FEATURE

Basic Electronics #1A

By Ron C. Johnson

Hello and welcome to a brand new series on the basics of electronics. In the next few issues we will explore the area of electronics: components such as semiconductor diodes, transistors, FET's, unijunction transistors, SCR's and a whole mess of other interesting electronic gadgets. If you were following my last series on basic electricity you will find that this new series carries on with learning how electricity can be used in a wide variety of interesting ways. In this series, in addition to giving you some qualitative theory on the components and circuits, we'll be learning how to actually hook up simple circuits on breadboards and vectorboards. We will also build some basic test equipment like a simple power supply and a diode checker, and we'll learn how to use meters, oscilloscopes and other kinds of bench test equipment.

In the first part of this segment let's consider some of the things you will need in order to get involved in the practical activities we'll try in subsequent issues. And by the way, if you just don't have some of this stuff and can't pick it up cheap, there will still be plenty of good reading from a theoretical point of view.

Let's assume you're just getting started in electronics. What do you need? Well, first, you need a place to work. The kitchen table is a great spot for short term activities but you will probably find that right in the middle of a project something silly like Thanksgiving dinner or the need for a few hours sleep will interrupt your latest project. You should try to find yourself a spot out of the way, with good lighting where you can work on, and leave, your projects out of harm's way. If you don't have an old desk or table available already I have a couple of suggestions, off the wall though they may be; both of them involve old doors. At a local lumber yard you can usually pick up brand new but slightly damaged doors really cheaply. Buy a couple of them at a good price and all you have to do is cut one in half and set the two pieces on edge, for legs, with the other door on top. A few angle brackets to hold the thing together and you have an instant workbench, large and already finished. Another way is to use one door and a set of folding legs from the local hardware store. Screw the legs on the bottom of the door and you have a portable table or bench that is easily transported. Of course another possibility is the garage sale circuit where some of the most amazing and useful (and sometimes useless) things can be obtained for virtually nothing.

Electronics Bench Checklist

- ☐ Bench, chair, light, outlet, shelves, cabinets, etc
- ☐ side cutters
- ☐ needle nose pliers
- ☐ screw drivers
- ☐ knife
- ☐ wire strippers
- ☐ square jaw pliers
- ☐ nut drivers
- ☐ small crescent wrench
- ☐ jeweller's screwdrivers
- ☐ surgical seizers
- ☐ Soldering iron
- ☐ Solder
- ☐ Solder sucker
- ☐ solder braid
- ☐ Breadboard
- ☐ Multimeter

Figure 1. Electronics Bench Checklist

Another item that may just be personal preference is a small piece of carpet to go on top of the bench. With all the small parts such as transistors and integrated circuits and hardware like screws, bolts, nuts and washers used in constructing small projects, there is a tendency for them to roll or be brushed off the bench. A piece of carpet keeps things from moving around. (Before I started using this it seemed like I spent half my time on hands and knees underneath the bench looking for lost parts.) A piece of carpet can be very handy when you are soldering or desoldering a printed circuit board as it keeps the board stable while you work on it.

Now that you have a desk or table, (and some kind of chair of course), you will need a good light source. Electronic parts are small, often with even smaller printing or colour codes on them. A good florescent overhead fixture and a gooseneck lamp on the bench can be very useful.

In order to plug in your lamp, and a few other things later on, you will need at least one plug nearby. Hopefully you will not be building anything (purposely or by accident) which will consume large quantities of current, so a separate circuit and breaker should not be needed. If you have one, though, a plug-in bar with its own switch and breaker can be handy so everything on your bench can be turned off at once.

Next you will need a small parts cabinet with a number of individual drawers to keep electronic parts and supplies. Again the garage sale circuit can be of help. Lots of hardware stores sell them as well, often at reduced prices. Also in the way of storage space, you will need someplace to keep magazines and books that you will eventually accumulate, and a place for tools. A shelf or two, and/or a desk with drawers would help here.

What about tools? These guys are expensive if you buy decent ones and cheap tools are really a pain in the neck. You would be better to limp along with a few good basics than buy a whole set that wear out or break prematurely. What do you need?

Probably the most important hand-tool you can have for this kind of work is a pair of side cutters. What you need is a small pair, not the average type you find at the hardware store. There are several good brands, such as Cooper, or Excelite, and for a set of four inch side cutters you can easily pay twenty to thirty dollars. If this is too steep, check out Sears or Canadian Tire but find out what the warranty is. It's important. The next most important hand tool would be a pair of needle-nose pliers. Again, you need a very small pair. They are used to bend wires, hold components, and lots of other uses. After this would come screw drivers—flat, Philips and Robertson (another great Canadian invention) — a knife (either a small Xacto type or a packing crate knife), a wire stripper, square jaw pliers, a set of nut drivers, a small crescent wrench, jewellers' screwdrivers, surgical seizers. . . Of course the list could go on indefinitely, and you certainly can get started without all the things I have listed, but there are a few more that I have not listed.

On the bench itself you will need a soldering iron. Soldering irons start in the ten dollar range and go up, but for this kind of work a certain level of quality is necessary. First, it should be temperature controlled which means that there is an internal control of some kind which sets the tip temperature to a fixed temperature. In electronics, if you don't use a temperature controlled soldering iron you will very likely destroy a lot of components while you are developing your soldering technique. Soldering irons are rated in watts which indicates how much heat they can supply. If you are heating a large solder joint more wattage is required to heat the joint to the rated temperature in a given length of time. Twenty-five watts is a small iron. Forty watts is about right for general electronic soldering. Sixty watts and higher are available, and are usually used for constantly doing large solder joints such as wires to lugs, etc. Ideally your soldering iron should have a grounded tip. (You know it is grounded if the power cord has a three prong plug.) Grounded tip irons are not only safer for the person using them but they can save the destruction of certain devices which are sensitive to static discharge. As with the other tools this kind of equipment is best obtained from an electronics supplier. Radio Shack stocks a reasonable selection of this kind of equipment for the beginner.

Still on the subject of soldering, sooner or later you will need to be able to desolder parts which usually means removing as much solder from the joint as possible before disconnecting it mechanically. There are a couple of choices for this job. One is to use solder wick. Solder wick is a braid of copper which comes on a small roll. When the wick is placed between the soldering iron tip and the solder joint the molten solder will be drawn up into the wick by surface tension. The wick absorbs the solder away from the joint allowing you to disconnect the joint mechanically. This stuff works pretty well and comes in a variety of widths for various sizes of solder joints. The disadvantages are that it is consumed in use and sometimes can not draw all the solder out of plated-through holes in printed circuit boards.

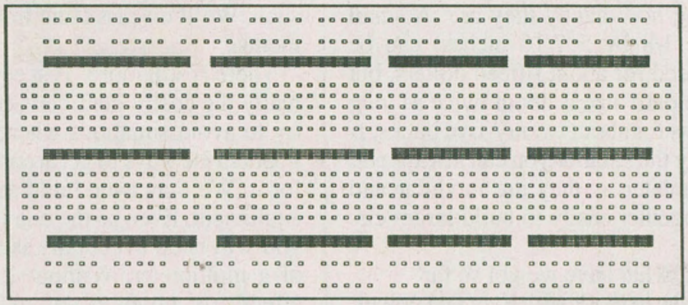

Figure 2. A solderless breadboard

The other choice is a solder 'sucker'. These come in various sizes and consist of a tube with a spring-loaded piston which, when released, creates a vacuum at the heat-resistant teflon nozzle. By melting the solder joint and then placing the nozzle over the joint and triggering the piston, the solder is sucked up into the tube. These work very well once you develop a little skill with them. They start in the ten dollar range and can go up to thirty or more. There are other devices available but the cheaper ones, such as vacuum bulbs, are not worth buying and the more expensive vacuum solder stations are for professional applications.

You will also need some solder. This stuff is not really cheap. If you buy it in larger quantities the price per unit drops but you have to consider how much you will use. We'll talk more about soldering and supplies in another issue but for now suffice it to say that you need electronic resin flux type solder, in a fairly small diameter and a good standard type is an alloy of 60% tin and 40% lead.

Soldering is not the only way to set up electronic circuits. In fact, most times you will want to breadboard the circuit to test and modify it and nobody wants to desolder and resolder the circuit every time they make a change. The answer is another tool which is practically indispensable to the hobbyist and experimenter: a breadboard. Breadboards are flat plastic devices (See Figure 2) with a matrix of holes on top into which component leads and wires can be inserted to make connection with conductors underneath. The holes are interconnected such that you can connect more than one lead together using jumper wires and in so doing set up temporary circuits. These units are relatively inexpensive considering how handy they are. A small one (2 1/8 by 5 7/16 inches) can be purchased for about fifteen dollars, but the standard size is about twice as long and runs for about twenty-five bucks. If you buy the smaller you can always add another later as they are modular and snap together easily to build larger circuits.

Well, what have we got so far?

A place to work with light and power. Hand tools and soldering equipment, a breadboard. You can probably see already that this hobby could become somewhat expensive. On the other hand, you can start with the basics and build up from there.

What about parts, supplies and test equipment?

There is really no point in spending money on electronic parts before you know what you need but if you come across old televisions, stereos, etcetera that have used parts in them don't throw them away. You might be able to scrounge something out of them. Also, hardware and metal or plastic boxes to house projects are expensive. If you have anything that can serve in this capacity, hold onto it. It will save you money in the long run. Of course, as we get into this series and attempt some of these projects, you may want to scrounge or buy the more specific components required. The same applies for other supplies like wire, chemicals and such. We'll discuss them in future segments.

There is still more. Test equipment is really the costly item here, but we will try to avoid situations where you need it, or devise ways to get around the need for it. We may even build some bench equipment. Even so the one item which you will need eventually is some kind of a multimeter. Without it you'll be effectively blind in determining how your projects work.

At the low end of the spectrum you can pick up a simple analog multimeter, which will measure AC and DC voltage, low range current, and resistance for around twenty-five dollars. These units are pretty basic, not exceedingly accurate and you won't want to drop them on the floor, but they will do the job. Meters with digital readouts start at about twice that price, but don't be fooled. Just because they have a digital display does not necessarily mean that the meter is any more accurate or has better loading characteristics. For a hundred dollars or more you will get into meters with input impedances over 1 Megohm which is very desirable in the kind of measurements we will do in electronics. Autoranging is a nice feature, but not really necessary. Also, we won't be measuring large quantities of current, or if we do we can use some simple tricks to use a voltage range to accomplish it. Another consideration is some of the new digital meters which have additional features such as capacitance measuring capabilities and transistor checkers. The features all boost the price of course.

With a multimeter and some of the other tools already mentioned we will build a simple DC power supply, which is probably the next most important thing you will need. Electronic circuits generally operate using DC voltages so a variable, regulated DC power supply will be useful as we continue learning about diodes, transistors and such. Once we have the power supply there are a number of other useful circuits we can build, like a simple pulse generator, a diode checker, a sine wave generator, a simple frequency counter and lots of other interesting circuits.

So stay tuned and check out Part B of this segment where we will take a theoretical look at semiconductors. ❐

FEATURE

Basic Electronics #1B

by Ron C. Johnson

In the first part of this segment we discussed what this series on Basic Electronics would be about and what you would need if you are a beginner hobbyist. I made some suggestions of things you might want in order to set up a work area and some of the tools and supplies which would be helpful. If you already have some or all of that stuff so much the better; you're ready to go.

This part is an introduction to the theory (don't shudder) behind semiconductor electronics. We will get started here with how diodes work and then next month we can try a small project. Here we go . . .

If you remember 'way back to the beginning of Basic Electricity we discussed the structure of the atom and how electrons travelled in orbits around the positively charged nucleus in a series of shells, each one with its own energy level. For an electron to leave its shell and move to a higher shell, energy had to be added to it (in the form of heat perhaps) while energy was released (heat or light) when the electron dropped back to a lower level. We said that the best conductors had only one electron in their outermost valence shell and that that electron was very mobile; it could move into the shell of another atom easily. When potential was applied to that conductive material, electrons would easily flow through it, skipping from one shell to the next as it travelled through the material. Materials in which the valence shell was completed by being filled with the required number of electrons (eight) became very stable, not easily permitting electrons to move. These materials are called non-conductors or insulators. Materials which have four electrons in their valence shell are called semiconductors and are the kind of materials used to create diodes, transistors and numerous other useful electronic devices.

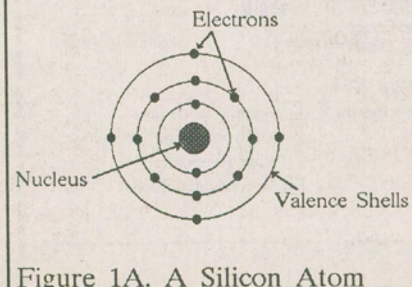

Figure 1A. A Silicon Atom

Each atom shares to make up eight electrons in the valence shell.

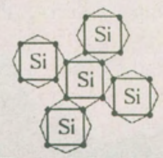

Figure 1B A Matrix of Silicon Atoms Sharing Electrons

Semiconductor materials, mostly silicon and to a lesser extent germanium, are not good conductors or insulators. Some electrons will flow through them but for the purposes of creating useful electronic devices they must be 'doped' with impurities which will selectively change their atomic structure so that they can be used. By introducing either trivalent or pentavalent materials such as aluminum, gallium or antimony (three or five electrons in the valence shell) during the manufacturing process, P-type or N-material can be formed. N-type material, with pentavalent doping, is a matrix of shared electrons similar to undoped semiconductor material except that because of the fifth electron contributed by the doping material, there are many free electrons, called majority carriers, available to move around in the material. P-type material, on the other hand has a deficiency of electrons. We can think of it as having an abundance of 'holes' (the spot in the matrix where there is an electron missing). In P-type material we call the holes the majority carrier. Minority carriers in N-type material are the holes while minority carriers in P-type material are electrons.

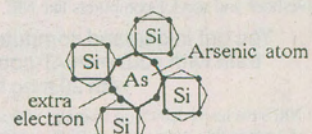

Figure 1C. Silicon matrix with doping

So what?

It turns out that if we put a piece of N-type material next to a piece of P-type material something interesting happens. At the junction of the two materials the extra electrons in the N-type material are attracted to the holes in the P-type material and they diffuse together to form a depletion layer which is neutral. This is called a PN junction.

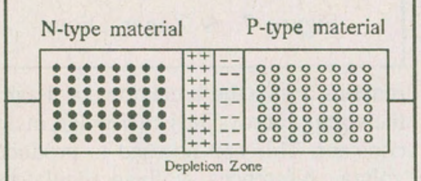

Figure 2. A PN Junction

(See Figure 2) Next we apply a voltage. Figure 3A shows a PN junction with a variable voltage source connected across it. When the voltage is connected as in Figure 3A positive voltage is applied to the P-type material while the negative side of the voltage source is

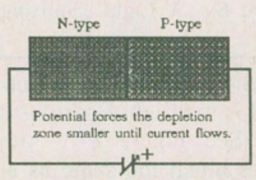

Figure 3A. A Forward Biased PN Junction

connected to the N-type material. The negative potential on the N-type material causes the extra electrons in the material to be pushed toward the junction while the holes are being pushed toward the junction by the positive side of the voltage source. As the voltage is increased, eventually the electrons will gain enough energy to break through the depletion layer and recombine with holes in the P-type material. When that happens conduction will occur.

Okay, but what does that mean?

Simply that when a voltage source is connected that way, after a small initial voltage is overcome the PN junction becomes a low resistance and allows current to flow through it readily. The small initial voltage (for silicon which is the most common material) is about 0.7 volts. (For germanium it is about 0.3 volts.) This is called forward bias.

The other interesting thing that occurs is that when the voltage across the PN junction is reversed (as in Figure 3B), the potentials applied tend to cause

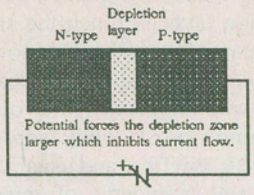

Figure 3B. A Reverse Biased PN Junction

the depletion layer to widen. Positive voltage on the N-type material draws electrons to it widening the depletion layer which is neutral. This stops electrons from flowing through the depletion layer which creates, in effect, a high resistance to current flow. So, when the PN junction is reverse biased it acts like a high resistance and effectively blocks current flow.

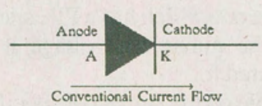

Figure 4. Schematic Symbol of a Diode.

We call this a diode. It conducts in one direction but blocks current flow in the other. Figure 4 shows the standard symbol for a diode with anode (P-type material) and cathode (N-type material) labelled. The anode symbolizes an arrow in the direction of current flow while the cathode symbolizes a blockage of current flow from the other direction.

Diodes are used in lots of common applications: your car's alternator for instance. The alternator works on the principle of moving a conductor through a magnetic field creating a voltage (just like we discussed in the segment on electromagnetism). The voltage generated is alternating, (changing from positive to negative repetitively). The diodes in your alternator are used to convert the alternating voltage into a DC voltage which can be used to charge the battery. When diodes are used for this purpose they are usually called rectifiers because they rectify the AC voltage to DC voltage.

We do the same thing when we convert the alternating voltage available from our 110 volt AC power outlets into DC voltage used in our televisions, radios, stereos, etc. In fact, next month we will be building a bench power supply and using rectifiers to obtain DC voltage from AC voltage. Let's take an advance look at how we'll do that.

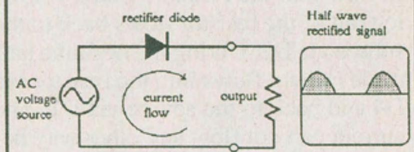

Figure 5A. A Half Wave Rectifier

In Figure 5A you will see a schematic diagram of an AC voltage source, a rectifier, and a resistor to complete a simple series circuit. Because of the characteristic of the rectifier diode, during the time that the AC voltage source is putting out a positive voltage, the rectifier will conduct current around the loop. During the other half cycle, when the voltage source has a negative polarity, the diode is reverse biased and so virtually no current flows. When a rectifier is used this way it is called a half wave rectifier. The voltage dropped across the load resistor is shown as it would look on the screen of an oscilloscope. The voltage is a replica of the positive half of the voltage source waveform.

It would be possible to build our power supply this way, using one rectifier, and half the voltage waveform, and sometimes it is done but this requires a high amplitude of AC voltage to get the DC we want. Another way to rectify the source voltage, and make use of the negative half of the waveform, is

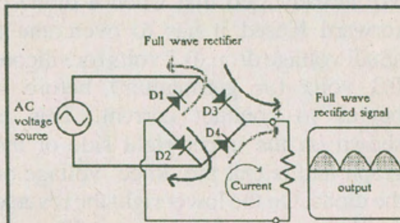

Figure 5B. A Full Wave rectifier

to use the circuit shown in Figure 5B. This is called a full wave or bridge rectifier. Using four diodes in this configuration 'steers' the voltage, whether it is positive or negative from the source, so that it always flows the same direction through the load resistor. (Bridge rectifiers can be created using four discrete rectifier diodes or can be obtained in a single package with four leads.)

As the arrows indicate during the positive half cycle D3 permits current to flow into the resistor. Current flowing out of the resistor flows back to the source via D2. During the negative half cycle current flows into the resistor via D4 and back to the source via D1. The current can not flow any other way because the blocking characteristic of the diodes prevents the current from flowing in the reverse direction. The oscilloscope diagram shows that both halves of the original AC voltage are supplied to the output, the negative half being inverted positive. The average voltage output is doubled from that in a half wave rectifier.

Having obtained a full wave rectified output, in order to use it for a DC power source filtering must be added to smooth out the ripple. We'll discuss this next month when we consider our power supply project. In the meantime let's look at some other aspects of diodes.

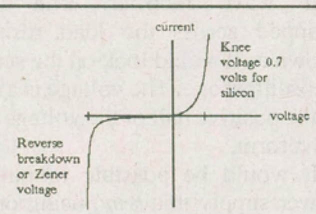

Figure 6. Zener and Knee voltages of a diode

In Figure 6 a graph displays the relationship between the current through and the voltage across a diode. We already said that when a diode is forward biased it has to overcome a small voltage drop (0.7 volts for silicon, 0.3 volts for germanium) before it begins to conduct current. This is shown on the upper right side of the graph and is call the 'knee' voltage of the diode. On the lower right the reverse breakdown voltage is shown. We said that diodes do not conduct when biased in the reverse direction (another way to say it is that the reverse resistance is very high), but if the voltage applied to the diode is increased high enough all diodes reach a point where the depletion layer can no longer withstand the electrostatic force applied across it. At this point electrons 'punch' through the depletion layer in much the same way that a capacitor will break down if too high a voltage is applied across it. The diode, when it reaches this voltage will very rapidly break down; large amounts of current will flow and usually damage will result. (Students of mine sometimes innocently describe this as "letting the smoke out of the diode.")

To avoid damaging diodes by reverse breakdown the correct part should be chosen for each application. (There are lots of different diodes, each designed for particular types of usage.) The reverse breakdown voltage is often given in specifications as the Peak Inverse Voltage, or PIV. This is the maximum reverse voltage the device should be subjected to. Rectifier diodes usually have higher PIV's than small signal diodes and there are wide ranges of PIV values even for rectifiers. Always choose one which has a PIV spec higher than the maximum voltage it will be subjected to.

While on the subject of specifications we should mention that the maximum forward current is another spec which is important to consider. For example, the maximum forward current of a power supply rectifier will be much greater than that of a small signal diode. Along with the higher current rating comes increased size and cost as well as a few other specification trade-offs which we won't get into here.

Before we get too far away from the subject of reverse breakdown voltage we should talk about zener diodes. Another name for the reverse breakdown voltage is zener voltage and because the breakdown characteristic, (shown in Figure 6) is so sharp we can make useful application of this characteristic. If we can predict the breakdown voltage and control the current through the device after we have exceeded that voltage (so that we don't destroy the device) the zener breakdown characteristic can be used as a predictable reference voltage. In other words, if we set up a circuit like the one shown in Figure 7, where the diode is reverse biased into the zener region and the current is limited, the voltage across the diode will be very stable within a certain range of loads and can be used as a voltage regulator. Even if the source voltage varies somewhat (as long as the voltage applied to the zener diode remains above the breakdown voltage) the voltage across the zener will remain constant. This can be used to produce voltage references, voltage regulators for power supplies, and many other uses.

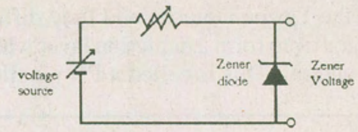

Figure 7. A Zener Diode

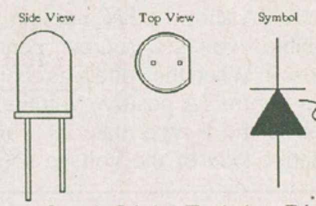

Figure 8. A Light Emitting Diode

Another type of diode which is widely used is the Light Emitting Diode, or LED. (See Figure 8) Although it operates much the same as any other diode, because of the semiconductor materials and doping materials chosen in it's manufacture, it emits light when forward biased with current flowing. The intensity of the light is proportional to the current level. Of course we see these all over the place: displays, calculators (the older ones at least), intelligent displays, etc. The only real difference electronically is that the forward voltage drop is higher than 0.7 volts depending on the material used to get a particular colour, size or intensity. Some forward voltage drops are over 2 volts.

As simple as diodes and rectifiers are, there is a lot that could be said about them. There are thousands of applications and almost as many specific part numbers for diodes and specifications differing from one to the next. We'll be talking more about them in future segments of this series and some of the practical aspects of the uses should come out then.

Next time: a simple DC power supply you can build. ❐