Department of Electrical and Computer Engineering
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DISCOVER ENGINEERING SUMMER CAMP 1996

LIGHT Emitting Diode Project

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Introduction

1.1 Welcome to Electronics!

Welcome to the **Discover Engineering 1996** Electronics project. In this project you will work through the theory, prototyping and building of an electronic Light Emitting Diode sculpture. On the way, you'll learn something about electronics and get some idea of what it's like to do electronic engineering. To guide you through this entertaining (we hope...) exercise we have prepared a set of notes for you.

How much of this do I have to know ?

We're assuming that you're coming into this project with no background in electricity. If you know something about electricity, then that will be a plus, but it's not necessary. Hopefully, these notes and your instructors will teach you all you need to know to do the project. However, it is important that you read over these notes ahead of time, and that you ask questions if you're lost.

We don't want to scare anyone away from this subject, so the main material is explained in fairly simple terms (we hope...). But for people who know something about electricity and electronics, we have provided some more challenging material in the footnotes. If you're a beginner, you can ignore the footnotes.

Since we would like you to leave this session with some idea of what Electrical and Computer Engineering is about, we also provided an appendix in these notes, explaining briefly what these areas of engineering deal with.

Can I get electrocuted from this project ?

Definitely no ! The voltages and currents in this project are small enough that even major errors should have no dangerous effects. That doesn't mean you should be careless - the soldering iron used in the assembly part of the project is hot, and you can ruin the LEDs and battery by connecting them improperly - but there is nothing particularly dangerous about the project. Read this document, and then feel free to experiment.

1.2 Description of the Project

The idea is to assemble some LEDs (Light Emitting Diodes) and FEDs (Flashing Emitter Devices) into a small circuit that is powered by a 9 volt battery and does something visually interesting. We'll give you a chance to learn the engineering principles behind the design. That way, you can use the information to build new circuits on your own. You can build the circuit into a piece of clothing or jewellry and use the ideas of this project to build new versions of the project.

And, just to give you some inspiration, in this booklet we included layouts of a few most popular designs.

Chapter 2

Project Basics

2.1 Voltage and Current

These are terms we're going to use a lot in this project, so it's important to have a correct visual image of them. The easiest way to get at these is to imagine electricity as water that flows through wires rather than pipes.

Voltage is like water pressure, it indicates the force with which the electricity is being pushed through the wire. (In fact, the original term for voltage is *electromotive force*, or *EMF*. Voltage is measured in **volts**. As the voltage goes up, it becomes more dangerous. For example, the wall outlet voltage, 117 volts, can give a very nasty, even fatal, electric shock [1].

Current is a measure of the **amount** of electricity that is being pushed through the wire, and it is measured in **amperes** or amps. In this project, the currents are quite small, and are measure in **milliamperes**. A milliamp is 1/1000th of an amp.

[1]A common question at this point: Is it voltage or current that kills? Answer: both. A certain voltage is needed to push current through the human body. As well, the source must have the capability of supplying enough current to cause damage to human tissues. A major factor is the resistance of the body at the time of the shock. A lower resistance, for example because the body is wet, will result in more current for a given voltage, and thus a larger probability of serious damage.

2.2 Electronic Diagrams

We will need to be able to decipher electronic circuit diagrams for this project. There are two types of diagrams: the **pictorial** diagram and the **schematic** diagram.

The pictorial diagram (Figure 2.1) shows us a picture of the circuit just as it appears when constructed.

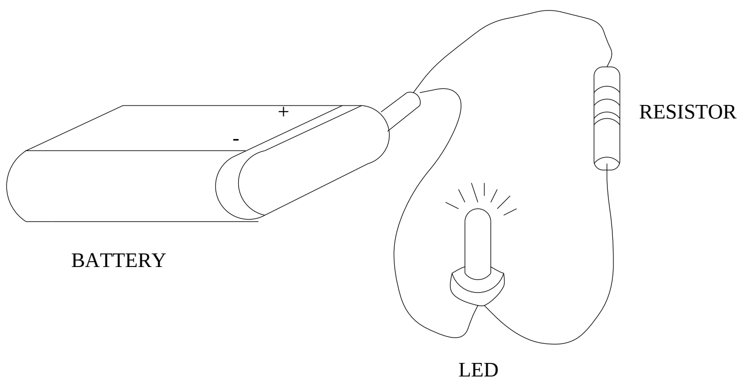

Figure 2.1: Pictorial Diagram

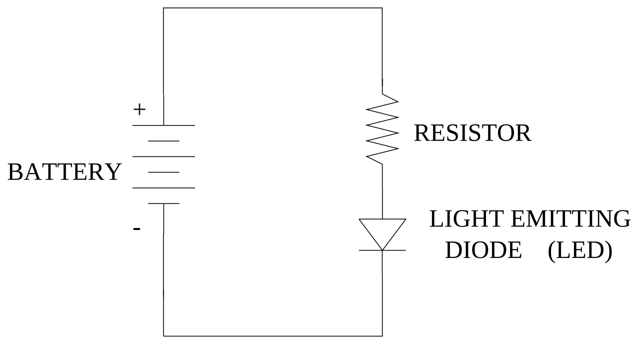

Figure 2.2: Schematic Diagram

The pictorial diagram is useful at first, but contains details that get in the way when the circuit becomes at all complicated. Moreover, components that physically look quite different have similar electrical behaviour, and the electrical behaviour is really what we're interested in[2]. Thus, we usually

[2]The real reason we don't draw pictorials is that it takes some artistic talent and most electrical engineers can't draw worth beans.

draw circuits in a schematic form, using **shorthand symbols** for various electrical devices, as shown in Figure 2.2.

2.3 Light Emitting Diode, LED

The main device we will be using in this project is the **Light Emitting Diode**, shown in Figure 2.3.

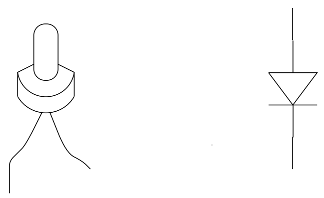

Figure 2.3: Light Emitting Diode (LED)

The LED is a solid state device, and depends on the same physics as the transistors and integrated circuits that make up all of electronic machines.

Like the incandescent lamp, the LED gives off light when a current is passed through it. Unlike an incandescent lamp, the LED cannot give off white light - it's only available in the colours red, yellow and green[3]. As well, the LED doesn't give off copious quantities of heat - it's a source of 'cold' light. As well as visible light, there are versions that give off infared radiation. These are the devices that are used in the television remote controls. And there are similar devices which are solid state lasers[4].

In this project, we'll be using the coloured LEDs as well as 'flasher' LEDs. The flasher (we'll call them FED's for Flashing Emitter Device) include a small circuit that causes the LED to flash on and off.

Two more things you should know about LEDs. First, they are a **polarized** component. That is, the LED will only operate if the current flows the correct direction through it[5]. The arrow in the schematic symbol indicates

[3]Light emitting diodes are monochromatic because the colour of the light produced depends on the band gap through which the electrons are falling in the semiconductor.

[4]The light from a laser is monochromatic and spacially coherent. That is, it produces one colour only and the wavefronts of the emitted light are in phase.

[5]This is not the case for light bulbs: they're quite happy to produce light whichever way the current flows.

the direction of current flow.

The two terminals of the LED are the **anode** and the **cathode**. The cathode of the LED is always marked with a flat spot on the case (though you have to look carefully to see it). The anode must be positive with respect to the cathode for current to pass correctly through the LED. If the voltage is reversed, nothing particularly nasty happens: the LED simply doesn't conduct and stays off. Very boring.

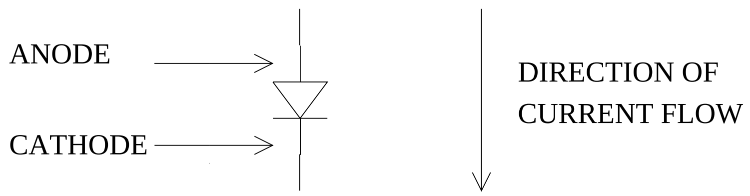

Figure 2.4: LED Polarity

The other thing to know about the LED is that it is a **constant voltage** device. That is, you must supply about 2 volts across it before it begins to conduct, and the voltage across its terminals will remain at 2 volts regardless of the current through it[6].

Because the LED requires at least 2 volts to do something interesting, we have to use a battery that produces at least 2 volts, and preferably more.

Finally, we need to know that the current through the LED determines its brightness: anything from 5 to 20 milliamps (0.005 to 0.020 amps) is satisfactory[7].

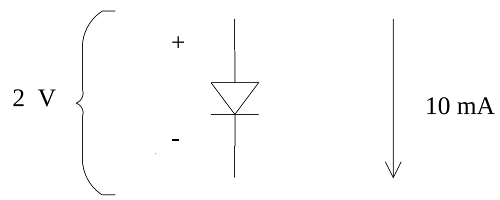

Figure 2.5: LED Voltage and Current

[6]This is not quite true. In fact, the voltage does increase slightly as the current increases.

[7]The perceived light output from an LED is not a linear function of the current through it, so 70% of the current does not lead to 70% of the visual effect. It's more like 95%. This works to our advantage by making the LED current very noncritical.

Light emitting diodes are available in a wide variety of shapes and sizes, and from a variety of electronic suppliers, for about $0.50 apiece.

2.4 The Battery and The Power Supply

The battery is a source of electrical energy. It has two terminals: electrical current flows out of the positive terminal (the long bar) and into the negative terminal (the short bar). [8].

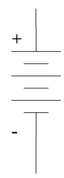

Figure 2.6: Battery Symbol

Just like the LED, the positive terminal of the battery is known as the anode, and the negative is the cathode.

The two properties of the battery that we are concerned about are the **terminal voltage** and the **current capacity**. The terminal voltage is the pressure with which the battery pushes out electrons at its terminals. In our case, the terminal voltage will be 9 volts. Other common terminal voltages are 1.5 volts (flashlight batteries) and 12 volts (car batteries)[9].

The current capacity of the battery determines essentially how long the battery will last. In our case, its life will depend on the kind of circuit attached to the battery, but you might expect an hour or so of continuous operation [10].

[8]In actual fact, the particles that make up a flow of current are negatively charged electrons. It's closer to the reality of what's happening to say that negative particles are flowing out of the negative terminal, than to say positive particles are flowing out of the positive terminal. In fact, because we very rarely deal with electrons as such, it is useful and convenient to view electrical current as positive particles flowing out of the positive terminal.

[9]The battery is made up of cells, each of which is 1.5 volts. More cells, connected in series, result in a higher voltage: larger cells result in longer battery life and higher output current capability.

[10]The capacity of a battery is specified in terms of ampere-hours, the product of the output current and the number of hours the battery can produce that current. According

Its useful to realize that a battery produces its voltage regardless of whether it is supplying any current. In fact, within certain limits, it produces its terminal voltage (in our case, 9 volts) regardless of the load current. For this reason, the battery, like the LED, is also known as a constant voltage device[11].

In the operation of an electronics lab using batteries would be impractical, as they would have to be replaced very often. That is why, while in the lab, you will use a device called a power supply. The faceplate of a power supply box is shown in Figure 2.7. The power supply contains a rectifying circuit which converts an AC power available from an electric outlet into a DC power source, for all practical purposes identical with the battery. However, its main advantages are that it has no limitations on how long it can be used (as long as it remains plugged in and switched on) and that we can adjust its output voltage as well as the amount of current that can be drawn. Positive and negative terminals of the power supply are clearly marked and color-coded (red for +ve and black for -ve).

You will assemble and test your circuit in the lab using the power supply. Its output voltage should be set to 9 volts, as this is the nominal voltage of a standard battery that you will yuse at home. Then, as a final step in the project, you will attach a battery clip to your circuit, replacing the power supply. The clip has a red and black wire. Again, the red wire indicates a positive terminal and the black is negative. At home you will be able to attach the 9 volt battery to the clip to operate your circuit.

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to the battery data book, this type of battery has a capacity of about 240 milliamp-hours. That is, it should be able to supply 240 milliamps for one hour, or 1 milliamp for 240 hours. The circuit in this project might require 60 milliamps, which would result in 4 hours operation. However, over the 4 hours, the terminal voltage would drop from 9 to 5 volts.

[11]The ideal constant voltage supply would produce its terminal voltage regardless of the load current. It could thus produce infinite current if its terminals were connected by an ideal conductor. In practice, a 12 volt car battery is very nearly an ideal voltage source. It can produce several hundred amperes of current if short circuited, and this magnitude of current can make nasty sparks, blow up wires, and start fires. This is why jumpering cars together in the winter when one of them has a dead battery, has to be done with extreme caution.

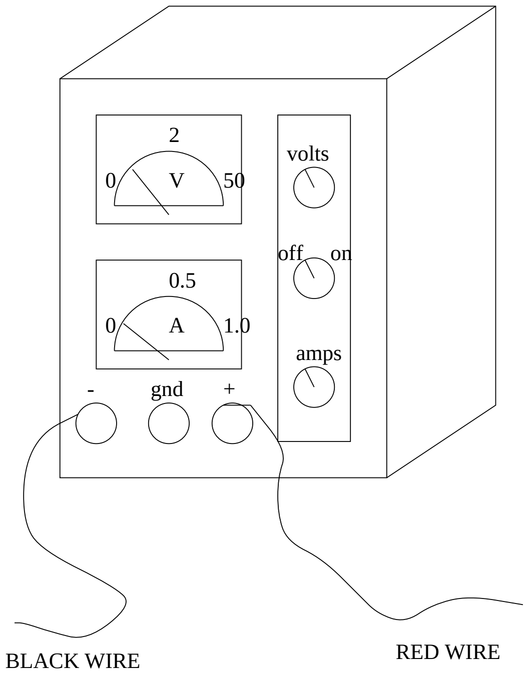

Figure 2.7: Power Supply

2.5 The Resistor

The resistor, as its name suggests, is a component that **resists** the flow of electricity. To continue with our analogy of water flowing through pipes, a small diameter pipe has higher resistance than a larger pipe. Or, the act of standing on a garden hose increases the resistance to the flow of water.

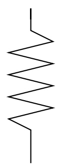

Figure 2.8: Resistor Symbol

In formula form, this is expressed as

$$I = E/R$$

where R is the resistance, measured in **ohms**, E is the voltage across the resistor, in volts, and I is the current through the resistor, in amperes.

If the voltage E is kept constant, and the resistance is decreased, the current will increase. If the resistance is increased, the current will decrease. This intuitively corresponds to the example of the garden hose: standing on the hose increases the resistance, and the current (the rate of flow of water) decreases. Opening the tap increases the pressure (voltage) which increases the amount of water flowing.

This equation is known as **Ohms Law**.

Now let's do an electronic example. Suppose a resistor has 7 volts across its terminals and a current of 10 milliamps through it. What is the value of the resistance?

$$\begin{aligned} R &= E/I \\ &= 7/0.01 \\ &= 700\ ohms \end{aligned}$$

In practice, the exact value of a resistance is rounded off to the nearest 'standard value', which in this case is 680 ohms. Knowledge of the standard values is one of those arcane pieces of knowledge that one acquires with age, just ask your instructor.

A resistor is marked with a 'colour code' which indicates its resistance. For this project, ask your instructor for help[12].

2.6 Using the Protoboard

We're about to actually wire up a circuit, so it's time to learn how to use the protoboard.

A wonderful and recent invention, the protoboard is used to interconnect electronic components for test circuits. It has the advantage that a lot

[12] The physical size of a resistor is completely unrelated to its resistance. However, the action of current flowing through a resistance transforms electrical energy into heat. In fact, the heat generated in watts is the product of the voltage across the resistor and the current through it. Resistors which have to dissapate more heat are made larger. We'll be using 1/4 watt resistors, which are quite dinky, because the amount of heat dissapated in this project is negligible.

of components can be fitted into a small space, it's quick to use, and the components can be plugged and unplugged as the circuit is developed[13].

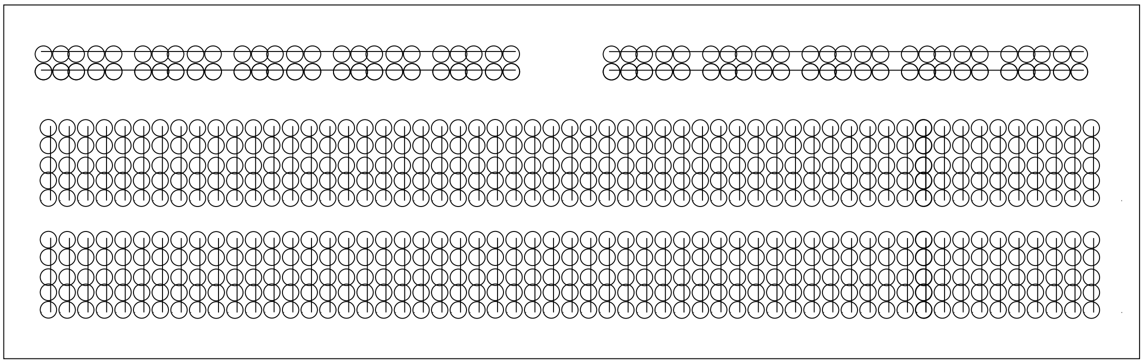

Figure 2.9: Protoboard Connections

The protoboard has holes on 0.1 inch centres, since this is a standard pin spacing on electronic components. At the top and sometimes also at the bottom of the board are horizontal **busses**, which are often used for power supply connections. In the centre of the board, there are vertical groups of 5 pins each. Unlike the busses, each of these 5 hole groups is separated from the other. The components of the test circuit are plugged into these points.

It's sometimes a bit difficult to get a lead into the protoboard hole, in which case it helps to cut the lead on a diagonal and/or push the lead in by grasping it with needle-nosed pliers.

[13]A test circuit is often referred to as a breadboard circuit because, legend has it, the first electronic circuits were built on a bread board that was stolen from the household kitchen.

Chapter 3

LED Circuits

We are now ready to design the first circuit: an LED driven from a power source with a 9 volt output (either a power supply or a battery). The circuit diagram (in pictorial and schematic form) is shown in Figures 3.1 and 3.2 below.

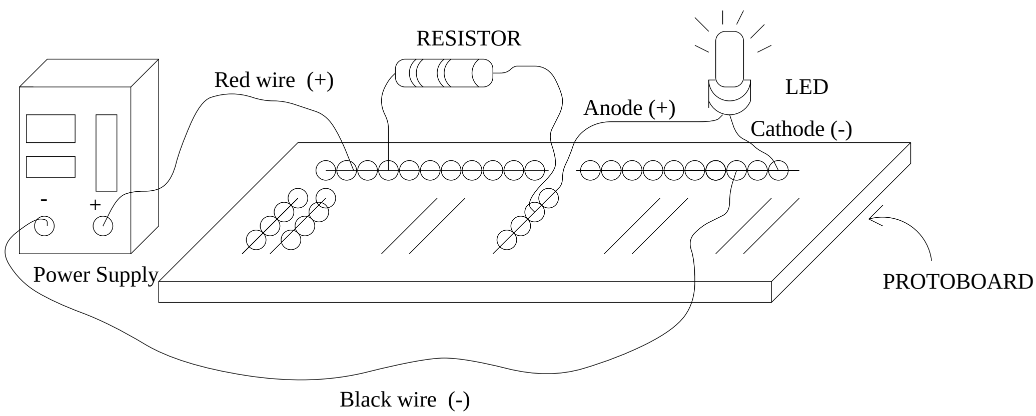

Figure 3.1: Test Circuit Pictorial

(Incidentally, the protoboard which you use may not look like the one shown in the pictorial. Get some help from one of the lab assistants or instructor to find out what's connected to what.)

The power supply produces a current out of its positive terminal which flows through the resistor and then the LED, and then back to its negative terminal. Current causes the LED to illuminate, entertaining nearby human beings.

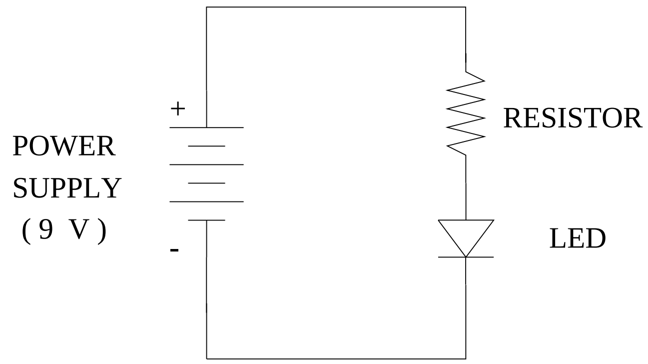

Figure 3.2: Test Circuit Schematic

There is one modest detail we need to take care of before wiring this up. We need to calculate a **value** for the resistor.

So:

Suppose we wired up this circuit without a resistor.The power source (either a power supply or a battery) and the LED are both constant voltage devices, so we can immediately indicate the voltages across their terminals, vis:

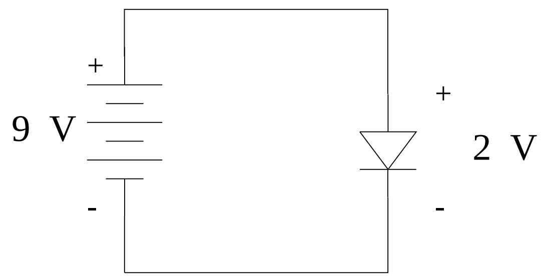

Figure 3.3: Circuit Without Resistor

Now, it turns out that the total voltage across the load must be equal to the total supply voltage[1].

[1] We are referring here to Kirchoffs Voltage Law (KVL), which says that the algebraic sum of voltages around a circuit loop must be zero. In this specific case, KVL amounts to saying that the supply voltage must equal the sum of the load voltages.

There is also a Kirchoffs Current Law, which says that the algebraic sum of currents into a circuit node, must be zero. This is the same thing as saying that the total current that flows into a circuit 'node' (connecting point) must also flow out. The circuits we will be describing are simple enough that we've avoided using the current law.

Thus, without a resistor, we have a circuit unbalance: the 9 volt supply exceeds the 2 volt load by 7 volts, and there will be far too much current in the circuit. (The LED would burn out and the battery would be run down very quickly. If you were using the power supply, excessive current drawn from it would eventually damage it.) The resistor is required to absorb the difference between the supply and load voltage.

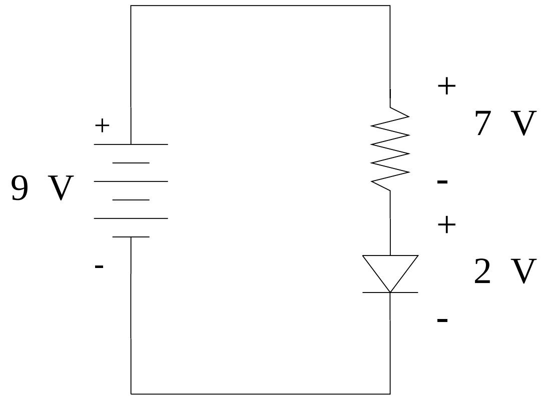

Figure 3.4: Circuit With Resistor

With a resistor, the extra 7 volts appears across the resistor, and the circuit is balanced. The value of the resistor can be calculated from Ohms Law, as above in the resistor discussion: we wish to drop 7 volts at a current of about 0.010 amps, for a resistance of 700 ohms.

The nearest standard value to 700 ohms is 680 ohms. Get this resistor from your instructor, wire up and test the circuit (see Figure 3.4).

3.0.1 Two LEDs in Series

Two circuit components are said to be in **series** if the same current flows through both of them. You can picture in Figure 3.5 below that an electron passing through the first LED must eventually pass through the second LED as well. Thus these two LEDs are said to be **in series**. We could also say that the battery and resistor are in series with the LEDs.

Now let's calculate the value of the resistor. Each LED will have 2 volts across it. Because the two LEDs are in series, their voltages add, in this case to 4 volts. The difference between the supply voltage (9 volts) and the load

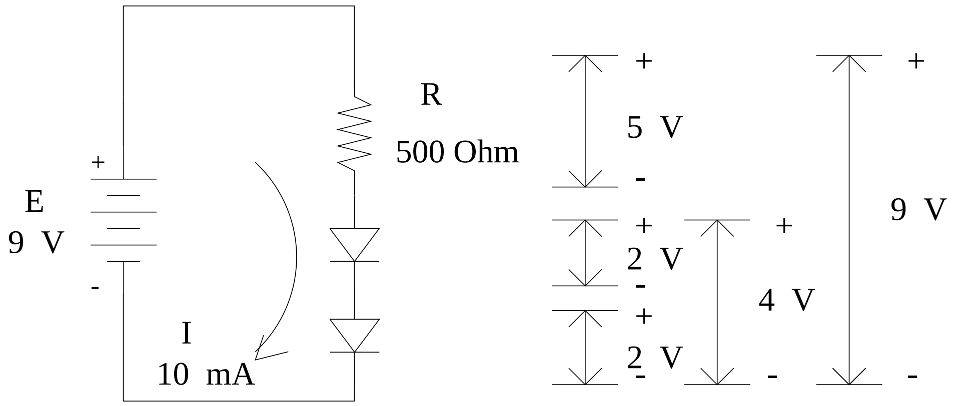

Figure 3.5: A Series Circuit

(4 volts) is now 5 volts. Assuming again that the LEDs are to conduct 10 mA, we should make the resistor:

$$\begin{aligned} R &= E/I \\ &= 5/0.01 \\ &= 500 \ ohms \end{aligned}$$

If we were lazy, we might wish to see what happens if we leave the supply voltage at 9 volts and the series resistor at 700 ohms. For this, we need to re-arrange Ohm's law to solve for the current.

$$\begin{aligned} I &= E/R \\ &= 5/700 \\ &= 0.007 \ amps \\ &= 7 \ mA \end{aligned}$$

This is close enough to our originally specified value of 10 mA that we really don't need to change the value of the series resistor.

3.0.2 Three LEDs in series

You should now be able to do this one. Calculate the resistor value for the three LED series circuit shown in Figure 3.6. Wire it up to see if it works.

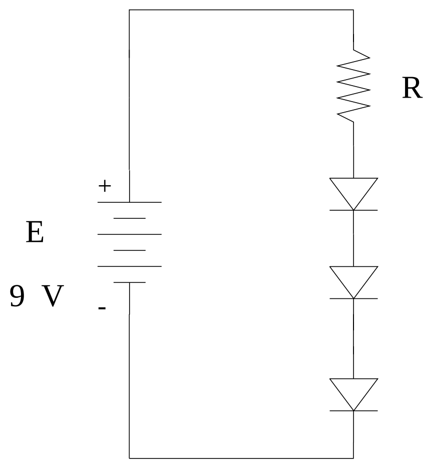

Figure 3.6: Three LEDs in Series

3.0.3 Three LED Circuit Using Resistors

In the previous section, we wired up a two LED circuit by using one resistor and connecting the two LEDs in series. An alternative circuit arrangement is shown in Figure 3.7 below.

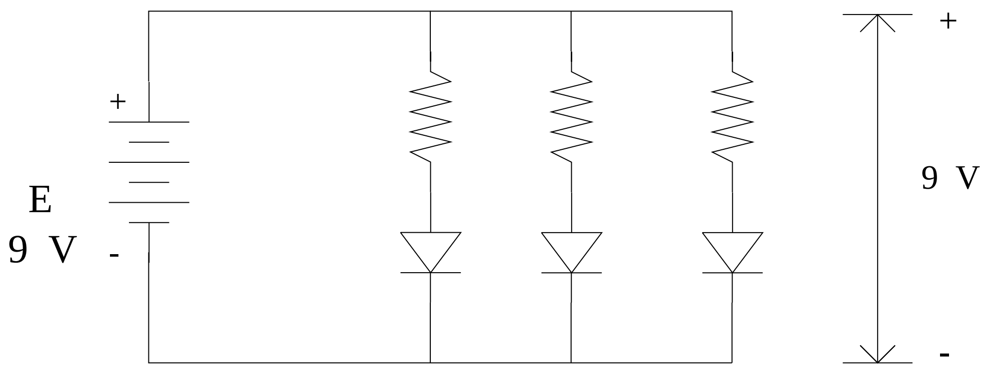

Figure 3.7: Three LEDs, Parallel Circuit

In this arrangement, each LED has its own resistor, and each resistor-LED combination is connected to the battery. Each **branch** of the circuit (resistor-LED) has the supply voltage across it and so may be designed as a simple resistor-LED circuit[2].

3.0.4 An Engineering Tradeoff

We now have two different ways to build a three LED circuit, as shown in Figure 3.6 and in Figure3.7. Each of these circuits has different advantages and disadvantages, and a very common engineering activity is to consider which of the circuits is better for a given situation.

For example, the series circuit has the advantage that only one resistor is required. This minimizes the number of components required and means that the brightness of the LEDs can be adjusted by changing only that one resistor. All the LEDs have the same current. If they're the same type of LED, then they'll all have the same brightness.

On the other hand, the parallel circuit has the advantage that the individual LED currents can be set independently of each other, and so can be set at different brightnesses. This might be an advantage if the LEDs are different colours and require different currents to appear equally bright.

In terms of battery life, the series circuit will quit entirely once the battery voltage has decreased to below the sum of the LED voltages: 6 volts in this case. The parallel string will show some life until the battery drops below the voltage required for one LED (2 volts), so the circuit is likely to last a little longer.

3.1 Flashing LEDs (FEDs)

The flashing LED is a light emitting diode with a built in electronic switch. The switch opens and closes at a rate of about 1 to 3 times per second.

Apart from the switching action, the principal difference between an LED and FED is the voltage drop. The FED is also a constant voltage device, but requires about 4 volts to operate rather than 2.

Once you start mixing LEDs and FEDs, you'll find you need to be able

[2] What happens to the battery current each time a new branch is added? Calculate the battery current for a three branch circuit.

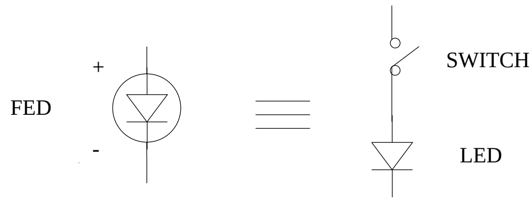

Figure 3.8: Flashing LED (FED)

to tell them appart. This can be tricky: they look quite similar. However, FEDs have a small circuit inside, which can be seen as a **black area** or **line** inside the FED. Put an FED and LED next to each other and see if you can tell them appart.

You now have all the information to design and build an FED circuit using a 9 volt battery and resistor. Wire the circuit in Figure 3.9 below and test it out on your protoboard.

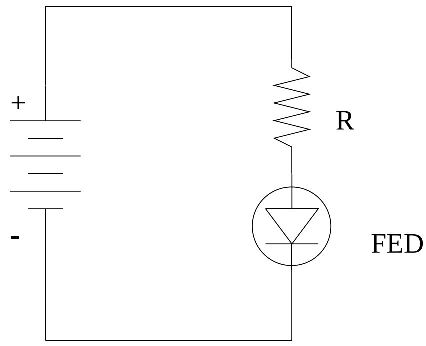

Figure 3.9: FED Circuit

3.1.1 Mixing LEDs and FEDs

If a switch is connected in series with a group of LEDs as shown in Figure 3.10 below, opening and closing the switch will turn all the LEDs in the series string off and on.

In the same way, wiring an LED in series with an FED causes them both to flash.

Calculate the nearest suitable value of resistance to cause the LED and FED current to be around 10 mA. Wire up the circuit and test it.

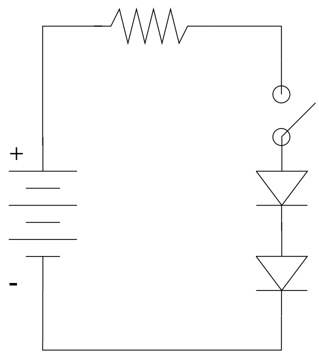

Figure 3.10: LED With Switch

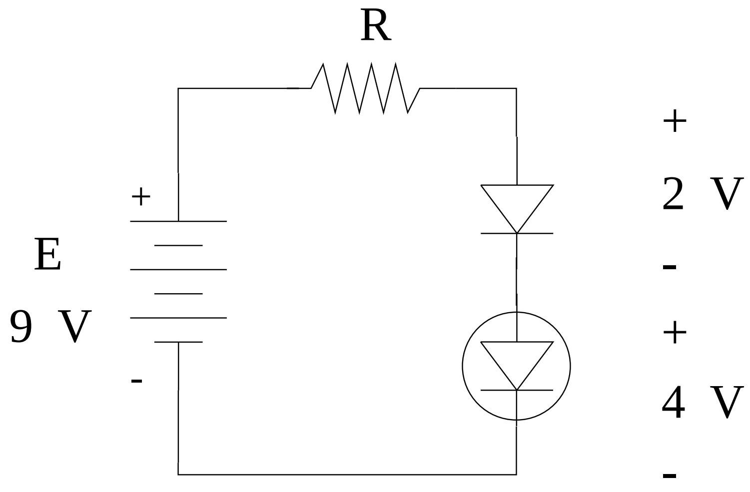

Figure 3.11: Using a FED To Flash a LED

3.1.2 Open Switches and Ohms Law

At this point, we need a bit more theory. Consider the single FED-Resistor-Battery circuit shown in Figure 3.12 below.

When the FED is conducting, the voltage across it is 4 volts. Because the battery is 9 volts, then the difference must appear across the dropping resistor, so it will have 5 volts across it.

Now consider what happens when the switch inside the FED opens. The FED current drops to zero, and the FED extinguishes. There is no current through the resistor, so the voltage drop across the resistor goes to zero.

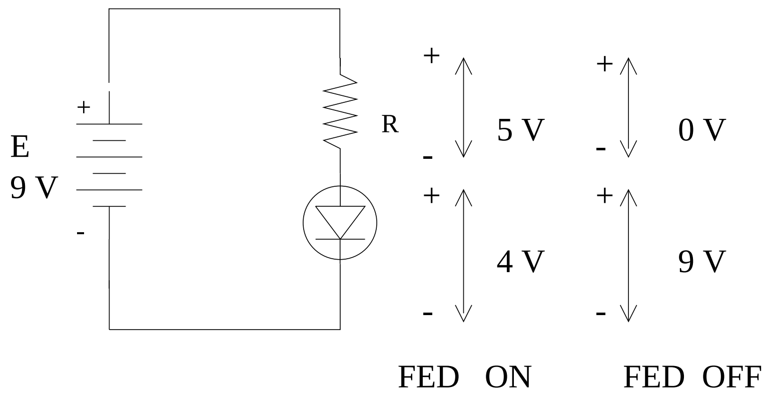

Figure 3.12: FED Circuit

$$\begin{aligned} E &= IxR \\ &= 0xR \\ &= 0 \ volts \end{aligned}$$

If there's no voltage drop in the resistor, then the entire supply voltage must appear across the FED. This is in fact what happens: when the FED is on, the voltage across it is 5 volts. When it is off, the voltage across the FED rises to the supply voltage, 9 volts.

3.1.3 Two FEDs

First, wire up two separate FEDs, each with its own series resistor (see Figure 3.13).

Each should flash at its own rate. Try it.

Now try wiring up two FEDs in parallel, so that they share the same series resistor (Figure 3.14).

You should find that they both flash away quite happily. Obviously, sharing a resistor does not affect the FEDs very much.

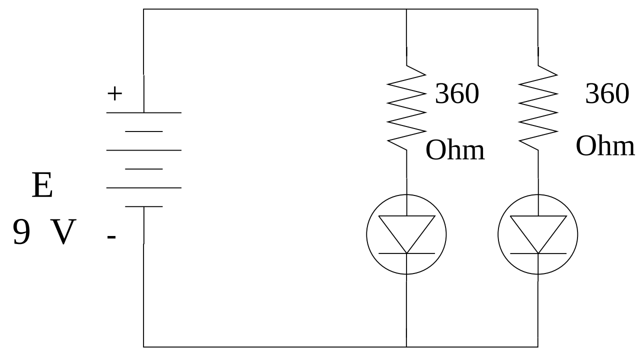

Figure 3.13: Dual FED Circuit

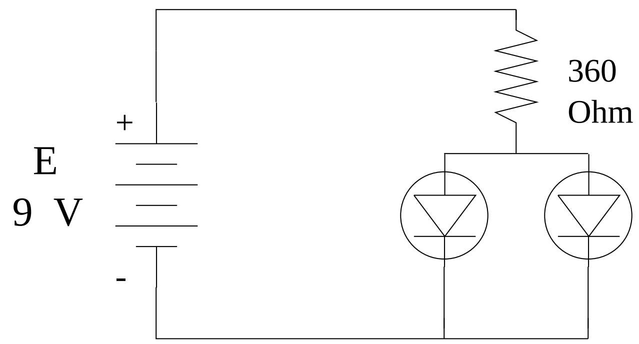

Figure 3.14: FEDs Share a Resistor

3.1.4 FED-FED-LED Flasher

Consider the next circuit (Figure 3.15). Here we have two FEDs connected in parallel, connected in series to an LED. Assuming that the two FEDs flash at a different rate, can you predict what the LED will do?

Wire the circuit up and see if it behaves as you predicted.

3.1.5 LED/FED Parallel Flasher

Now something a little more challenging. Wire up the circuit shown in figure 3.16 below and observe it's operation. (If it doesn't operate, get some help: it should...)

A simple way to visualize the circuit operation is this:

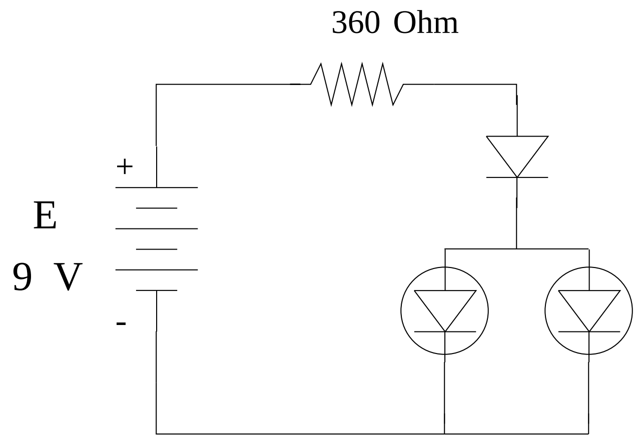

Figure 3.15: FED-FED-LED Flasher Circuit

When the FED is On, all the current flows through it, and the LEDs are Off. When the FED is Off, the FED current is diverted through the LEDs and they turn On[3].

[3]More detailed reasoning behind this circuit is a little complicated.

Consider first the case when the FED is conducting. It has 4 volts across it. In order for the series string of 3 LEDs to turn on, they require 6 volts across them. The FED and LED string are connected together and thus have the same voltage across them. When the FED is On, and has 4 volts across it, the LED string has 4 volts across it, which is not enough to turn it on. The LEDs are thus Off when the FED is On.

When the FED turns off, the current through it drops to zero. When the FED current drops to zero, the voltage across the resistor also drops (Ohms law). The resistor voltage and FED voltage must add up to the supply voltage, so as the resistor voltage drops, the voltage across the FED increases. When the voltage across the FED reaches 6 volts, the LEDs begin to conduct, causing them to illuminate. The LED string is a constant 6 volt device, so the voltage stabilizes with 6 volts across the LED string and 3 volts across the resistor. Thus the LEDs are On when the FED is Off.

Eventually, the FED turns On again, its voltage drops to 5 volts, and the LEDs go out. Thus the FED and LEDs alternate.

Whew.

Question: If we used 1 or 2 LEDs in the series string, rather than 3, the circuit wouldn't work. Why?

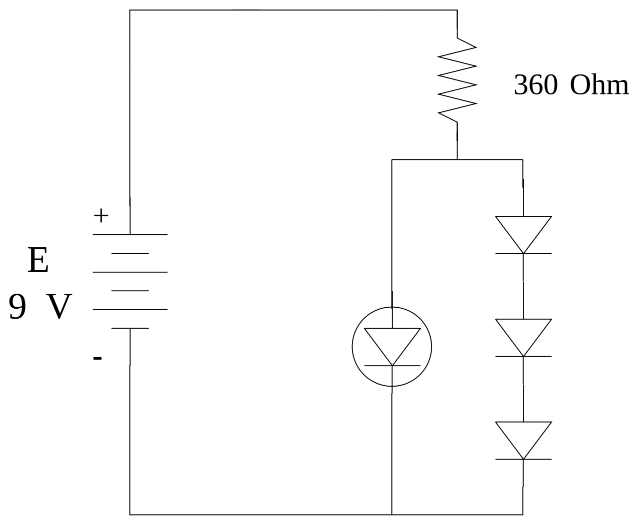

Figure 3.16: LED/FED Parallel Flasher Circuit

Chapter 4

The LED Project

4.1 Circuit Examples

A catalogue of some LED and FED circuits is shown in Figures 4.1 through Figure 4.4 below. Use these circuits and your new knowledge of how they work to put together some kind of interesting LED and FED circuit.

Remember, in considering these circuits, that you can use different coloured LEDs and FEDs interchangeably. The colour of an LED or FED has no effect on its operation.

You will have been given an initial kit of parts containing 6 LEDs and 3 FEDs. You should use these parts, or you can trade with other students. If you wish, you are welcome to work with a friend on the designs.

4.2 Design Examples

Figures 4.1 through 4.4 show circuit diagrams which can be used to create different patterns. A few of such patterns are drawn in the following pictorials. Rather than just copy them, try to understand the relationship between a diagram and a pattern and to create your own, unique design.

In Figure 4.5 dashed lines indicate wiring under the piece of a perforated board. Also dashed line resistors are supposed to be placed under the board. In this design both "eyes" (FED's) and both "mouth-corners"

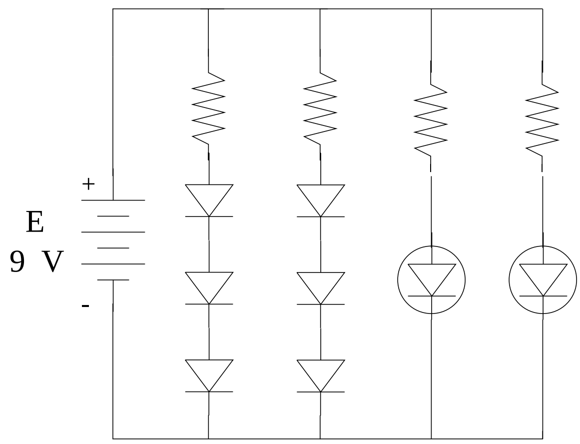

Figure 4.1: Example Circuit A

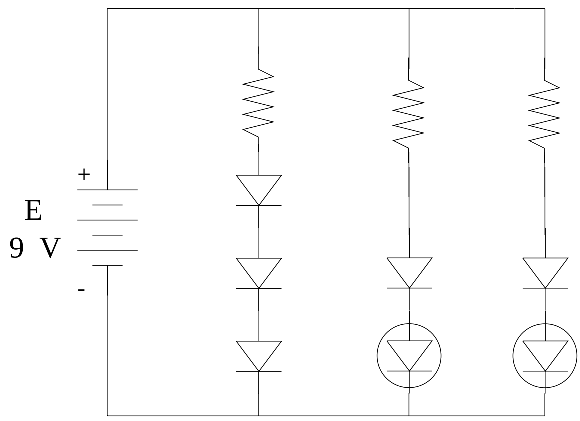

Figure 4.2: Example Circuit B

(FED-connected LED's) will blink, while "nose" and the rest of the "mouth" will not (LED's). Resistors are used to protect diodes, since their working voltages add up to less than the nominal voltage of our supply (9 V) - check this ! Choose your own color scheme.

In Figure 4.6 the protective resistors could be wired on top of the perforated board, serving as a flower stem. This pattern will only have the center of the flower blinking (FED), while all the petals are made out of LEDs.

In Figure 4.7 all three corners as well as the middle of the initial letter "A" will blink (FED's). As with the smiley-face, protective resistors will be hidden on the back of the perf-board, as indicated by dashed lines on the diagram.

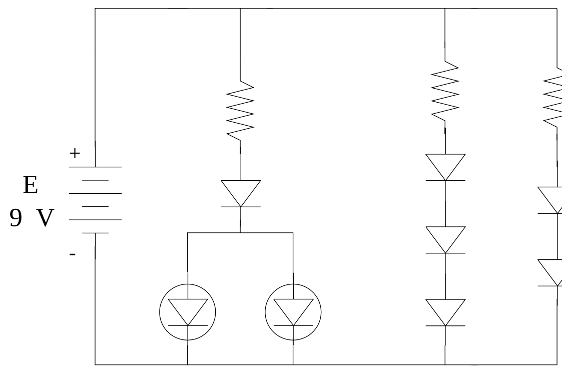

Figure 4.3: Example Circuit C

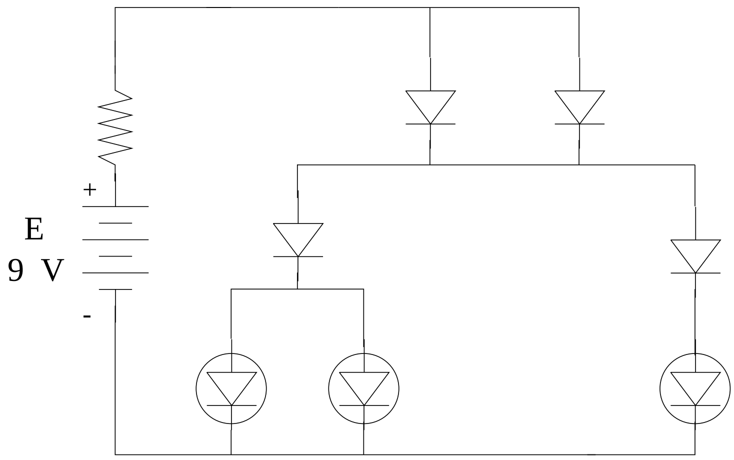

Figure 4.4: Example Circuit D

4.3 Project Design in Steps

1. A good first step is to sketch out a schematic on paper, based on a vague idea of what you'd like the circuit to do.

2. It's **much** easier to debug a small circuit, so set up a small part of your circuit on the protoboard, and test it out. Then, when that part is working, add more of your circuit until you have the final version[1].

[1] Engineers call this process 'incremental development'. The trick is to balance experimental work on the protoboard with enough understanding that you aren't just experimenting in the dark. It's essential for any serious project that you be able to analyze your design, but that's something you learn in engineering school, not in a three hour workshop.

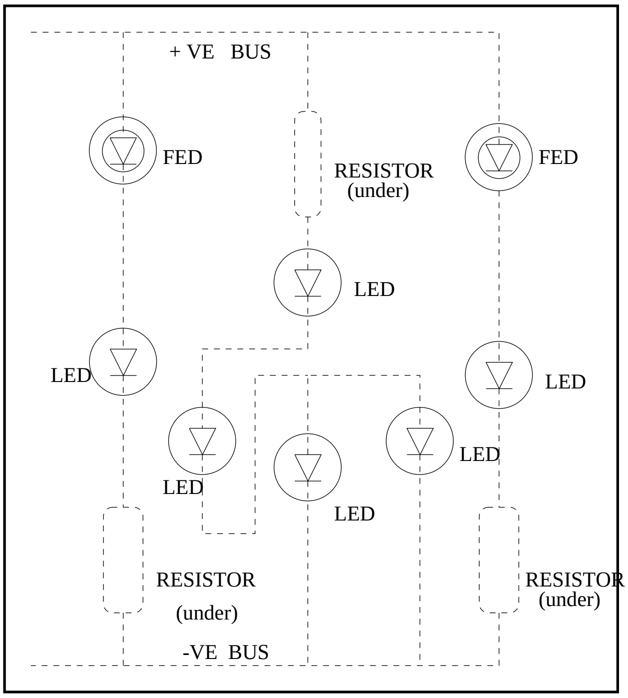

Figure 4.5: Example Pattern: a Smiley Face

3. It's quite likely that the results won't be exactly as you intended. Modify your design to make the results more interesting. If you can visualize the circuit in your head, you may be able to work directly on the protoboard. However, most people find it helpful to draw out schematics as they work along.

4. Ask for help if you get stuck!

5. **This is really important**: Once you have the circuit working, carefully draw out the schematic diagram or a pictorial diagram. You'll need this information in constructing the final version.

4.4 Project Construction

Now that the circuit works to your satisfaction, you have to make it into its final form so that it can be carried away, made into a piece of jewelry, attached to a piece of clothing, installed in a hat or whatever.

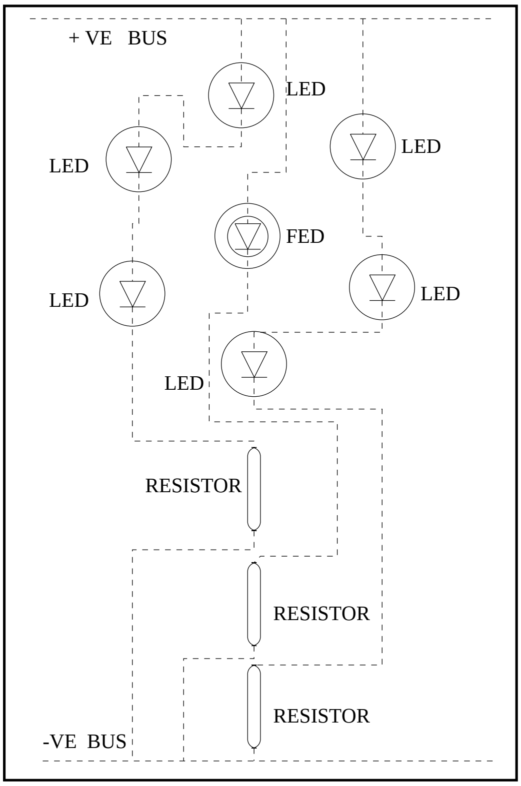

Figure 4.6: Example Pattern: a Flower

To put it into this form, the working circuit that you build on the protoboard needs to be transferred to a **circuit board**. The circuit board in this case is a perforated fiberboard. The wires of the various components are pushed through the holes in the board and then *soldered* to each other.

You can bend over the lead wires of the electronic parts to hold them in place on the board. Later, use a glue gun or epoxy glue to hold the parts firmly in place. (Glue won't affect the operation of the circuit.)

4.4.1 Soldering

We'll show you how to solder as part of the lab. However, there are a few things you should know before starting.

Soldering is used to interconnect the wires of electronic components. To interconnect two components, the wires are twisted together. **Solder**, a lead-

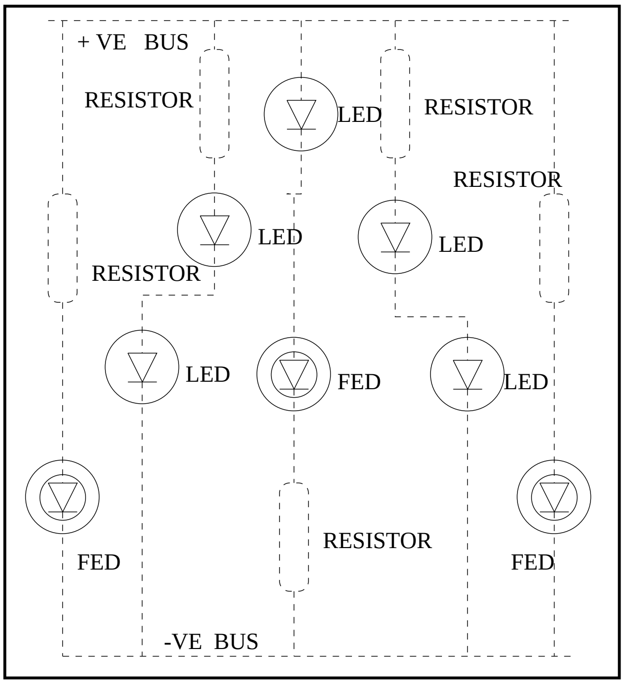

Figure 4.7: Example Pattern: an Initial - Letter A

tin compound, is then melted with a **soldering iron** onto the two wires. It flows into the wire joint, making a good electrical connection.

The important points with respect to soldering are as follows[2]:

- Solder can't fill very large gaps. The wires must be at least touching (and preferably twisted together) before soldering them.
- Heat the wires to be soldered, not the solder itself. If the wire is hot, the solder will flow nicely into the cracks of the joint. If the wire is cold when the solder is melted onto it, it will sit on top of the wire and make a poor joint.
- Use the soldering iron as a heating device, not as a paint brush. Push

[2]If you buy solder for an electronic project, it is vital that you use solder with ROSIN CORE flux, not ACID CORE flux. The flux is a paste that helps to clean the metals to be soldered, and it's built into the solder. Acid flux is used to help solder plumbing pipes together, but it will eat away the small wires used in electronic projects. To be safe, always purchase solder for electronic projects from electronic supply houses, not the local hardware store.

it firmly up against the wire to be heated, apply solder, remove the solder, and then remove the soldering iron.

- Keep the tip of the soldering iron clean. We'll provide little wet sponges for this purpose. Wipe off the iron each time you use it.
- Please do not burn yourself or anyone else with the iron.

4.5 Building and Testing

If you want to be careful about circuit construction, make a pictorial diagram of your circuit and show it to an instructor before soldering it together.

If you're more adventuresome, wire up a section of the circuit and then test it by attaching the battery to the clip. Always disconnect the battery when adding to the circuit.

Watch the polarity of the LEDs! It's a real pain to undsolder and reverse an LED, and it's likely to be broken in the process. Carefully check your circuit before soldering.

4.6 How Not to Do Things

There are several sure-fire ways of destroying circuit components which we should try to avoid. We listed a few of them below:

- Cranking up the output voltage of the power supply. If you set the output on, say, 50 volts, even if your LED's are protected by resistors, the circuit components will get very hot and will burn out due to a small power rating of the resistors.
- Connecting a single LED or FED, unprotected by the resistor, across the power supply. This one never fails: you will see some spectacular meltdowns, especially if your power source is set for, say, 15 volts or so. The LED will burn very brightly for a short moment and then get very hot and quickly expire !
- Repetitive bending of component leads and/or forcing them into protoboard holes, 'threading" component leads through the perf-board.

Component leads are usually quite fragile and when subjected to excessive force, break, rendering the component useless.

- Putting a soldering iron on top of the component, or very close to it for prolonged periods of time. LEDs and FEDs are fragile and when subjected to excessive temperatures, they melt. It is therefore important to do soldering relatively quickly so as not to heat up the circuit.
- Attempts to 'unsolder' the component, once it is found to be in the wrong position. It is next to impossible to make any corrections to the circuit once it is soldered (or even once the leads are twisted and tightened together), without destroying it in the process. That is why it is so important to go through a testing procedure before the circuit is finalized.

4.7 Do it Yourself!

Now that you've learned how to design and build LED and FED circuits, you have the tools to build other versions of these circuits. If you'd like to do more of this, we encourage you to get the parts and tools from one of the suppliers listed below, and do some building on your own.

Good luck!

4.8 Check Your Retention

If you can answer all the questions in this section, you have a pretty good grasp of the material.

1. Explain the difference between voltage and current.
2. The LED is a **polarized** component. What does that mean?
3. What voltage is the battery we will be using in this project?
4. Why don't we use 1.5 volt batteries in this project?
5. What current should we feed through the LED?

6. How much current will pass through a 360 ohm resistor if it is connected across the terminals of a 9 volt battery?

Chapter 5

Appendix A: Finding Electronic Parts

Half the battle in doing electronic projects is finding the parts, and preferably not paying a fortune for them. We're lucky in Toronto at having a number of very good sources for electronic parts.

Do not be intimidated by the fact that you don't know much electronics when you go into these estabishments - they're quite used to dealing with beginners. However, don't expect to get much reliable advice. These people are in the business of selling bits, not advising people how to use them.

- **Active Surplus Annex, 347 Queen Street West** The pre-eminent place in Toronto to shop for bargains in electronics. Good source for LEDs, FEDs and all kinds of science fair parts. Prices and selection much better than just about anywhere, except silicon valley in California. Check out the basement for motors and wire. Some interesting kits available. Unequalled entertainment value.

- **Accurate Computer Warehouse, Beverley Street, West Side, 100 Feet North of Queen** Just around the corner from Active Surplus Annex, smaller, but with some notable bargains. Appears to lack central heating. No phone.

- **Active Electronics, 100 Lombard Street** The supermarket version of the electronics store. A bit less hectic than Active Surplus Annex. Get a copy of their free catalogue. Electronic parts are compeditive in price, but hardware and equipment are somewhat pricey. Some useful books on display. Anyone who enjoys shopping at Loblaws will feel at home here.

- **Electrosonic, 1100 Gordon Baker Road** This is it, **the** major local industrial source for electronic parts. If you can afford it or know someone in the biz, get a copy of their 1600 page catalogue. Not only do they list just about every conceivable electronic part in the catalogue, most of it is in stock in the warehouse. You have to shop by catalogue number, but the folks on the counter can help. Open Saturday morning during the winter.

- **Toronto Surplus and Scientific, 596 Gordon Baker (in an industrial mall)** Next door to Electrosonic. Few parts, but some very good deals on used test equipment. Great entertainment if you like looking at used electronic stuff. Unlike most of these places, the owner (Mike) is quite knowledgeable.

- **Double H Electronics, 3800 Victoria Park Avenue** Just around the corner from Electrosonic. A good source for electronic parts of all kinds. Some good kit values, if you can get an expert to back you up if it doesn't work. A good place to buy a voltmeter, essential for any experimentation.

- **Radio Shack, Everywhere** Some useful parts (get a copy of the free catalogue), but usually available elsewhere for less. The batteries are a good deal and the educational kits are a great way to get into electronics.

- **Electronic Surplus Industries, 1191 Lawrence Avenue West (at Caledonia)** A great place to take mom and dad if they've been complaining about the tidiness of your room. ESI is a little on the informal side for organization, but has the occasional useful thing. Be prepared to deal on the price.

5.1 Reading Material

Most public libraries, even the Toronto Reference Library, are not very useful for reading material on electronic circuits. A better source is a nearby community college library. Ryerson has an entire floor of electronic texts and back issues of electronics magazines, and you're welcome to use it, though only Ryerson students can take material off the premises.

Some of the electronic stores mentioned above - Active Electronics and Electrosonic - stock a good collection books on electronics. If you're interested in Amateur Radio, a must-have is the ARRL Handbook, available from Electrosonic.

Chapter 6

Appendix B: Electrical Engineering

6.1 What is Engineering ?

Engineering is a profession in which a knowledge of mathematics and sciences, gained by study, experience and practice, is used to put natural and manufactured materials to work for the benefit of all.

Professional engineers have a code of professional conduct and ethics, and a series of legal requirements that ensure that they operate at the highest standards, always in the best interests of the society. Engineers are respected professionals. More than 60,000 professional engineers belong to Professional Engineers of Ontario (PEO) - a professional association for engineers.

Many engineers spend their careers in offices, where they design products or systems, or write reports. Some teach at universities. Others use their engineering background as a stepping stone into management positions. Some go on assignments that take them around the country or around the globe. Such jobs involve construction, planning, exploration, business negotiations. Engineers are everywhere making things work properly. And they are well paid, too.

6.2 Electrical Engineering

Electrical Engineering deals with the development and manufacture of electrical and electronic equipment, the design and implementation of telecommunication systems, control systems and electrical generation and distribution systems.

Electrical engineers use computers to design electrical networks and systems. Some work in manufacturing plants or on projects such as subway systems or power generating stations, others work in laboratories and research centres. Yet others choose careers in sales and marketing of electrical and electronic devices.

6.3 Computer Engineering

Computer Engineering grew out of Electrical Engineering and it differs from Computer Science in that it deals with designing of computer hardware and interconnected computer networks, as opposed to developing new computer programs and operating systems. However, computer engineers do a great deal of software development too. Computer components of networks, telephone switching systems or consumer electronics all need software engineering.

6.4 Different Areas of Electrical and Computer Engineering

The following diagram shows different areas of specialization available in Computer and Electrical Engineering.

6.5 Emerging Technologies

As we approach the year 2000, Electrical and Computer Engineering are the most rapidly expanding areas of engineering. Large numbers of scientific breakthroughs and new advances in technology are connected with computers

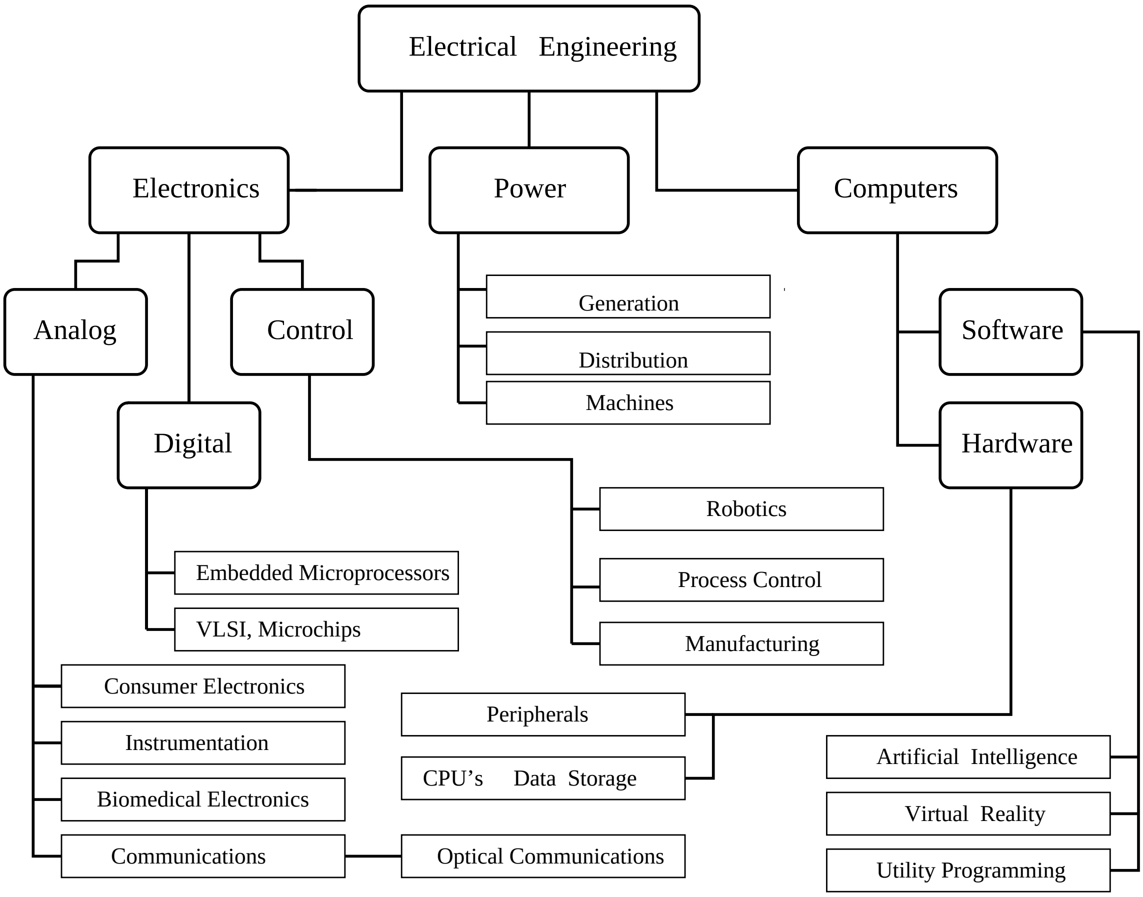

Figure 6.1: Different Areas of Electrical and Computer Engineering

and communications. TIME magazine has recently published a list of 10 disciplines labelled as the new emerging technologies of the *21st* century:

- Hydrogen Fuel-Cell Vehicles.
- High Temperature Superconductivity.
- Genetic Engineering.
- Bionics.
- Universal Personal Telephones.
- Voice-Activated Computers.

- Nanotechnology.
- Optical Electronics.
- Virtual Reality.
- New Materials.

Out of this list, seven areas are directly in Electrical and Computer Engineering ! As a second example, consider this short list of the current "hot topics" which are often written about in mainstream newspapers and magazines (as opposed to specialized computer and technology-oriented press). You may have also heard about some of these on TV:

- Internet and World Wide Web.
- Multimedia in Teaching and Entertainment.
- High-speed Interactive Computer Services (Banking, Movies-on-demand, Shopping, Education).
- Cellular Phones.
- Satellite Global Positioning and Navigation Systems.
- Smart Highways.
- Decentralized Flight Control.
- Robots and Unmanned Vehicles.
- Space Station, Shuttle Flights.

Again, all these topics have to do with electronics, computers or control systems. Next time you read an article or listen to a program discussing technology or engineering, try to identify the discipline. Chances are, it will, again, be electronics or computers. Electrical and Computer Engineering creates the most career opportunities in engineering at present and will continue to do so in the forseeable future.

If you are curious about any of the topics mentioned in this chapter, ask your Discover Engineering Summer Camp instructors and they will be only happy to talk to you about them.

Chapter 7

Appendix C: Internet and Us

If you have the Internet access to the World Wide Web through your school or at home and you would like to learn more about Ryerson Polytechnic University, Electrical Engineering or activites of Women In Engineering Committee at Ryerson, which organizes the Discover Engineering Summer Camp you enjoyed this summer, you may want to check out the following Web addresses, which in a computer lingo are called URL's[1]:

- Ryerson Polytechnic University; URL is as follows:

  http://www.acs.ryerson.ca

- Department of Electrical and Computer Engineering at Ryerson; URL is as follows:

  http://www.ee.ryerson.ca:8080

- Women in Engineering Committee at Ryerson (including Discover Engineering Summer Camp Project); URL is as follows:

  `http://www.ee.ryerson.ca:8080/~gosha/wiec.html`

[1]URL stands for the Universal Resource Locator and works in the same way as the address on an envelope - it allows your Web browser program to find a specific Web site.