## **CHAPTER**

1

## Introduction

Welcome to the world of Electrical and Computer Engineering. In the series of laboratory exercises presented in this text, we hope to give you a "hands-on" tour of much of what this field is about. In working through this set of laboratory exercises, you will gain practical insights and experience with a series of basic concepts in Electrical and Computer Engineering. This series of laboratory exercises is organized around the construction of a very simple programmable robot - the Graymark Model 603A Programmable Robot. This robot can be programmed to turn its light on, beep, turn left, turn right, and drive straight forward. Although one goal of this series of laboratory exercises is the construction of the robot kit, they are designed to take the reader much further than simply assembling a robot kit and getting it to work. In each chapter one or more important concepts are first illustrated by assembling the circuit being studied on a prototyping board (protoboard) and then by performing a series of experiments and observations. Only after the basic concepts have been fully explored is that subsystem of the robot kit is soldered onto the robot's printed circuit board.

Assuming that you pursue further study in Electrical and Computer Engineering, you will have many opportunities to delve deeper into the theory behind how the circuit elements presented in this text work and interact. One of our goals in this text is to give you a broad set of experiences with some of the elements of Electrical and Computer Engineering. As your practical knowledge is developed through experience, you will have a greater pool of observations and experiences to which your later theoretical understanding can be connected.

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The following is a terse overview of the various electronic components that will be used in the laboratory exercises presented in this text. It is included here for reference only and it is not intended to stand alone as a presentation of this material.

**Electrons** All matter is composed of atoms. These atoms have a heavy middle part called a nucleus made up of protons and neutrons. The proton carries a "positive charge" and the neutron carries no charge. Around every nucleus there is a cloud of little particles called electrons, which carry a "negative charge." The reason that the electrons are there is that they are attracted to the protons – opposite charges attract. If the protons weren't there, the electrons would push away from each other – like charges repel. So everything we see and touch is actually composed of millions of nuclei floating in a sea of electrons.

This all becomes relevant to electrical engineering (named for the electron) because we can access the energy inherent in electrons moving around. About 150 years ago, a scientist named Michael Faraday discovered that when electrons were moving, part of their kinetic energy could be transferred to a nearby magnet, thus making the magnet move. Conversely, if you physically moved a magnet near an electron sea, you could get an electric current to flow. This was a very important discovery, for it was the link between our mechanical world and the world of electrons (also known as elec-Mechanical energy could be transferred to electrical tronics). energy, where it could be stored and transported efficiently, and then brought back to mechanical energy. For example, water going over Niagara falls can spin large magnets through metal coils. This causes electricity to flow in the coils, which can be wired into nearby homes. The energy is then available through wall outlets, where you can plug in your vacuum cleaner, and the electric currents can spin the magnets in the vacuum cleaner's motor.

**Current** and Voltage Electric current flow is the means of communication between different parts of any circuit. Effectively, a circuit is just a network of different components that allow the electric current to flow in specific ways. Together, the materials can act as switches, amplifiers, oscillators, etc. The network is arranged so the desired input/output relationship holds for the circuit.



As you build your robot throughout the sequence of laboratory exercises described in this text, you will be able to see some of these electrical communications. The wheels, the beeper, and the lights will all be controlled by the circuits you will assemble. You will tell the circuit what to control and how to control it by a connected pushbutton box called the "teach pendant".

Fundamentally, one of the causes of current flow is a difference in the potential energy of a free electron at two different points. This is analogous to the gravitational potential energy difference that causes water to flow down a hill. When electric currents were first being studied it was known that things were flowing, but it was not known exactly what was moving, nor in which direction. Benjamin Franklin chose a convention for current flow, objects flowing from a positive electrical potential (called voltage) toward a negative electrical potential, which turned out to be wrong. This is the reason that the charge on an electron is by definition negative. If point A is at a higher voltage than point B, then electrons want to move from B to A (see Fig. 1.1). However, the direction of current flow is defined to be from A to B, opposite to the direction of electron flow. We take care of the difference in direction by assigning a negative charge to the electron. For example, in a battery, the current flows from the positive terminal to the negative terminal, but the electrons go from the negative terminal to the positive terminal. In electronics, the standard is to talk of the current flow, not the electron flow.



Figure 1.1 Current flowing in a wire.

Current is measured in units called Coulombs. A Coulomb is defined as the negative of the charge of  $6.25 \times 10^{18}$  electrons. When 1 Coulomb per second passes by a given point, we say that 1 Ampere of current is flowing. It is written as 1A. The letter I is the standard variable for current in equations.

We also need to measure the driving force making the current flow.

When there is a high voltage (electrical potential) at a location, it is like a compressed spring whose energy will be released when charge can move "down hill" to a lower voltage. The higher the voltage, the more energy electrons lose as they move to a lower voltage. If one Joule of energy is released when one Coulomb of charge moves from A to B, we say that the point A is 1 Volt higher than the point B. One volt is written as 1V. Voltage is always measured between two points. When you say that a particular point in a circuit has a voltage level, you are really giving the voltage relative to the defined reference voltage for the circuit. This reference voltage is typically called ground or common.

In order for charge to flow from one place to another, there must be some path for it to take. Referring back to our water analogy, even if a field is lower than the river, water will not flow into the field if there is a dike that is higher than the river in between. If there is an air gap between two objects, electrons cannot flow between them even if there is a voltage difference. However, a high enough voltage difference will cause the electrons to jump through the air. This is what happens when lightning strikes. In a laboratory, this is both dangerous and impractical for manipulating current flow. It has been discovered that some materials require very little voltage across them to allow a sizable current flow, due to their higher free electron concentration. These are called conductors. Most metals are good conductors, and thus metal wires are useful in connecting parts of the circuit together. Generally, it is assumed that there is no voltage difference between any two points of an unbroken metal wire because electrons move easily throughout the metal.

On the opposite end of the scale, there are other materials that are very resistant to current flow. These are called insulators. Plastics are commonly used as insulators. In between conductors and insulators, there exists a third class of materials called semiconductors. These are materials which can conduct current, but not nearly as well as conductors. Semiconductors have useful current-regulating properties when two different kinds of semiconductors are placed in contact. You will learn about that later.

**Resistors** In many cases it is necessary to produce a specific current given a specified voltage. To accomplish this, elements known as resistors are constructed. They look like color banded cylinders with wires coming out either end. They limit the current that goes through them. The value of a resistor is determined by the ratio of the voltage across it to the current through it. The unit used for resistors is the Ohm, abbreviated as  $\Omega$ , and it is defined as 1Volt per Ampere. For example, if 2A are flowing through a 5 $\Omega$  resistor, then there

must be 10V across the resistor. The key formula here is that voltage= current x resistance, which is known as Ohm's Law. Symbolically,

#### V = I R

where V, I, and R are the standard variables used in representing voltage, current, and resistance, respectively. In electronic circuits, 2A is a fairly large amount of current. Usually, it is convenient to write current in terms of thousandths of an Ampere, or milliamperes (mA). Resistors, on the other hand, often have values of thousands of ohms, or kilohms (K $\Omega$ ). In a typical lab, you might have 6V across a 2K resistor, resulting in 3mA of current.

Normally, a circuit will contain more than one resistor. When there is a voltage difference between two points, we know that a resistor connecting the points will allow a current to flow through it. If there are two or more resistors each connecting the same two points together, those resistors are said to be in parallel with each other. The current through each resistor is given by Ohm's Law. The equivalent resistance would be one which caused the same total current to flow (see Fig. 1.2); i.e.,

$$Req = 1 / (1 / R1 + 1 / R2)$$

If a current that flows between two points must go through at least two resistors, those resistors are said to be in series with one another. When resistors are used in a line like this, they act as one big resistor whose value is the sum of the component resistors. The current that flows through all of the resistors is the voltage between the endpoints divided by the sum of all of the resistances. The voltage across each component resistor is the current times the individual resistance (see Fig. 1.2); e.g., for 2 resistors in series,

$$Req = R1 + R2$$





Figure 1.2 Examples of parallel resistors and series resistors.

Remember that the voltage across a resistor is the amount of energy released when one coulomb passes through the resistor. The current is the number of coulombs passing through the resistor per second. When you multiply the voltage and the current, you get the energy released per second, which is the power dissipated.

$$\mathbf{P} = \mathbf{V} \mathbf{I} = \mathbf{V}^2 / \mathbf{R} = \mathbf{I}^2 \mathbf{R}$$

This electrical energy is converted into heat energy by the resistor, and it warms up. Resistors can usually cool off into the surrounding air, but only so fast. There is a maximum power, or rate of heat energy, that you can put into a resistor before it becomes damaged. Most of the resistors you will use have a power rating of 1/4 Watt. 1 Watt is 1 Joule / second and equals 1 V times 1 A.

A standard color coding convention is used for specifying the value of a resistor. Table 1 shows the numerical value associated with each color. The first two color bands indicate the first two digits in the resistor's value. The third color band indicates the power of ten that the first two digits are multiplied by. The fourth color band specifies the tolerance of the resistor. For example, a resistor with a band set of yellow-violet-orange-gold will have a value of 47 x  $10^3$  ohms (47K $\Omega$ ) with a tolerance of 5%.

#### Table 1: Resistor Color Code

Black Brown Red	0 1 2	Gold Silver No Band	5% 10% 20%
Orange Vellow	$\frac{2}{3}$		2070
Green	5		
Violet	7		
White	o 9		

Next, we introduce an element called a capacitor. In its simplest form, it consists of two metal conducting plates parallel to each other separated by an insulator. Capacitors are energy storage devices. When a current flows into a capacitor, the electrons leave the positive plate, leaving a positive charge. The extra positive charge pulls electrons onto the negative plate and the electrons are held there. Consequently, a charged capacitor holds a voltage across its terminals. The voltage between the plates is proportional to the amount of charge. Symbolically,

Capacitors

#### Q = C V

where Q is the charge stored, and V is the voltage across the terminals. C is called the capacitance of the element. When you divide the charge stored in a capacitor by the voltage across it, you get the value of the capacitor in units of Farads. A 1F capacitor is quite large for most circuits, so capacitors are usually specified in microfarads (uF) -  $10^{-6}$ F - or picofarads (pF) -  $10^{-12}$ F.

The capacitor discharges when current is allowed to flow between the plates. This causes the electron concentration to equalize on the two plates, and a current flows through the connection. When the connection is a circuit, the capacitor acts as a power supply for the circuit as it discharges. For this reason, a capacitor is called an energy storage device. This is illustrated in Fig. 1.3.



Figure 1.3 Example of capacitors being charged and discharged.

There are two kinds of capacitors in your robot, polarized and non-polarized. The two polarized capacitors are electrolytic, and cylindrical in shape. In these electrolytic capacitors the dielectric only acts as a good insulator for voltages of one polarity. When voltages of the opposite polarity are applied the dielectric may fail and allow significant currents to flow directly from one plate of the capacitor to the other – usually resulting in its destruction. For these polarized capacitors you must always make sure that the terminal labelled with a "+" will be connected to the point in your circuit that is at a higher voltage and the terminal with a "-" will be connected to a point in your circuit at a lower voltage. There is a black stripe down the side of each of the capacitors in your robot kit, which indicates the **negative** lead of the capacitor. All the electrolytic capacitors have their value written on them. The rest of the capacitors have a three digit number on them followed by a K (or JT). The three digit number reads just like the three color bands on resistors, and the K stands for pF. For example, a capacitor reading 682K would be a  $68 \times 10^2$  pF capacitor.

**Diodes** The simplest "semiconductor" device is the diode. A diode is like a one way street for current flow. It is made from two different kinds of semiconductors (called N and P - but don't worry about why now) next to each other. The current can flow from semiconductor P to semiconductor N, but not the other way around. You can also think of a diode as a water pipe with a valve inside that can only swing one way. Water can never flow in the direction that would push the valve the wrong way. Water can flow in the other direction, though, as long as there is a little pressure to push the valve

open. In diodes, this "little pressure" is usually about 0.7V. When current is flowing through diodes, there is almost no resistance, but the end of the diode where the current enters is always about 0.7V higher than the end that the currents exits. Fig. 1.4 illustrates the schematic representation of a diode, along with the water pipe analogy.



Figure 1.4 Example of how a diode operates

Of course, nothing is perfect. If you do put a large voltage across a diode in the wrong direction, a current will push through the wrong way (breaking the "one way valve" in the pipe). The voltage at which this occurs is called the reverse breakdown voltage, and it varies between diodes. This characteristic of diodes is utilized in Zener diodes. Zener diodes are designed to have well controlled reverse currents at predetermined breakdown voltages. They are characterized by the voltage at which they allow reverse current. In this lab we will be using a 5.6V Zener diode. This means that 5.6V across the diode in the reverse direction will cause reverse current to flow, just as 0.7V in the forward direction will cause a forward current. The Zener diode but for the crooked bar. An example of what current would flow if you applied various voltages to the 5.6V Zener diode in your Robot Kit is shown in Fig. 1.5.



Figure 1.5 Zener diode symbol (left) and I-V curve (right).

There are three kinds of diodes you will be using in your robot. First, there are standard diodes D1-6. These are the orange elements with a black stripe and labeled with the number "4148." You will note that the stripe is closer to one of the diode leads. The end with the stripe is the N type semiconductor (see Fig. 1.6). Hence, current will only flow from the other end toward the end with the stripe.



**Figure 1.6** Schematic symbols for diodes. From left to right: normal signal diode, Zener diode, and light emitting diode.

There is another orange element similar to diodes 1-6, only it is labeled as "5.6" or "5232." This is the Zener diode used in the power circuit. Just as in regular diodes, the black stripe is on the N side of the diode (see Fig. 1.6). However, a Zener diode is nor-



mally used in reverse breakdown, hence the current will flow from the end with the stripe to the other end.

The last kind of diode you will be using is the light emitting diode (LED). This is a domed red element with two leads coming out of the bottom (see Fig. 1.6). When sufficient current flows through it in the forward direction, it will light up red. You will notice when you look down on the LED that it has a circular base except for a flattened edge on one side. This flattened edge is directly above the N semiconductor side of the diode.

Another important device is the transistor. Like diodes, they are **Transistors** made of semiconductors. In our robot, we will use them as current multipliers and as switches. There are three leads into a transistor, and they are called the emitter (E), base (B), and collector (C). If you leave the C lead floating (i.e. not connected), and just look at the B and E terminals, you would find that between these leads there is just a diode. There are two types of transistors depending on whether the base region is P or N type semiconductor. The Emitter and Collector are always of the opposite type from the base; therefore, the transistors are called NPN or PNP indicating the semiconductor type of the Emitter-Base-Collector. In an NPN transistor, current can only go from B to E, and when it does, lead B is typically about 0.7V higher than lead E. When lead C is hooked up to a voltage greater than the voltage at lead B, a current will flow from C to E which is a multiple of the current going from B to E.

This current multiplier is called the  $\beta$  (the second letter of the Greek alphabet, "beta") of the transistor, and usually varies from about 75 to 400. However, it is nearly constant for a given transistor, and doesn't vary much with the current it multiplies. The current coming out of the E terminal (called the emitter current) equals the current going into the B terminal (the base current), plus  $\beta$  times the current going into the B terminal (which is the current going into the C terminal). Symbolically,

 $IE = IB + IC = IB + \beta IB = (\beta+1) IB.$ 

Another kind of transistor which we will be using later is the PNP transistor. It acts just the same, only type of semiconductor in the E, B, and C regions is reversed, so the small current goes from E to B, and the large current goes from E to C. The emitter terminal will have an arrow on it to distinguish it from the collector terminal. Since the current leaves the emitter in an NPN transistor, the arrow points outward. The schematic of a PNP transistor will have the emitter arrow pointing toward the base.

There are three kinds of transistors you will need to build your robot; 4 regular NPN transistors (2SC1815's), 1 regular PNP transistor (2SA1015), and 3 higher power NPN transistors (2SC2120's). They all look like black semicircular cylinders with three leads coming out of one end. To determine which lead is which, do the following: facing the flat side of the transistor, with the leads pointing down, and reading from left to right, the leads are Emitter, Collector, and Base, in that order. This is the same for all three kinds of transistors (see Fig. 1.7). You have a list of replacement transistors in case you lose or destroy one of the kit's transistors. Unfortunately, we were not able to obtain exactly the same transistor. Although the replacement transistor looks similar, its leads are swapped internally as shown below. If you need to use one of the replacement transistors, you will have to carefully bend the B and C leads around each other without allowing them to touch. If you hold both transistors with the flat facing you and the leads coming out of the bottom, the leads of the replacement transistor are E, B, C (from left to right), rather than E, C, B as in the original robot kit transistor. Keep this in mind if you have to use them.



Figure 1.7 The physical appearance of the Bipolar transistor.

For your reference, we next include a schematic diagram that shows how the electronic components that make up your robot are connected together. You will need to refer to it periodically as you carry out the laboratory exercises. Following that we include a parts list for all of the components that are associated with the laboratory exercises in this text.



**System Perspective** 







Chapter 1: Introduction

### **Electronics Parts List**

### **Parts From the Robot Kit**

Resistors: All 5%, 1/4W Capacitors						
R1 R2 R3 R4 R5 R6 R7 R8 R9 R10	220K 100K 51K 100K 15K 51K 1.8K 20K 100K 15K	,	C1 C2 C3 C4 C5 C6 C7 C8 C9 C10	47 uF-1 6800pF 6800pF 6800pF 6800pF 6800pF 6800pF .01uF 3300pF .47uF		
R11	1.8K		C11	100uF-	polar	
R12	68K				-	
R13	1K					
R14	750		<u>Transis</u>	stors	<u>R</u>	eplacement
R15	100					
R16	15K		Tr1	2SC18	15Y	2N3904
R17	15K		Tr2	2SC18	15Y	2N3904
R18	4.7K		Tr3	2SC212	20	2N3053
R19	1.8K		Tr4	2SA10	15	2N3906
R20	120K		Tr5	2SC18	15Y	2N3904
R21	100		Tr6	2SC212	20	2N3053
R22	15K		Tr7	2SC212	20	2N3053
R23	220K		Tr8	2SC18	15Y	2N3904
R24	330					
R25	15K	Diodes	6	-	Replace	ement
R26	15K					
R27	4.7K	D1-6	1N414	8 1	N4148	
R28	4.7K	ZD (Z	ener) 52	232B	1N5232	2B or 1N4734A
R29	4.7K	LED	Light H	Emitting	; Diode	
VR	500KΩ poten	tiomete	r			
<u>Integra</u>	nted Circuits- C	<u>MOS</u> f pins	<u>R</u>	eplacen	nent	
Δ	4011	14		4011		
B	4011	14		4011		
C	4013	14		4013		
Ď	4069	14		4069		
Ē	4040	16		4040		
Ē	5101	22		5101		
1	5101		(h	e carefr	1] - its e	expensive)
			(U	c curcit	1 1030	Aponsi (C)

Also, you should have a small speaker, 10 connector posts, a pushbutton switch, a SPDT switch, 2 motors, and a collection of mechanical hardware that is detailed in the Graymark instruction manual.

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### **Electronics Parts**

### **Additional Parts - Not in Robot Kit**

Resistors: All 5%, 1/4W

 R30
 120K

 R31
 20K

 R32
 6.8K

 R33
 1.5K

 R34
 1.0K

 R35
 750Ω

 R36-R50
 330Ω (15 of them)

**Diodes** 

LED2-13 Red LEDs (12 pieces)

**Integrated Circuits** 

G LM741CN (8 pins)



# General Circuit Construction Guidelines

Circuit construction and testing is an important skill that you should learn as you carry out the exercises described in this text. When wiring circuits, begin with a complete 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. Semiconductor devices can be very easily destroyed if they are improperly connected. To minimize the risk of burning out components, you should double check the wiring of the circuit before applying power. Be especially wary of mixing up the pins of a transistor or integrated circuit. You should always turn the power supply off before changing connections. If you suspect that a device is bad, you have test equipment to check it. Equipment failure is rare; the source of the problem is almost always incorrect wiring, component failure, or incorrect use of the test instruments.

One important method that is used in electronics for connecting circuits permanently is to solder the wires to a printed circuit board. Solder is a special metal that can be melted at a low temperature. We can connect two metal leads together by melting metal across both leads and allowing it to cool. This is the method that is used in your robot kits.

To prepare you for soldering your robot, you will first spend some time learning to make good solder joints on scrap circuit boards. It is important to practice this first, as excessive heating or excessive solder can destroy the robot PC board. There is a soldering iron, a cleaning sponge, and rosin core solder in the lab tool kit. **ALWAYS** use **rosin core solder** when soldering electronic components. The acid core solder used by plumbers will corrode delicate electronic components. At the beginning of the lab you should plug in the soldering iron to allow it to warm up fully before attempting to solder. If you plan to purchase your own soldering iron, always use a low wattage (25-40W) soldering iron. High power soldering irons can overheat delicate electronic components. If your soldering iron does not seem to be getting warm, you should check to make sure that the soldering iron is plugged in and that the power switch for your lab bench is turned on. You should also wet the sponge before each soldering session. Each time you are about to use the soldering iron to solder a wire, you should first brush it lightly across the wet sponge. This removes the corrosion that tends to build up on the tip when it is hot. Solder cannot stick to paint, grease, oil, wax, hair, or other organic substances. In addition, solder will not stick to corroded wires, printed circuit board traces, or component leads. Any corroded surfaces should be buffed with steel wool or fine sandpaper in order to remove the corrosion before soldering is attempted. Wires, component leads, and the copper traces on a printed circuit board should always appear shinny.

Wires or components to be soldered should be held in place by bending their leads to keep them fixed in place or by holding the component with a pair of pliers. If you are holding a component with a pair of pliers, you must keep the pliers perfectly still until the solder has cooled, otherwise you will have a poor and unreliable solder joint. It is dangerous to hold a component being soldered in your hand, as heat will be conducted from the point at which it is being soldered throughout the component or wire. Note, the most common error in soldering is to apply the solder to the tip of the soldering iron. A small drop of solder placed on the tip of the iron before it is brought in contact with the wires to be joined can facilitate heat flow from the iron into the wires. This is called "tinning" the tip. However, additional solder applied to the tip will tend to form a ball on the soldering iron rather than flowing into the solder joint.

You should first bring the soldering iron into contact with the wires and/or printed circuit board traces that are to be soldered together. Typically holding the iron at roughly 45° to the printed circuit board surface. Try to have the tip of the iron touching all of the different wires that are to be joined. Wait about two seconds for the wires that are part of the joint to heat up. Then bring the solder in from the opposite side of the joint. It should also approach at roughly 45° to the printed circuit board surface. You should only touch the solder to the wires to be joined. They should be hot enough to melt the solder. **NEVER** bring the solder in to touch the soldering iron tip. Feed in solder until a smooth fillet appears between the leads being joined and the printed circuit board trace. Too much solder will result in a large ball enclosing the joint. This should be avoided. Too little solder will leave the leads coated in solder but without solder bridging between them and the printed circuit board. This should also be avoided.



**CAUTION**: The solder joint you just made, and all of the components attached to it will be very hot for several minutes after being soldered. You should use care in touching metal leads, or any component that has been recently soldered. In addition, the tip of a soldering iron is very hot. It will burn you. One dangerous practice it to allow the power cord of the soldering iron to loop off the edge of the lab bench. This is dangerous because passers by might bump it causing the soldering iron to pull free of the holder and injure someone. You should keep the cord of the soldering iron completely on the surface of the lab bench. In addition, you should never leave the soldering iron sitting directly on the lab bench surface as it can easily spin around and burn objects on the bench. Instead always return the soldering iron to its holder.

Because it is possible to make a mistake and solder together the wrong components (though hopefully this is extremely rare), you should also learn how to "unsolder" components. The key job in unsoldering components is removing the solder from the joint without damaging the components or the circuit board. All approaches to removing the solder require reheating the solder joint with the soldering iron to return the solder to a molten state. Just as with soldering, when you are about to use the soldering iron to unsolder a wire, you should first brush it lightly across the wet sponge. This removes the corrosion that tends to build up on the tip when it is hot. In addition, you may find that it helps to place a small drop of solder on the tip of the iron before it is brought into contact with the solder joint to be unsoldered.

Wires or components to be unsoldered should be held using a pair of pliers. Remember, it is dangerous to hold a component being heated by the soldering iron in your hand, as heat will be conducted throughout the component or wire.

You should first bring the soldering iron into contact with the wires and/or printed circuit board traces that are to be unsoldered. Typically holding the iron at roughly 45° to the printed circuit board surface. Wait until the solder joint begins to soften. Usually this is evident as the tip of the soldering iron sinks into the solder joint slightly. At this point, the component being held by the pliers can be removed from the solder joint by **gently** pulling on the pliers. **Do not** pull hard or the copper trace may be pulled away from the surface of the printed circuit board.

The solder left on the circuit board can be removed using solder wick or a "solder sucker." Solder wick is a copper braid which absorbs molten solder. First the end of the solder wick is brought into contact with the solder joint. Then the solder joint is heated with the soldering iron until the solder melts at which point it is absorbed into the solder wick. Next remove the solder wick and then the soldering iron from the joint which should have been drained of its solder. The end of the solder wick, which has become matted with solder is then cut off using a pair of diagonal cutters – but be careful it is very hot. If there is still solder remaining on the solder joint, this process can be repeated until all of the solder is all removed.

Another approach to removing the solder from a solder joint is to use a "solder sucker" which is a small suction device that actually pulls the solder away from the board using suction. The soldering iron is first used to heat the solder joint until it is molten. Then the tip of the solder sucker is brought into proximity with the solder joint and the solder sucker is triggered. It sucks some of the solder up into its suction chamber. This process is repeated until all of the solder is removed from the joint.

Note, many components are sensitive to prolonged heating with the soldering iron. Therefore, it is a good idea to heat a solder joint, remove the solder, and then let it cool before repeating the process. In addition, extended heating can also cause the copper traces on the printed circuit boards to detach from the surface of the board.

<u>**CAUTION</u>**: The solder joint you just unsoldered, and all of the components you removed will be very hot for several minutes after being unsoldered. You should use care in touching metal leads, or any component, or the printed circuit board that has been recently unsoldered.</u>



The first step in this laboratory exercise is to practice soldering and unsoldering. Making good solder joints takes practice. Therefore, you should first practice soldering wires onto a piece of scrap printed circuit board. These will be provided in the laboratory by your teaching assistant (TA). Unsoldering solder joints without damaging circuit components also takes practice. Once you are confident of your ability to solder wires to the printed circuit board,



you should proceed to practice unsoldering some of these wires. Carefully remove the excess solder from the printed circuit board with either solder wick or a solder sucker. Pay particular attention to removing all of the solder from the holes in the printed circuit board as a new component may need to pass through the holes where an old component was removed.

Once you have attained proficiency at soldering at soldering and unsoldering, you should show your work to a laboratory teaching assistant. After your soldering is approved, you may proceed to solder selected components onto your Robot PC Board. The board is diagramed so you can see exactly where each element belongs. The following parts are to be soldered onto the Robot Printed Circuit (PC) Board in the order presented:

- 1. All Jumper Wires These are indicated with a "J" in the Robot Instruction Manual and on the printed circuit board itself. Remember to trim off any excess leads on the jumper wires. Before going on to solder any other parts onto the board ask a TA to take a quick look at your board to make sure that your soldering technique is acceptable. If you run out of jumper wire included in the robot kit don't worry, there is plenty of spare wire in the lab. (Make sure you get all 16 jumpers.)
- 2. All IC sockets four 14 pin sockets, one 16 pin socket, and one 22 pin socket. DO NOT solder the IC into the circuit. You can tell the difference between the ICs and the sockets because the sockets have pins sticking out 1 side and holes on the other side whereas the ICs have pins sticking out one side and are flat on the other side. The easiest way solder the sockets into the board is to insert the socket into the board and then tape it down with scotch tape or masking tape. Then flip the board over so that the socket is resting against the lab bench. One person can press the board down gently to make sure the IC socket's pins are sticking out of the PC board while another person carefully solders each of the IC socket pins on the back of the PC board. NOTE, the sockets have a notch that indicates the end of the socket which will be next to IC pin 1. The robot PC board has silkscreen lines that also show a notch for pin 1. You must be careful to line up the notch in the socket with the notch in the silkscreen line before you solder it into the PC board.

- 3. The 8 Connection Posts (see the Robot Instruction Manual for a description of these posts) 5 of these are located around the round hole in the center of the circuit board. Starting at the 1 o'clock position and moving clockwise, they are labeled: +3V, ML, MR, COM, COM. Two posts are between Tr6 and Tr7 and are labeled: ML and MR. The remaining post is +9V by R9. These should "snap" into the PC board with a modest amount of pressure. They should then be soldered carefully into place. Make sure the end of the post that sticks out from the board is on the silkscreened side not the copper side.
- 4. Capacitor C1, a 47uF polarized capacitor. Note this is located in the upper right part of the Robot PC Board. Because this capacitor is polarized, you must insert it correctly so that it will only have positive voltages applied to it. Therefore, insert the lead of the capacitor nearest the black stripe into the hole in the board with the "-" sign next to it and the other lead into the hole marked with the "+" sign. NOTE: cut the leads of components leaving about 1/4", enough so that you can clip onto any component with the miniclips on your meter. Leave this much length on all components until you have completed Robot assembly and testing and are ready for the final mechanical assembly!!!
- 5. Capacitor C3, 6800pF (marked 682JT). The "682" stands for 68 X  $10^2$  pF). This should be located just to the left of C1. It is a nonpolarized capacitor and can be inserted with the leads in either orientation.
- 6. Capacitor C8, 0.01uF (marked 103KT). The "103" stands for 10 x 10<sup>3</sup> pF. This is located just below the 16 pin IC socket. It is a nonpolarized capacitor and can be inserted with the leads in either orientation.
- 7. Resistors R26 and R16, both are 15K. They are located just to the right of the 22 pin IC socket. Inset these resistors with the body parallel to and flat against the PC board. See the example in the Lab if you are uncertain how to do this.
- 8. Resistors R25 and R17, both are 15K. They are located just below and to the left of the 22 pin IC socket. Inset these resistors with the body vertical, pointing away from the PC board. The lead coming out of the top of the resistor should be bent back downward so that it is



parallel to the bottom lead of the resistor. See the example in the Lab if you are uncertain how to do this. Vertical mounted resistors are indicated on the Robot PC Board by a circle with a dot in it. Make sure you recognize these now so that you can insert other vertical resistors appropriately in the future.

 Solder in the reset switch (SW2) and power switch (SW1). They are on the lower left outside of the board. The reset switch has two posts to solder, and the power switch has 5.

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