3

ELECTRONIC FOUNDATIONS

CONTENTS AT A GLANCE

This book presents a collection of Stamp-based projects as recipes for you to follow. This is an excellent way for you to gain the skills you will need to design and build your own original projects. Before you can build projects, you will need some fundamental skills:

- Understanding and identifying electronic components.
- Reading and following schematic diagrams—the blueprints of electronic projects.
- Constructing electronic circuits.

If you already possess these skills, great! If not, the sections that follow will help get you started. If you find electronics interesting and fun, you'll probably want to expand your skills through additional reading and education. Appendix F lists books and magazines that can help.

Consider enrolling in an introductory electronics course at your local community college. These classes are a lot of fun, and just one semester will answer all of a beginner's most pressing questions about electronics. Courses emphasize hands-on skills and require only rudimentary math. A growing number of classes even feature BASIC Stamp projects! If you're shy about the competitive aspects of schoolwork, you should know that most colleges will let you "audit" a class on a noncredit basis. No grades, no tests.

Before we pack you up and send you off to college, let's start with a quick seminar on electronics fundamentals.

Electricity

You've probably seen drawings of atoms like Figure 3-1 with tiny electrons orbiting a nucleus consisting of a cluster of protons and neutrons. That drawing is useful for telling the story of electricity. I say "telling the story" because there are many ways to explain electricity that are total fiction, but are useful to understanding the way circuits work. Since I want to help you build circuits, I'm going to tell the story in a way that suits my purpose.

OK, back to the atom. The figure depicts the nucleus as large, solid, and stationary and electrons as small, quick, and flighty. Electrons are attracted to protons; that's what keeps them in orbit around the nucleus. Electrons are repelled (driven away by) other electrons. And electrons can be knocked clear out of orbit by other influences—light, heat, chemical reactions.

There are two ways to look at an atom's loss of an electron: (1) There's a loose electron needing a nucleus to orbit, and (2) there's a nucleus with room in orbit for an electron. Things would balance out if only that electron would come back! Just as good would be if another electron would fill the vacancy in the atom's orbit.

The fate of one electron doesn't mean much in the larger scheme of things, but suppose there was a mass migration of electrons. Over here—lots of electrons. Over there—lots of atoms with empty orbits. If we could create a path to bring the electrons to the atoms that need them, why they would stampede to fill those orbits.

Now we can define some basic electrical terms. A surplus of electrons is called a *negative* charge; a shortage of electrons is a *positive* charge. A path along which electrons can move is called a *conductor*, and a material that blocks electrons is called an *insulator*.

Everyday examples of conductors are metals like copper, silver, gold, and aluminum; insulators include air, glass, rubber, and most common plastics.

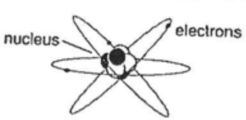


Figure 3-1 The atom.

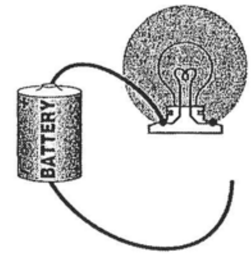


Figure 3-2 With a break in the circuit, the bulb remains dark.

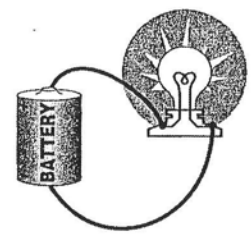


Figure 3-3 A complete circuit lights the bulb.

When a negative charge and a positive charge are joined by a conductor, we call the resulting stampede of electrons electrical *current*. Because that current consists of unruly electrons bouncing off everything in their path, the flow of current in a conductor converts some of the electrical energy into other forms of energy—especially heat.

BATTERIES AND CIRCUITS

The previous discussion goes a long way toward explaining the electrical shorthand seen in everyday life. Batteries are marked with a plus (+) on one hookup and a minus (−) on the other, a quick way of saying positive and negative. The potential energy represented by the difference between these positive and negative charges is written on the label in units of *volts*. This gives us an idea of how much energy would be released by connecting a conductor (for example, a piece of wire) between + and −.

The classic demonstration of the release of electrical energy uses a battery and a light bulb. The battery is connected to the bulb by wires (conductors). In order to light the bulb, there must be a complete path from + through the bulb to −. If there's a break anywhere in the path, the bulb stays dark (Figure 3-2). Once the path is complete, the bulb lights (Figure 3-3).

A complete electrical path from + to − can release energy, like lighting a bulb. All working electrical hookups follow this basic pattern—out from the power source, through some electrical device like the bulb, and back to the power source. You could say that the current flows in a circle, which is exactly why electrical and electronic hookups are called *circuits*.

RESISTANCE

If the wires from the battery are conductors and the innards of the light bulb are conductors, why do the conductors inside the bulb get hot and light up while the wires stay cool and dark? Is there something else going on here?

Yes. Not all conductors are the same. Some conductors let current flow easily; others resist the flow of current. This resistance causes electrical energy to be converted into heat. It's not hard to figure out that the filament of the bulb (the curly wire that lights up) has a higher resistance than the other conductors in the circuit. That's why the filament gets hot and the wires don't. See Ohm's Law below for a more complete answer.

ELECTRICAL PROPERTIES, MEASUREMENTS, AND UNITS

In our Stamp projects, we'll discuss measurements like voltage, current, resistance, and power. You can buy an inexpensive tester that will measure these factors, but you can also calculate them using simple math. If you know any two electrical properties, you can calculate the others. Table 3-1 lists the properties we'll be talking about.

Some units are frequently written with the prefix milli-, which means one-thousandth. In other words, 1000 millisomethings is equal to 1 something. We use the milli-versions of units because it's often more convenient to say "three milliamperes" than "point zero zero three amperes."

In the case of ohms, we often deal with large numbers like 47,000 ohms or 1,000,000 ohms. The prefix kilo- stands for one thousand, and lets us say "47 k" or "47 k ohms" when we mean 47,000. Likewise, mega- stands for 1 million, so 1,000,000 ohms becomes "1M" or, in speech, "1 megohm" or even "1 meg."

OHM'S LAW: A QUICK PREVIEW

Appendix C discusses electrical calculations in more detail, but a preview will help explain the bulb-hot/wires-cool phenomenon and provide an insight into working circuits.

Ohm's law defines the relationship between volts, amperes, and ohms with three easy formulas:

$$\text{Volts} = \text{Amperes} \times \text{Ohms}$$
$$\text{Amperes} = \text{Volts/Ohms}$$
$$\text{Ohms} = \text{Volts/Amperes}$$

If you know any two of these values, you can calculate the third. Electronics technicians have a simple trick for remembering the formulas, based on the pictogram in Figure 3-4.

If you cover up the symbol for the value you want to calculate, the other two symbols will show you the correct formula. Cover the horseshoe-shaped ohms symbol (Ω) and you see V over A—the formula for calculating ohms.

TABLE 3-1 ELECTRONIC UNITS OF MEASURE

PROPERTY	UNITS OF MEASURE	SYMBOLS/ABBREVIATIONS
Potential	Volts and millivolts	V, mV
Current	Amperes and milliamperes	A, mA
Resistance	Ohms, kilohms, megohms	Ω, k, M
Power	Watts and milliwatts	W, mW

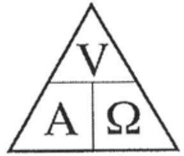


Figure 3-4 Ohm's Law pictogram.

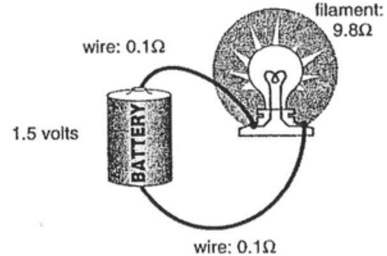


Figure 3-5 Bulb filament has higher resistance than wires.

Figure 3-5 illustrates the situation with the battery and light bulb. The wires have low resistance, while the filament has higher resistance. Since we know the resistance and the battery voltage, we can use Ohm's Law to compute the current through the circuit.

The resistance of the circuit is the total of all resistances in the path between + and −. In this case, it's 0.1 + 9.8 + 0.1 = 10Ω. So the current (V/Ω) would be 1.5/10 = 0.15 A.

One of the effects of resistance is to cause voltage—potential energy—to drop. We can use Ohm's Law and our current calculation to figure voltage drops through various parts of the circuit. For example, each of the wires has 0.15 A of current flowing through 0.1Ω resistance. V = A × Ω, so each wire has a 0.15 × 0.1 = 0.015 V voltage drop across it. That means that the voltage reaching the filament is 1.5 − (0.015 + 0.015) = 1.47 V.

This partly explains the hot bulb and cool wires; most of the battery voltage is across the filament. Since you've come this far, let's complete the answer using a new concept, power.

Power is a measure of work. In electrical circuits, the most common sort of work is the generation of heat; more power means more heat. Power is expressed in units of watts (W). There are two simple formulas for calculating power:

$$\text{Watts} = \text{Volts} \times \text{Amperes}$$
$$\text{Watts} = (\text{Amperes})^2 \times \text{Ohms}$$

Let's see where the power goes in the battery/bulb circuit. Each of the wires has a 0.015-V drop and 0.15 A of current flowing through it, so each consumes 0.015 × 0.15 = 0.00225 W of power. The filament has 1.47 V across it with 0.15 A of current through it, so it's getting 1.47 × 0.15 = 0.2205 W of power. That's 100 times as much power (heat-generating potential) as the wires. No wonder the filament is hot!

It may seem like a long way from light bulbs to computers. And to tell the truth, the field of electronics encompasses some fancy physics and mind-boggling math. But digital electronics (the kind we'll be doing with Stamp microcontrollers) can be done at a practical, useful level with little more than Ohm's Law and arithmetic.

In fact, if you're content to follow recipes like the ones presented later on in this book, you can build neat projects without any math at all. But you will need to understand, identify, and assemble electronic components.

Electronic Components and Symbols

Electronic circuits are normally drawn not as realistic pictures like our bulb/battery illustration but as skeletal blueprints called *schematic diagrams* or just *schematics*. Using standard symbols for electronic components makes it easy to draw and understand schematics. Unfortunately, beginners find schematics hard to follow, since they don't know what the components might look like. The circuits presented in this book are all in schematic form, so it's important for you to understand schematic symbols and the components they represent. Along the way, I'll even throw in some electronic theory.

BATTERIES AND POWER SUPPLIES

Batteries are represented by the symbol shown in Figure 3-6. The symbol is based on the way early batteries were made from metal plates soaking in acid. You will sometimes see batteries drawn as a single pair of plates (a cell) or more pairs of plates (a high-voltage battery). Don't worry about it. Batteries and schematics are marked with the required voltage rating, so there's no need to count plates.

Note that the wide plate indicates the + end of the battery and the narrow plate the – end.

A more general way of indicating a circuit's power connections is with supply and ground symbols, as shown in Figure 3-7.

For our purposes, supply means the + connection and ground means the – connection. In the more general sense, ground means the common point to which all current in a circuit flows (based on the notion that current flows from + to –).

RESISTORS

Batteries and power supplies provide voltage and current; resistors let us adjust the voltage and current at various points in a circuit. The fact that resistance is the third leg of Ohm's Law—the foundation of all electronics—should go a long way toward explaining resistors' importance.

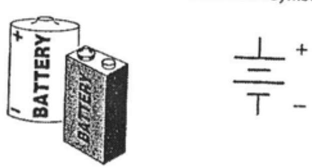
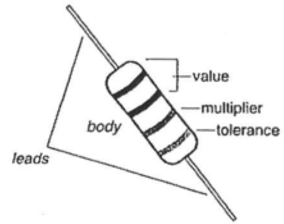


Figure 3-6 Batteries and their schematic symbol.

Figure 3-7 Supply and ground symbols.

Resistor and Color Code



color	value	multiplier
Black	0	1
Brown	1	10
Red	2	100
Orange	3	1000
Yellow	4	10,000
Green	5	100,000
Blue	6	1 million
Violet	7	10 million
Gray	8	100 million
White	9	1 billion

tolerances	
No color	20%
Silver	10%
Gold	5%

Schematic Symbol

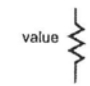


Figure 3-8 Resistors, color code, and schematic symbol.

Most resistors are marked with colored stripes to indicate their value in ohms. Figure 3-8 shows the color code. Figuring resistor values is easy. Suppose a project requires a 47k resistor. We know that k stands for thousand, so that's 47,000 ohms. Looking at the table in Figure 3-8 we see that 4 is yellow, 7 is violet, and thousand is orange. So we want a resistor whose first three bands are yellow-violet-orange.

What about the fourth, tolerance band? It's normal for a resistor's actual value to be a little bit off from its marked or nominal value. The tolerance band tells you how much variation to expect; a 5-percent resistor can range from 95 to 105 percent of its marked value. Many schematics will not specify resistor tolerance, leaving you free to use any tolerance up to 20 percent.

Another resistor characteristic is power rating, given in watts. The more power a resistor must handle, the larger it has to be. Resistors used in the circuits presented in this book can be any wattage from 1/8W on up. If a higher-power resistor is required a note in the schematic will say so.

Resistors, like many components, come with short wires attached for connection and assembly into circuits. These wires are called *leads* (pronounced "leeds").

POTENTIOMETERS ("POTS")

A *potentiometer* (*pot* for short) is a form of adjustable resistor. As the symbol in Figure 3-9 shows, pots consist of a resistor with a sliding connection called the *wiper*. As you turn the control shaft, the resistance between the wiper and one leg of the pot goes up; resistance from the wiper to the other leg goes down. This relationship allows the pot to be used as a voltage divider, a circuit that accepts a steady voltage across the legs and outputs a variable voltage (controlled by turning the shaft) between the wiper and one of the legs. See Appendix C for more on voltage dividers.

CAPACITORS

In its most basic form, a *capacitor* consists of two conductive plates separated by a thin layer of insulation. This setup is a trap for electrical charges. When you connect a voltage

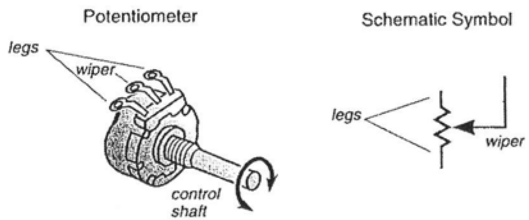


Figure 3-9 A potentiometer is an adjustable resistor.

to a capacitor, + and − charges arrange themselves on opposite plates. The insulator blocks them from coming together, but their attraction holds them in place. The charges are stuck. Trapping charges like this is called *charging* the capacitor.

There is a way to release the charges; connect a conductor between the plates. This causes current to flow until the trapped charges have all come together. This is *discharging* the capacitor.

These properties lead to two main uses of capacitors in the circuits we will build: temporary storage of electricity and timing. The storage aspect is pretty plain. When an external voltage is higher than the charge voltage of the capacitor, the capacitor will charge. When the external voltage is less, the capacitor will discharge. This makes capacitors helpful for smoothing out variations in a power supply.

Timing is more interesting. The process of charging and discharging capacitors takes a predictable amount of time based on the value of the capacitor and the characteristics of the circuit doing the charging or discharging. See Appendix C for examples. The important thing to remember is that a capacitor can help set the timing of a circuit to generate time delays.

Capacitors come in a variety of shapes and sizes. Figure 3-10 shows some examples. Note that electrolytic and tantalum electrolytic capacitors are fussy about *polarity*—the connection of + and −. Make sure to connect them as shown in the schematic or they can be damaged. In power-supply circuits improper connection can make them explode! Fortunately, electrolytic capacitors are marked with a + or − symbol next to one of the leads. As an additional clue, the + lead is usually noticeably longer than the − lead.

All capacitors have a maximum working voltage. Make sure that the capacitor you use has a working voltage equal to or greater than the voltage listed in the schematic. If no working voltage is given, just select a capacitor whose working voltage is more than twice the highest voltage in the circuit.

The basic unit of capacitance is the farad, abbreviated F. However, most common capacitor values are in millionths of a farad (microfarads, abbreviated uF) or trillionths (picofarads, pF). Figure 3-10 shows how to read capacitor markings. To test your understanding, what are the values of the capacitors in the illustration, marked "103M" and "222J?" The formula is value × multiplier, so 103M is $10 \times 0.001 = 0.01$uF (or $10 \times 1000 = 10{,}000$pF). The M tells us that the actual value may be 20 percent higher or lower than the nominal value. For 222J: $22 \times 0.0001 = 0.0022$uF ($22 \times 100 = 2200$pF), plus or minus 5 percent.

Electrolytic capacitors often use two-digit markings, since their units are always uF or F, never pF.

DIODES AND LEDS

A *diode* is a one-way door for electrical current. It acts like a conductor when + is connected to its anode and − to its cathode, but like an insulator when the connections are reversed. Because of this choosy behavior regarding conduction, diodes are the most basic of a class of components called *semiconductors*. The fancier members of this group are *transistors* and *integrated circuits*.

Most small diodes are cylinders with wire leads, looking somewhat like resistors. They are generally marked with a printed part number, often beginning with "1N" as in "1N4148," a common type of diode. Since it's important to distinguish the anode from the cathode, manufacturers put a stripe on the cathode end of the diode as shown in Figure 3-11. On some diodes the cathode end is tapered to mimic the arrow of the schematic symbol.

A special type of diode lights up when current passes through it. These are *light-emitting diodes* (LEDs). LEDs are often made in a bullet shape so that their package can serve as a simple lens. On such packages, a flat spot on the base marks the cathode, while the longer lead is the anode.

The brightness of an LED is proportional to the amount of current passing through it, but too much current can damage it. Circuits with LEDs usually use a resistor to limit this current. Appendix C shows how to figure the appropriate resistor value.

TRANSISTORS

Transistors let a small current control a large current, like the gas pedal controls a powerful engine. This makes transistors valuable for amplifying weak signals or turning power-hungry

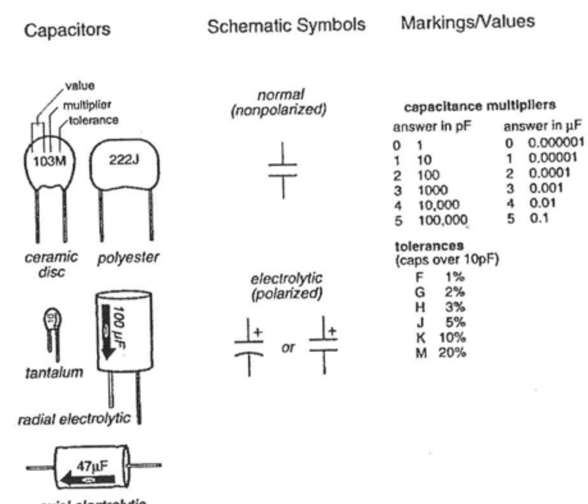


Figure 3-10 Capacitors come in a variety of styles.

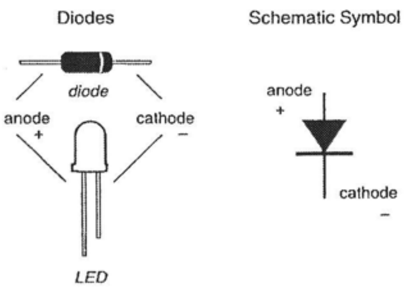


Figure 3-11 Diodes and light-emitting diodes.

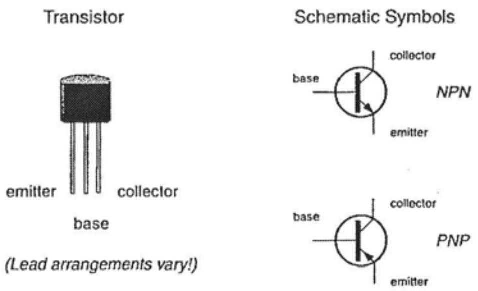


Figure 3-12 Transistors let a small current control a large one.

devices on and off. The control current goes through the transistor's base and emitter, while the larger current being controlled flows through the collector and emitter.

Figure 3-12 shows a typical transistor. I say typical, because there are many different styles of transistors specialized for particular jobs. Each has its own shape and lead arrangement. Don't worry, though; schematics and catalog listings generally include drawings to help you figure it all out.

In this book, the only type of transistors we'll be using are called bipolar transistors. You should be aware that there are other types, like field-effect transistors (FETs) and metal-oxide semiconductor FETs (MOSFETs).

The Stamps can handle enough current to directly drive many small loads like LEDs. Transistors can help them control larger loads. Appendix C includes some basic transistor switching circuits suitable for use with the Stamps.

INTEGRATED CIRCUITS

Integrated means "combined," so an integrated circuit (IC) combines many components into one compact package. When the term was first coined, ICs consisted of only a dozen or so components—mostly transistors. Today's ICs combine thousands, even millions, of transistors and other electronic components onto a single silicon chip.

The term chip is sometimes used interchangeably with IC, but there's a difference. A chip is a minuscule piece of brittle silicon, while an IC is a chip enclosed in a sturdy package made out of plastic, ceramic, or metal.

There are many styles of ICs to suit different methods of electronic assembly, but one of the oldest and easiest to work with is called the *dual-inline package* (DIP). DIPs are relatively large and have stiff leads or pins that can be plugged into sockets for temporary circuit hookups, testing, or prototyping. All of the ICs used in the projects in this book are DIPs.

Figure 3-13 shows how the pins on a DIP are numbered. The number of pins on a DIP depends on the function of the IC and ranges from 6 to 40 or more. However, all DIPs use the same numbering methods. Locate pin 1 by the telltale dot or notch in the IC. The rest of the pins are numbered down that side and up the other as shown in the figure.

All of the components we've examined so far had schematic symbols that hinted at their function. The zigzag line of the resistor certainly gives the impression of a path with more "resistance" than a straight line. But since ICs can include thousands of parts performing very complex functions, a single, standard symbol doesn't cut it. Schematics generally take one of two approaches: depicting the outline of the IC package or using symbols that represent the IC functions with pin numbers next to the connections. Schematics in this book use the representation that makes the most sense for a given circuit.

OTHER COMPONENTS

The symbols used in schematic diagrams are a kind of visual language. Once you get the hang of a few standard symbols, you will find yourself understanding new symbols without much trouble.

Figure 3-14 is an example. It introduces two new symbols: a switch and an electromagnet. A switch is just a break in a wire that can be opened and closed. An electromagnet

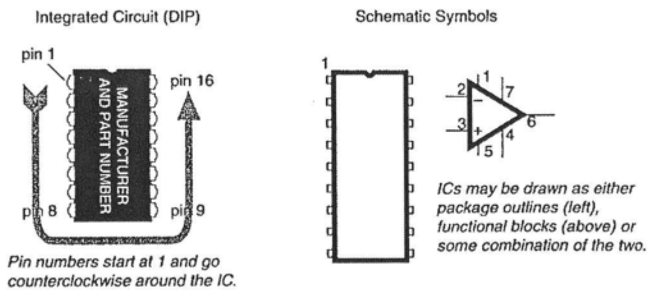


Figure 3-13 ICs incorporate complex circuits into one small package.

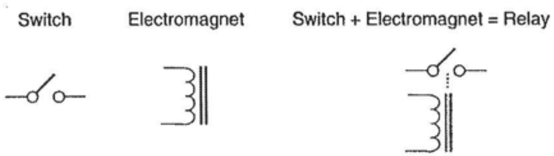


Figure 3-14 A relay is a switch controlled by an electromagnet.

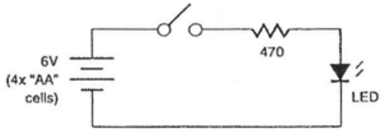


Figure 3-15 Example schematic lights an LED when the switch is closed.

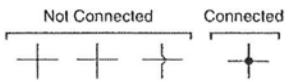


Figure 3-16 In schematics, wires don't connect unless there's a dot.

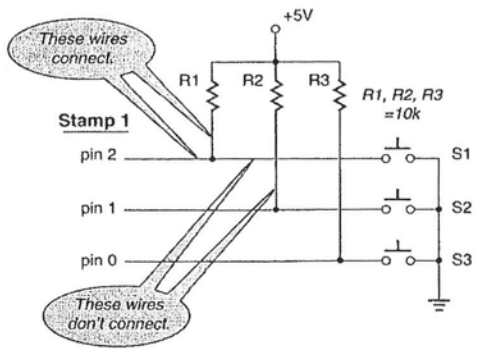


Figure 3-17 Example schematic with wire crossings, part numbers.

is a coil of wire wrapped around an iron core. When current passes through the coil, the iron becomes temporarily magnetic. If you combine the two as shown in the figure, you have a switch that is controlled by an electromagnet—a component called a *relay*.

Combining Symbols into Schematics

Now that we have seen some of the more important electronic symbols, we can take a look at a schematic diagram. See Figure 3-15. As the figure shows, connections between components—wires—are represented by lines. The schematic includes all the information needed to make the circuit, which lights an LED when the switch is on. The schematic does not specify things that are best left up to you, such as the color of the LED, the exact style of switch, or the method of construction. This is a common characteristic of schematics—saying only what needs to be said.

In more complex schematics, it's common for the lines representing wires to cross one another. Sometimes wires cross without connecting; other times they cross and connect. Figure 3-16 shows how to tell the difference, while Figure 3-17 is an example of a schematic with both kinds of crossed wires.

Figure 3-17 also illustrates a couple of more advanced schematic techniques. Notice the use of part numbers like R1 and S1. These numbers, also known as designators, serve as keys to a separate parts list, which gives component values and other information. Using designators and a parts list keeps the schematic relatively uncluttered but gives you a lot of detailed information about the circuit and its components.

Figure 3-17 also introduces another symbol. S1 through S3 represent a special kind of switch, a pushbutton that closes the circuit when you push it and breaks the circuit when you release it. Note also that the figure does not show the complete schematic of the BASIC Stamp connected to it, but treats it as a sort of supercomponent instead, just calling out the pin numbers to which this extra circuitry will be connected.

The name of the game with schematics is to present the least detail that will let someone build the circuit.

4

BUILDING ELECTRONIC CIRCUITS

CONTENTS AT A GLANCE

There are many ways to assemble circuits. We'll start with the ones that are most suited to beginners' skills and budgets. A couple of words you will encounter in this section are breadboard and prototype. A breadboard is a temporary mockup of a circuit built in order to test basic design ideas. A prototype is the first item or production run of a product that may later be made in quantity. In everyday speech, though, techies use these terms interchangeably to mean the first draft of a circuit.

Plug-in Prototyping Boards

Figure 4-1 is an example of a plug-in prototyping board. These go by a variety of names, such as socket boards, circuit strips, experimenter sockets, and even waffle boards. I like waffle board, because it describes their appearance and their function. They let you change your mind—waffle—over the design of your circuit until you get it just the way you want it!

Waffle boards are easy to use. The perforated plastic conceals a series of metal contact strips inside. When you push wires or component leads into the holes, springy grippers inside grab and hold them. As the drawing shows, the contact strips run vertically in the central part of the board, and horizontally along the edges. Figure 4-2 shows how plugging wires into the board connects them together. (Insulated wire—wire covered with a plastic coating—must have its insulation stripped off the ends before they can make electrical contact.)

Most waffle boards will accept a range of wire sizes, but solid #22 wire works best. This matches the size of most component leads. If wires are to be reused, use wire that has a bright plating on the conductor. Plain, unplated copper wire tarnishes, increasing the resis-

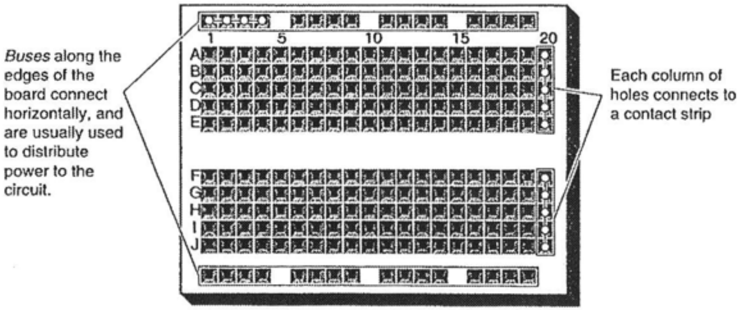


Figure 4-1 Plug-in protoboard or waffle board.

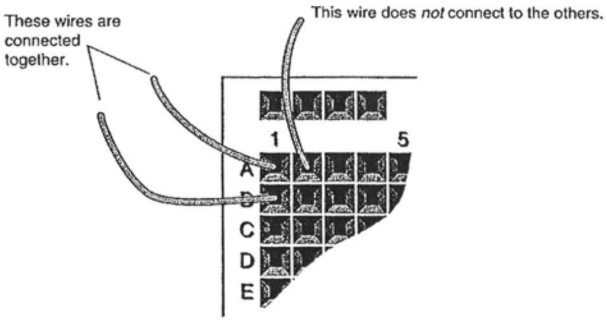


Figure 4-2 Wires in the same column are connected.

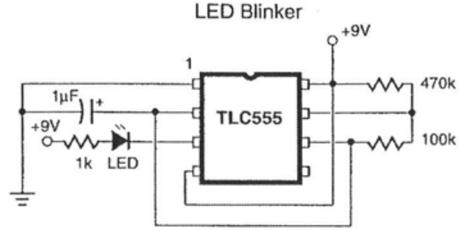


Figure 4-3 Example schematic for waffle-board layout.

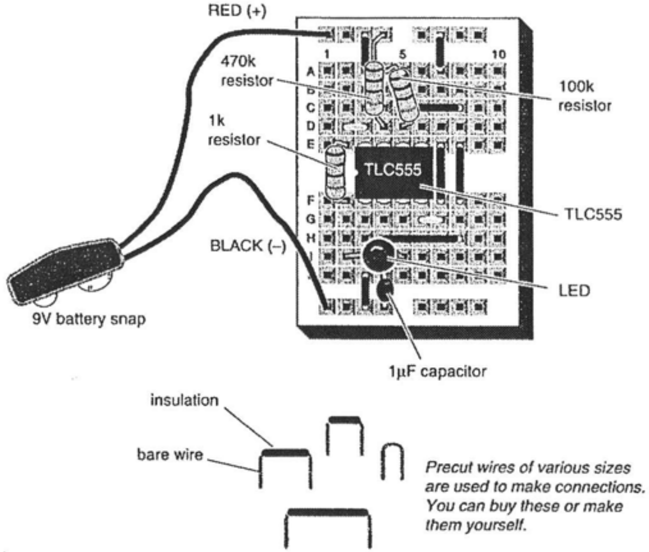


Figure 4-4 Waffle-board layout of circuit from Figure 4-3.

tance of connections or preventing good contact altogether. You can also purchase sets of staple-shaped wire jumpers in various sizes to match the spacing of waffle-board holes. As our example will show, this makes for a neat layout. And the fact that the wires are already stripped and bent is a real time saver.

Let's take a simple schematic and translate it to a waffle-board layout. Figure 4-3 shows a circuit that blinks an LED using a common IC called a TLC555. Figure 4-4 shows how that circuit might be built on a protoboard.

Trace the waffle-board layout and see how it matches the schematic. For example, look at pin 2 of the TLC555. The schematic shows that pin 2 goes to the + end of the 1μF capacitor, and to pin 6. You can see the 1μF capacitor has one lead plugged into the same column of holes as pin 2. And (slightly obscured by the LED), a wire goes from pin 2 to the right. Another wire jumps over the middle of the waffle board. One more wire goes left again, ending at pin 6. In fact, the way this path is laid out on the board looks just like the schematic.

I could have connected pin 2 to pin 6 with a single piece of wire; just bent it into a big hoop and jumped right over the IC. But using the preformed wire staples sold for use with waffle boards makes layouts that are tidy and easy to modify. Imagine a layout with lots of wire arches standing over it like a rib cage—it'd be impossible to change components inside that cage without first removing some of the wires.

Appendix E lists sources for waffle boards, precut jumper wires, and other components mentioned in this section. Parawax, maker of the Stamps, offers several waffle-board kits, such as the Board of Education.

Waffle boards are great for experimenting with circuits. They can be put together and taken apart easily without special tools. Unfortunately, they are not the best for permanent circuits. Parts can work loose if the board is handled too much, and the boards are somewhat bulky compared to other construction methods. When you build a good circuit with a waffle board, record it with a schematic diagram for future assembly using one of the more permanent methods.

CRIMP CONNECTORS

When you need to connect a waffle-board circuit to some other electronic device (like a BASIC Stamp), you may need to make connections to header posts. Header posts are metal pins 0.025" square and about ⅜" tall. Header posts are common because they are inexpensive and can be used with wire-wrapping (see next section) or crimp-on connectors.

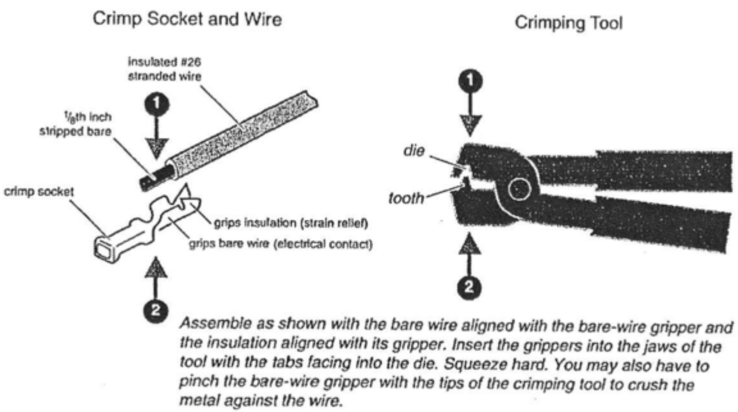


Figure 4-5 Crimp-on sockets are easy to use.

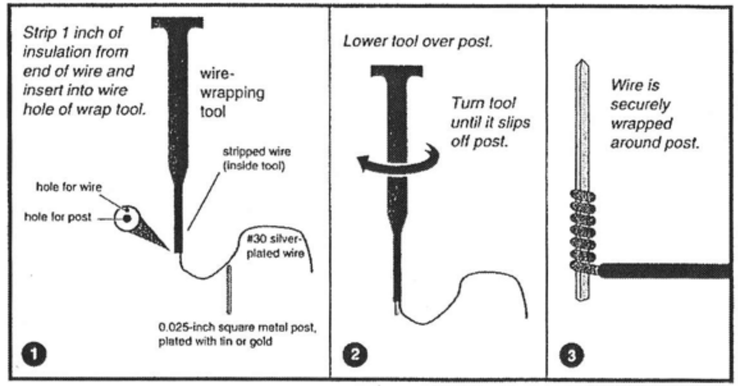


Figure 4-6 Basic steps in wire wrapping by hand.

Crimp connectors for headers are tiny sockets that can be squeezed onto the stripped end of a piece of stranded wire. Special pliers let you squeeze—crimp—these connectors with enough pressure to make a reliable electrical connection. Figure 4-5 shows how it's done.

Crimp-on sockets will also fit the leads of some components, like resistors and capacitors. They will not fit the pins of ICs or other small, oddly shaped leads, though.

Wire Wrapping

Wire wrapping is the prototyping technique that helped launch the age of computers. In the 1970s, wire wrapping was the construction method of choice for engineering prototypes, hobby projects, and even limited production runs.

The reason for wire wrapping's bloom of popularity is that it produces a finished circuit that is more-or-less permanent, but can still be modified. Seems like the best of both worlds. Unfortunately, wire wrapping has some significant disadvantages:

- For beginners on a budget, buying an initial set of wire-wrapping tools, panels, sockets, and wire can be overwhelming.
- Wire-wrap posts add a whole inch of thickness to a circuit board.
- Although wire-wrapped connections are in theory more reliable than soldered connections (see upcoming sections), in practice they can be fragile or intermittent.
- Wire wrapping is done from underneath the components, so it is very easy to get confused regarding IC pin arrangements.
- It can be next to impossible to trace connections in a wire-wrapped circuit, with a rat's nest of wires crossing every which-way.

Those drawbacks, along with cheaper and faster printed-circuit-board methods (see upcoming sections), have reduced wire wrapping's popularity.

Although wire wrapping may have passed its prime as a construction method, it's still a useful technique to know. Figure 4-6 shows the basic principle.

The figure shows how wires join to posts, but how do posts join to components? For ICs, there are wire-wrap sockets. The sockets have one post for each pin of an IC. You wrap all your connections to the sockets, then plug in the IC. For other components, like resistors and capacitors, you can mount them in IC-shaped frames called DIP plugs or DIP headers, then plug those into wire-wrap sockets. Or you can use special posts that have little claws designed to grab the component leads. What you should *not* do is try to wire wrap directly to component leads. Leads are round, while wire-wrap posts are square. Wire wrapping works only because the sharp corners of the square posts dig into the relatively soft metal of the wire. Wrapped wires will eventually slip off (or make poor connection with) round component leads.

Wire-wrap posts and sockets require a sturdy support surface. Wire-wrap panels are 1/16-inch fiberglass boards perforated with holes at 0.1-inch intervals—the same as the spacing of pins on standard DIP ICs. Each hole in a panel is surrounded by a metal ring to allow you to solder sockets and pins into place, although a friction fit is sometimes good enough.

If you want my advice, avoid wire wrapping for constructing projects unless you already have the tools and materials. But you should have at least a small spool of wrap wire and an inexpensive wrapping tool. Wire wrapping a couple of connections between header posts can make quick work of small jobs.

Soldering

Waffle boards are great as reusable sketch pads for circuit ideas. And wire wrapping lets you make a more permanent version of a circuit that can still be modified. But circuits that must be built to last are inevitably assembled using solder (pronounced sodder in the United States).

There's so much misunderstanding about soldering that you'd think it was a voodoo ritual rather than a time-tested craft. Even if you have soldered before, please read this section. Soldering is not difficult, but if you don't understand a few basic principles, it is very easy to develop bad habits that make your soldering unreliable.

Solder is an alloy of tin and lead in a ratio of 60/40 or 63/37 (i.e., 60 percent tin and 40 percent lead). Solder melts at a relatively low temperature—less than 400°—compared to other metals commonly used in electronics. For example, a temperature of almost 2000° F is needed to melt copper.

As metals go, the tin/lead solder alloy is not particularly strong. It's soft and easily weakened by repeated bending. What makes it good for securing electronic connections is stickiness. Solder is a sort of metal glue. Most glues are not very strong by themselves. Think of that skin of dried glue that collects on the nozzle of the glue bottle; it's soft and easily broken. Yet a good glued joint can be stronger than the materials it secures.

So we can glue metals together with molten solder. How do we melt the solder? And how do we make sure that the solder sticks properly?

The tool for melting solder is a soldering iron as shown in Figure 4-7. The figure shows some of the features required for electronic soldering: grounded plug, 20- to 30-watt heating element, and a removable cone- or screwdriver-shaped tip. More expensive irons come with a control box that lets you set the temperature, and even adjusts the power to the heating element to hold that temperature steady.

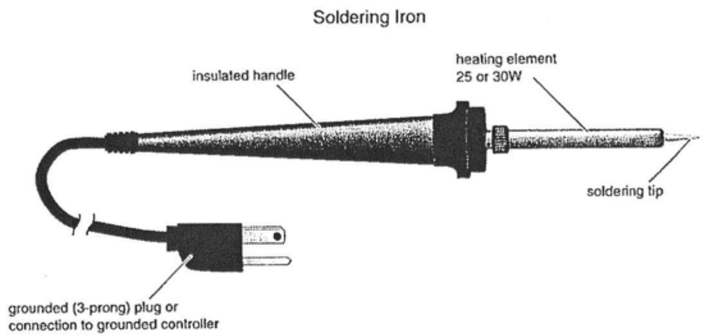


Figure 4-7 Anatomy of a soldering iron.

You will also need a stand to hold your soldering iron when it's not in use. Most stands have a pan to hold a moistened sponge, which is essential for cleaning the soldering tip.

The tip of the soldering iron gets hot enough to melt solder, but that's only part of the story. The key to a good solder connection is something called *flux*. The solder sold for electronic purposes looks like wire, but it's actually a tube filled with flux, a fast-acting cleaner. When the solder gets hot, flux gushes out onto the metals being joined. This flux bath removes minor corrosion and contamination that might prevent the solder from sticking. An instant later, the solder itself melts, flows over the freshly cleaned metal, and sticks like crazy. The whole process takes only a couple of seconds.

Enough theory! Here's how to get your soldering off to a running start:

On your mark: Set up your soldering iron stand in a well-ventilated area. Soldering produces fumes that contain lead and other toxic substances. Consider setting up a table-top fan to draw the fumes away from your face. Wear safety glasses to protect your eyes from spatters. Don't eat, drink, or smoke while soldering; you may accidentally ingest lead! Keep soldering equipment and materials out of reach of children, and always stow the hot iron in its stand when you're not using it.

Moisten the sponge with water so that it is damp but not soaking wet. Put the iron in the stand, and plug the iron in. Wait a few minutes for it to heat up. Do not touch the heating element or tip! If you do, painful burns and the stink of burned skin will remind you not to do it again.

Get set: When the iron is hot, take it out of the stand and wipe the tip on the sponge with a striking-a-match motion. Don't leave it in the sponge very long; you just want to wipe the tip of the iron. Quickly apply a little solder to the tip of the iron. If it beads up, wipe the iron on the sponge again and reapply the solder. Repeat this until the solder clings to the tip. This intimate contact between solder and metal is called *wetting*. Wetting the tip with solder is called *tinning*.

GO: Bring the freshly tinned tip of the iron into contact with the wires/metals you want to solder. The tinning of the tip will help transfer heat into the target metals. After a second or so of this preheating, bring the solder into contact with the metals, not the soldering iron itself. If the metals are hot enough, the flux will flow out of the solder and clean

Figure 4-8 Soldering a component to a circuit board.

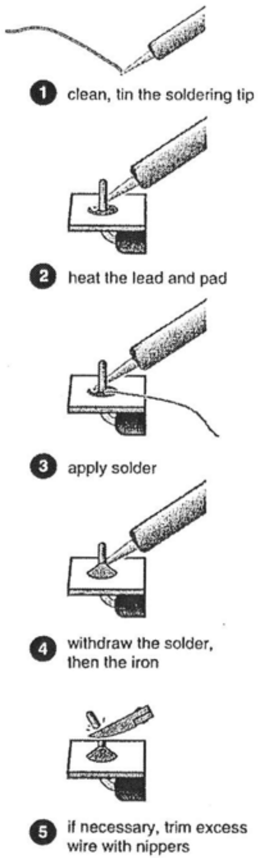


Figure 4-9 Steps in producing good solder joints.

the area, then the solder will melt and wet the metals. Remove the solder—pause—then remove the iron without jostling the molten solder left behind.

Figure 4-8 shows the most common sort of soldering job—connecting a component lead to a printed-circuit-board pad. Figure 4-9 illustrates the soldering sequence.

Although it is possible for a good-looking solder joint to be bad, it is nearly impossible for a bad-looking solder joint to be good. Figure 4-10 shows good and bad solder joints. Practice soldering until you consistently produce good-looking solder joints. Even if your first efforts look bad, keep going. Constantly clean and tin the solder tip to keep it clean and shiny. Always apply heat to the joint, not to the solder itself (except when tinning the tip).

It sounds old-fashioned, but good soldering takes discipline. Many beginners go wrong by giving up on good soldering technique before they get the hang of it. They start trying things at random—typically melting big wads of solder on the tip and dropping them on the solder joint. The result may sometimes look OK, but it's not a solder joint! It will work intermittently, or not at all.

Follow the procedures and practice, practice, practice.

Here are some additional hints for good soldering:

- If you're having trouble tinning a tip, try using a brass-bristle brush to remove stubborn crud or corrosion. There are also tinning compounds and tip cleaners that can help.
- Once a soldering tip is too old or corroded to tin, replace it with a new one.
- Hard water in the soldering sponge can leave deposits on the tip. Use distilled or de-mineralized water instead of tap water.
- Avoid specialty solders—those other than 60/40 or 63/37 tin/lead with a flux (not acid) core. No-lead solders and silver solders can be much more difficult to use without the right training and equipment.
- Use thin solders, 0.020" to 0.031" diameter, as these melt quickly. Avoid solders that are thicker than 0.031" or thinner than 0.020".
- Just touch the soldering iron and solder to the joint; never press hard. Pressure damages fragile printed-circuit pads, and can cause them to peel away from the board. This kind of damage is almost impossible to undo. If a joint isn't heating properly, stop. Clean and tin the soldering tip and try again.
- If you make a bad solder joint, clean and tin the soldering tip, and reheat the joint. You may have to apply a little more solder, primarily to get a fresh application of cleansing flux.
- To correct really bad solder joints or other mistakes, you may have to remove the solder. See your electronics store for tools and supplies. Spring-loaded solder suckers and desoldering braids are very helpful.

Printed Circuit Boards

Before the printing press was developed, scribes copied books by hand. That's how it was in the early days of electronics, too. Assemblers mounted components on an insulating board and connected each wire by hand. Then, just prior to World War II, engineers realized that the wiring could be manufactured right on the insulating board. The process they came up with resembled printing and increased the speed, ease, and quality of electronic manufacturing in

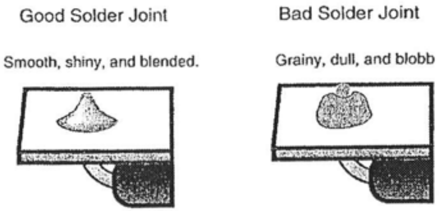


Figure 4-10 Bad solder joints often look bad.

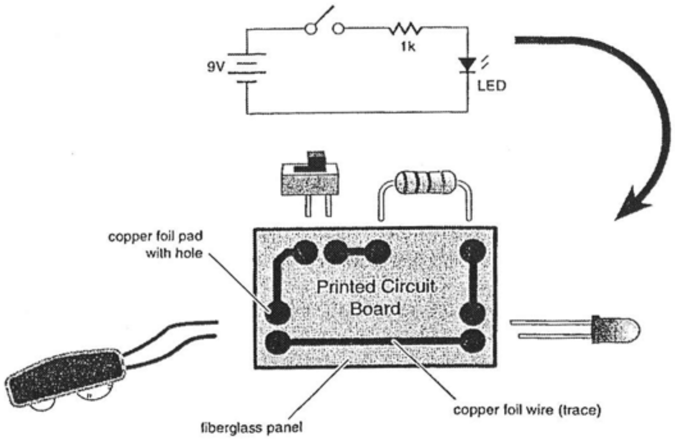


Figure 4-11 How a circuit translates to a circuit board.

the same way printing revolutionized communication. They invented the printed circuit board.

The process is simple. Start with a panel of insulating material—typically fiberglass—and glue a thin sheet of copper foil to it. Print chemical-resistant ink onto the copper in the pattern of the circuit's wiring. Dunk the board into a chemical called *etchant* that dissolves copper. The etchant eats away the copper foil except in the areas protected by the ink. What's left is a perfect reproduction of the printed wiring pattern. You can clean off the ink and solder components to the board.

Figure 4-11 shows how a simple circuit translates to a printed circuit board (pcb). In pcb lingo, foil wires connecting components are called *traces* or *tracks*, and the foil shapes to which the components connect are called *pads*. The pcb in our example is called a through-hole board, because components are mounted by passing their leads through holes in the board. A more modern type of pcb uses surface-mount techniques in which smaller, leadless components are soldered directly to the pads. Other innovations in pcb technology allow for multiple foil layers separated by thin insulating layers. This allows fabrication of very complicated circuits in which many traces cross without touching.

You can make your own pcbs using materials available from your electronics supplier (Appendix E) and the guidance of a good book (Appendix F). If you'd like to plunge in

and start designing your own PCBs, visit www.expresspcb.com. They supply free PCB design software that can automatically upload your design into their manufacturing system. A few days later, your boards are delivered to your door. You can also buy ready-made pcbs for some projects, or generic pcbs that resemble the prototyping boards discussed earlier (Appendix E). Wire-wrapping panels are also generally a form of pcb with pads to support pins and sockets and tracks to distribute power throughout the circuit.

If you're just starting out, the first pcbs you are likely to use are those included with electronic kits and generic boards. Since kits come with their own instructions, let's talk about generic pcbs.

Figure 4-12 depicts a typical generic pcb. I say typical, because there are many different styles available. The type shown is best for the kinds of circuits presented in this book. The row-and-column layout makes it easy to interconnect ICs and other components.

Tools and Test Equipment

Figure 4-13 shows an assortment of tools that you will find useful for electronic assembly and testing. It's by no means a complete set. As you progress, you will find some small jobs that seem harder than they ought to be; the next time you go into an electronics store or browse a catalog, you'll find a tool designed to make that job easy.

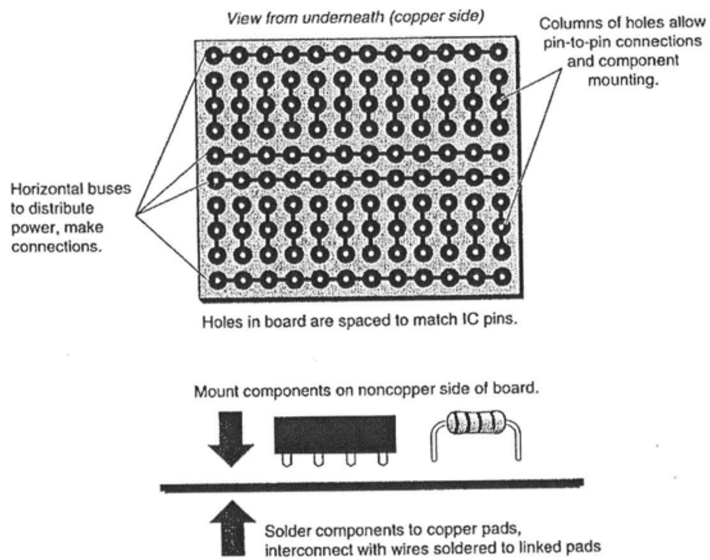


Figure 4-12 Row-and-column arrangement of a generic pcb.

Tools for Electronic Assembly and Testing

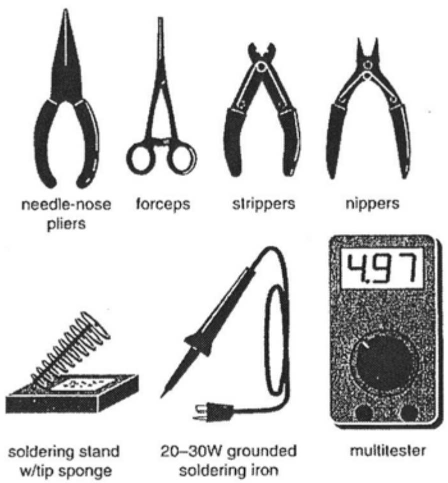


Figure 4-13 Basic assortment of hand tools for electronics.

One of the most important tools shown in the figure is the multimeter. These days, you can get a decent unit for less than $100, enabling you to measure volts, ohms, and amps; check for continuity (connection of wires), and test diodes and transistors. Some models include a frequency counter, computer interface, high/low/average sampling, capacitor tester, and a host of other convenient features.

Perhaps the best feature of all is that modern, auto-ranging multitesters are very hard to damage either by physical abuse or incorrect hookup. Buy the best unit you can afford, and read the user manual from cover to cover for practical tips on making common measurements. Build some of the circuits from Appendix C, use Ohm's Law to predict a measurement, then verify your figuring with the meter.

Summary of Construction Techniques

I have only scratched the surface of available electronic construction methods. Cruise through an electronics store or catalog, and you will see many more products, tools, and materials that you may find useful. Manufacturing electronic circuits is advanced technology, but prototyping is a handicraft. Once you learn the basics, you are welcome to improvise your own techniques, or mix and match from existing methods. See what others are doing, through electronics magazines, Internet newsgroups, clubs or classes, and adopt ideas that make sense to you.

5

GETTING STARTED WITH STAMPS

CONTENTS AT A GLANCE

This chapter will walk you through the process of getting a Stamp up and running for the first time. We'll cover the BASIC Stamp I (BS1) and BASIC Stamp II family (BS2, BS2-SX, BS2-E).