or outputs) to make it easier to debug the board.

We illustrate a few of these wiring “style” do-s and don't-s in Fig. 2.5.

When wiring circuits up on your protoboard, begin with a complete

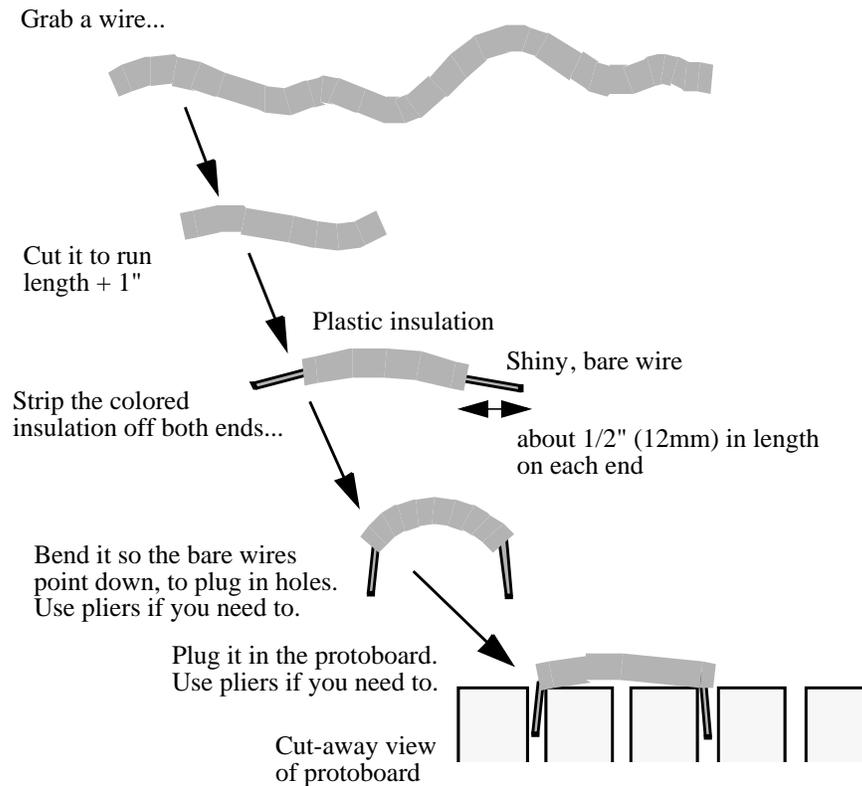


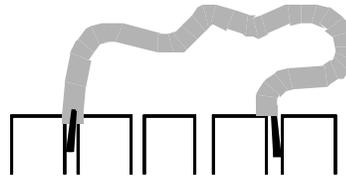
Figure 2.4 Preparing wires for use on the protoboard.

circuit diagram, including pin numbers on any integrated circuits and pinouts for transistors. A physical correspondence between the schematic and the layout of the circuit will help to avoid wiring errors. You should be concerned with the mechanical stability of the circuit; alligator clips and oscilloscope probes can pull components out of protoboards if you are not careful. Try to keep wires short and press them down against the protoboard. Do not connect your circuit up with long wires looping into the air. Semiconductor devices can be very easily destroyed if they are improperly connected. To minimize the risk of burning out components, you should always double check the wiring of your circuit before applying power. You should always turn the power off before changing connections. If you suspect that a device is bad, you have test equipment to check it. Grounding is very important for making accurate electrical measurements. Note that coax shields are frequently connected to the instrument case. If you are using several instruments to apply and measure signals, the instrument cases represent different "grounds". To minimize the effects of these different grounds, all of test lead shields should be tied to the same part

This is a nice wire: right length, flat, enough bare wire exposed to make a solid connection



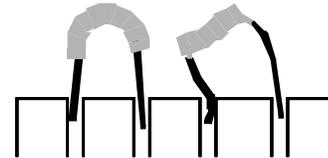
Too much wire. Imagine a board with 30 or 40 connections like this. You can't see what you are doing!



Stupid! How are you going to make a connection if you forget to strip off the insulation? It's the same if you don't strip enough insulation off, too.



Risky. Too much bare wire exposed. If you bend one of these just right, you connect it to something wrong.



Inconvenient. What if your chip happens to be bad, or it's the wrong chip, or whatever? You have to pull out the wire to replace the chip. This is a pain for a lot of wires.

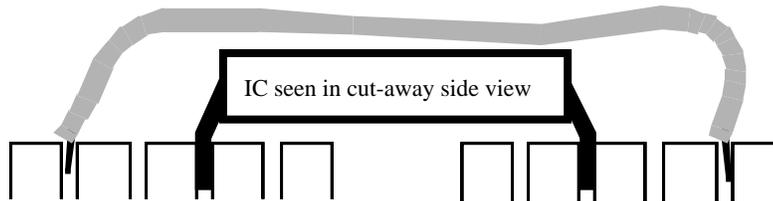


Figure 2.5 Wiring styles and things to avoid.

of the circuit. If the shields are tied to different ground points in the circuit, then any ground current between instruments will introduce (small) voltages between the grounds in different parts of the circuit. Equipment failure is rare; the source of the problem is almost always incorrect wiring, component failure, or incorrect use of the test instruments.



Laboratory Exercises

1. First, find a $1\text{K}\Omega$ resistor (color code = brown, black, red) in your kit. Note, Chapter 1 includes a description of how to read the color bands on the resistors. Press the Ω button on the digital multimeter (DMM). Connect one lead of your resistor to one ohmmeter terminal, and the other lead to the other terminal. Hold it for a second, and it should tell you that you have something close to $1\text{K}\Omega$ of resistance. It should be accurate to within the resistor's tolerance given by the fourth color band. An ohmmeter measures resistance by placing a small voltage across the resistor's terminals and then measuring the current that flows.
2. Set the power supply to the +20V scale and adjust the voltage to read 5V. Make sure you are reading the correct scale. Change your multimeter setting from ohms to DC volts. Using the same terminals that you used to measure resistance, measure the voltage across the power supply terminals by touching the top meter lead to the +20V terminal and the lower meter lead to the common terminal of the power supply. Note that your DMM, when the leads are in the COMMON (LO on right) and Volt-Ohm jacks, acts like an open circuit that can be placed between any two points in your circuit and will indicate the voltage difference between those two points. **WARNING:** when the test leads are plugged into the COMMON and AMPS jacks, the DMM looks like a short circuit (a piece of wire) and can be used to replace any piece of wire in your circuit allowing you to measure the current that flows through that piece of wire. Placing the DMM in AMPS mode across any two circuit nodes **SHORTS** them out. You may wish to attach a piece of wire to each of the power supply terminals so that you can clip the meter on to the end of these wires – of course after you have stripped the insulation from both ends so that the metal makes good contact with the power supply terminals and the DMM clip leads. Within a second, the meter reading should stabilize near 5V. Assume that your meter's reading is the true voltage between the power terminals. By watching

the meter reading as you make fine adjustments to the power supply voltage, set it to exactly 5V. Now, switch the meter leads so the one measuring the common terminal measures the +20V terminal, and vice versa. Your voltmeter should read - 5V.

3. Insert a $1\text{K}\Omega$ resistor into your protoboard and then connect one end of your resistor to the +20V power terminal and the other end to the common terminal using hookup wire. You have created a 5V difference between the ends of the resistor. You should check, using your DMM as a voltmeter, to make sure that adding the resistor, and the current it draws, did not change the power supply voltage. How much current should be flowing through the resistor? To check, we will use the ammeter. An ideal ammeter should be a wire that measures the current that flows through it. Consequently, you have to hook it up as you would a wire – in this case we replace the wire between the +20V terminal of the power supply and the resistor. Then, the current that goes through the resistor should go through the meter. Change the multimeter setting to DC Amps, and be sure to use the two ammeter banana jacks of the multimeter. Disconnect the +20V power lead from the resistor, and connect it to one lead of the ammeter. The other lead of the ammeter should be attached to the resistor lead which you disconnected from the power supply. Now the current goes from the power supply, into the ammeter, back out of the ammeter, into the resistor, out of the resistor, and back to the power supply. The current reading should follow the $V=IR$ formula. (Voltage equals current times resistance). Does it? It may be + or - depending on which direction you set up the meter

