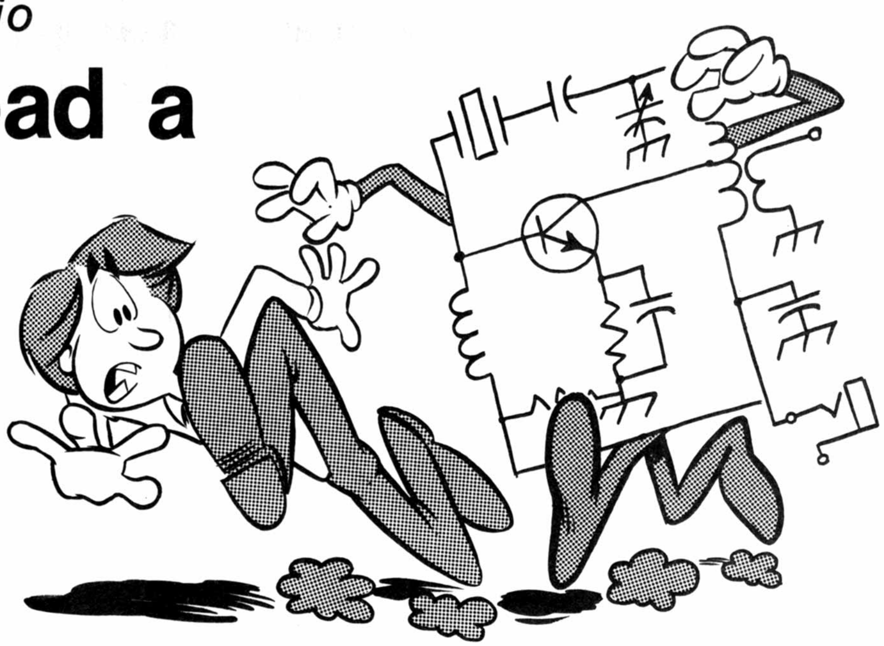
• *First Steps in Radio*

How to Read a Schematic Diagram



Part 2: The first step toward learning the basic theory of this series is to understand circuit diagrams — the "road maps" that allow us to build or repair equipment.

By Doug DeMaw,* W1FB

"Sure, I can handle the electronics — up to a point. I start having problems when I try to figure out what's going on in schematic diagrams." Many newcomers to radio electronics have this problem. Perhaps you're one of them.

In this installment, we'll learn what the various electronics symbols stand for, and we'll get a feel for how the diagram relates to the actual circuit-board layout.

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Learning the Symbols

We must first accept the fact that very few electronics symbols look like the physical item they represent. Only a *pictorial* diagram can satisfy that requirement. Most electronic parts are encased or encapsulated in some manner, which prevents us from peering inside to see what is there. Semiconductors (diodes, transistors and integrated circuits) are the worst in this regard, for if we did saw one open for a look-see, we might be hard-pressed to recognize the various elements (drain, base, emitter, collector, source, gate, or whatever) unless we understood the philosophy of semiconductor design and fabrication. So, our best approach is to ignore for now the contents of the enclosed components and think mainly about how the leads relate to the inner elements, as defined by the assigned symbol. In the days of vacuum tubes we could dismantle a tube and easily identify the grid, plate, cathode and filaments, but things have changed!

Unfortunately, each publisher of amateur and commercial electronics magazines or journals follows his or her own symbology. For this reason, diagrams found around the world can conflict. The ARRL has adopted and used the IEEE (Institute of Electrical and Electronic Engineers) standard symbols for many years. Only a few exceptions exist, and that is done to simplify (or unclutter) the drawings in *QST* and other League publications. We will focus on the *QST* symbology here, and despite differences found in other publications, you should be able to determine what a symbol stands for, because there will be ample similarity. Some magazine publishers, in order to establish a distinctive "style," have more or less ignored the recommended standards for electrical symbols. It is unfortunate, but we must accept it.

An abbreviated presentation of electrical symbols is provided in Fig. 1. You will see that some symbols do, indeed, resemble what they stand for, such as the headset, speaker and hand key. Conversely, the symbols for ICs (integrated circuits) would in some instances fill one or two *QST* pages if we were to see all of what was inside the IC. So for these complex circuits we accept the practical solution — to use just a box, a triangle or similar representation. In a real-life situation we think only about where each external lead connects, according to the numbers assigned to the pins by the manufacturer. This was for many years known as the "black box" approach. In other words, don't worry about what's within the box; just concentrate on what the box will do for us.

You will note that for some symbols we have more than one format. This means that we may use any of the illustrations given, and we may find one or all of them in a single issue of *QST*. The wiring junctions at the lower right of Fig. 1 are an example of what we are discussing.

The best advice I can offer at this time is to spend a few evenings studying and memorizing the symbols in Fig. 1. When you feel that you have the data implanted

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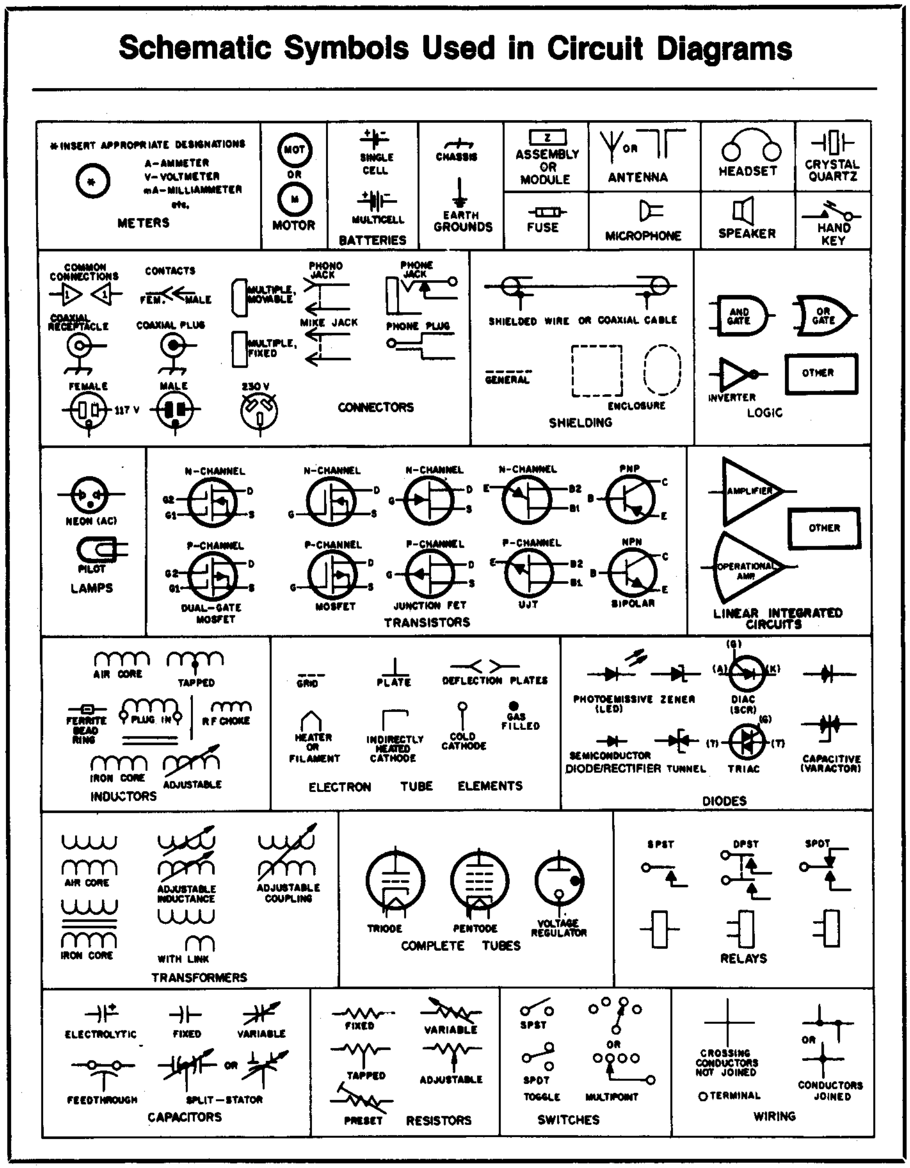

Fig. 1 — Collection of standard symbols used by the ARRL for circuit diagrams. Most of these symbols were adopted from the IEEE standards.

firmly in your mind, put away the symbols page and try to draw each symbol by memory, writing its name next to it. Continue with the exercise until you make no mistakes. This knowledge will prove invaluable to you as you pursue that ham license. It will be helpful to know the symbols after you pass the exam, also. You will need to have this knowledge in order to repair your equipment, to duplicate home-construction projects in the magazines, or to do your own circuit designs. If you are a person without sight, have a friend provide you with word pictures of the symbols and learn them that way. I know at least two blind amateurs who repair their own equipment by having someone give them word pictures of the diagram section that applies to the problem.

A Simple Circuit Example

Let's try our luck at relating a simple circuit to a pictorial diagram. This will enable you to see how things hook together when assembling a circuit from a schematic diagram. Fig. 2 shows two schematic diagrams of a two-stage audio amplifier, such as we might find in the early stages of a receiver. Although the two drawings look quite different at first perusal, you will observe that they represent the same circuit in complete detail. The difference is only in the manner of illustrating the circuit schematically. Fig. 2A shows the ground connections separately. Likewise with the two +12-volt connections. Fig. 2B shows the ground and +12-volt lines joined together, respectively. The net result is the same in either case: In a practical circuit the ground or +voltage lines would eventually be joined at a common point when example A is followed. It merely illustrates that you may find more than one style of presenting a circuit. You will note also that the resistors which connect to the +12-volt source (Fig. 2B) are routed upward rather than downward, as in Fig. 2A. You may find a mixture of the two methods in a given drawing, so don't let that confuse you. The main objective is to make sure that all of the parts are connected to the appropriate circuit points. A pictorial representation of these circuits is provided in Fig. 2C.

A Few Subtleties

You are probably wondering why the capacitors (sometimes wrongly called "condensers") have a curved line at one end and a straight one at the other end. The curved line indicates the end of the capacitor that goes to the terminal of lowest impedance or potential, such as circuit ground or the least positive of the two circuit points between which the part is installed. This applies mainly to polarized capacitors. Most of these parts are marked with a + symbol or may have a black band at the opposite end to indicate the negative terminal of the capacitor. This concept does not apply to disc-ceramic, mica and other nonpolarized capacitors, but the curve is always used in the symbol to show which end represents the low-impedance side of the circuit. Always pay close attention to the + symbols of capacitors: Hooking them up backward can cause them to short out or even explode!

Notice also that within the circular borders of Q1 and Q2 are arrows on the emitter line. When the arrowhead points toward the outer circle, the device is an NPN type, which requires a positive voltage on the collector terminal. If the arrows point inward toward the junction of the three lines, it signifies a PNP transistor, which needs a negative collector voltage. If you use the wrong transistor you may destroy it when voltage of the improper polarity is applied to it.

The arrowhead on R6 — the audio-gain control (sometimes called a "pot" for potentiometer) — tells us that the resistor value is variable by means of mechanical adjustment. In this case we would have the control mounted on the front panel of our equipment. Its shaft would be fitted with a knob to permit us to adjust the value of R6 when we wished to. If the adjustment were to be made only one time, then left in a preset position, we might install a trimmer pot at R6 (screwdriver adjust), and it could be installed right on the circuit board or chassis. Some hams call these controls "trimpots," but Trimpot® is a trade name, not a generic term.

J1 and J2 are jacks into which we may plug our outboard circuits or accessories, such as a microphone at J1. This electrical symbol is representative of a number of styles of jack. So just think of it as a connector of your choice — one that has a "hot" (center) terminal and a ground point (outer ring). It could be a phono jack, or one that a standard audio plug mates with. It could even be a coaxial-cable jack, if you wanted to use something that unusual for

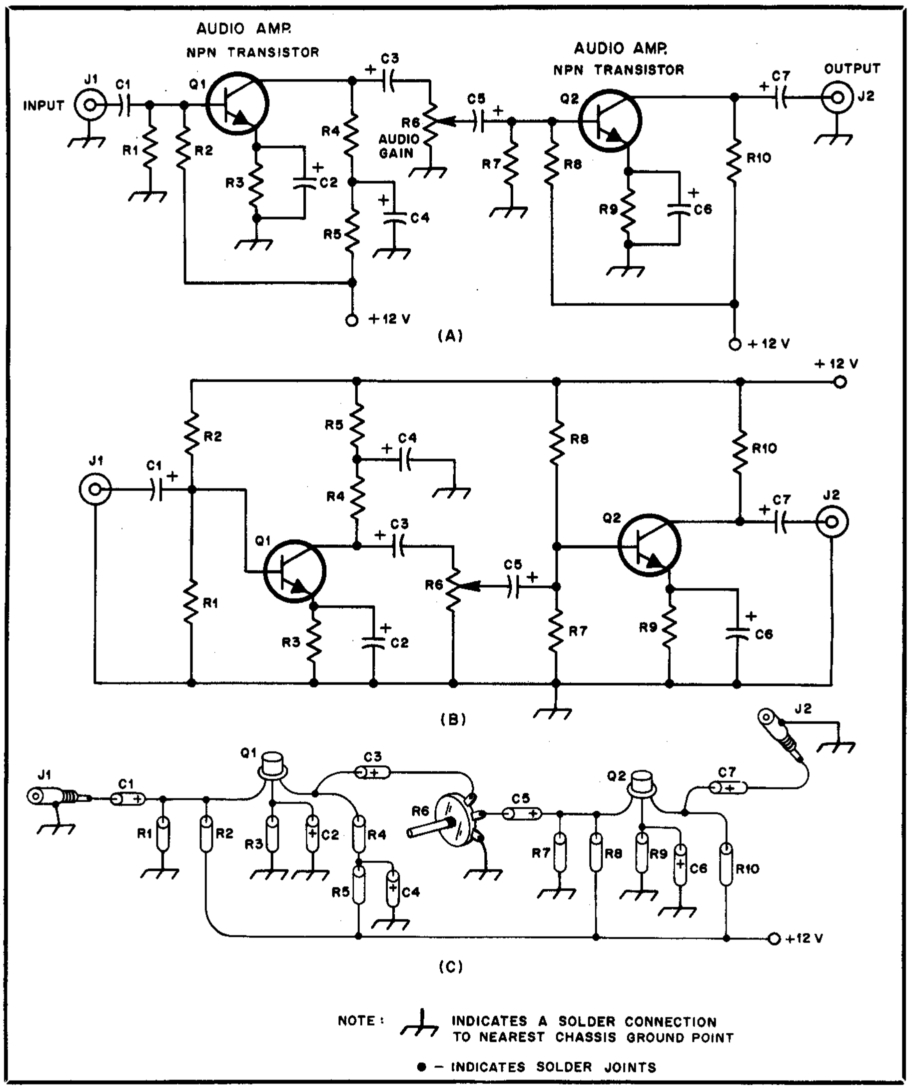

Fig. 2 — Examples of an identical circuit (A and B), drawn in different ways (see text). The pictorial representation at C is for the circuits shown in illustrations A and B. This shows how we can relate the drawing to the assembled circuit, which would normally be mounted on a circuit board or a metal chassis.

audio work! Examination of Fig. 1 will show that jacks with additional electrical contacts have a more complex symbol.

Notice that the symbol for ground in Fig. 2 looks like a rake. This is the proper symbol for *chassis ground* in a circuit. The earth-ground symbol of Fig. 1 is frequently misused by publishers for indicating chassis ground. Try not to be confused if you encounter disparity of this type: There is a significant difference between an earth ground and a chassis ground!

Voltage- and Ground-Bus Lines

I've noticed that one of the points of greatest confusion among beginners is how to configure the chassis-ground connections and the voltage-line network. In bygone days, when hams used wooden chassis, it was standard practice to run a ground-bus wire across the chassis. Each ground point in the circuit was then tied to this line by means of the shortest connecting lead possible. Other builders would return all ground connections for a single-circuit stage to a nearby common terminal, then route a lead from that point to the ground-bus wire. Although these techniques could still be applied, it is easier for us (and often better in terms of circuit performance) to bring each ground return to the metal chassis or circuit-board ground in the immediate area of the stage being wired. Not only does this impart a neater end product, it aids circuit performance (stability and reduced losses) when the ground leads are kept short and direct. The chassis or circuit board ground foil serves as the old-style ground bus when we do this. The "bottom line" here is to not worry about the maze of ground lines in the diagram. Simply make your ground connections short and direct near the related circuit elements.

Voltage-bus lines are treated like the old-time ground-bus conductors. That is, they are "floated" above ground on insulating terminals (or along specific voltage-bus foils on circuit boards). The various circuit points that connect to the voltage lines are connected by means of short jumper wires, or by the related components themselves (resistors, for example).

Circuit Direction

Another question that is asked frequently is, "Which way does a circuit run on a diagram?" The confused person means, does the first stage of a circuit start at the left or right of a drawing? Frankly, it makes no difference. Traditionally, for reasons I don't comprehend, a circuit has commenced at the left of the page and proceeded to the right. For example, considering a transmitter, the VFO or crystal oscillator would begin at the left of the sheet, followed by the intermediate stages, with the PA (power amplifier, or last stage) at the far right. Hams have developed the habit, as a consequence, of laying out the assembled unit from left to right also. I always did! But, it matters not how you lay out your project, provided you isolate one stage from another by reasonable physical separation, or by means of individual shield compartments. The last stage should never be placed alongside the input stages, lest unwanted feedback occur. The straight-line layout is the best method to adopt when in doubt.

Although it may not be apparent when examining a schematic diagram, we should always try to physically isolate the input and output components of a circuit stage from one another. Grouping them together will often cause feedback (output energy being fed back to the input circuit), which can cause a stage to self-oscillate, which renders the circuit useless. Some diagrams show a particular stage or stages enclosed in dashed lines. This indicates that that part of the circuit is contained in a shielded compartment to isolate it from the remainder of the circuit. A solid line around a circuit normally indicates that it is a separate module of a composite unit.

Potentiometers and Meters

We can't tell from the electrical symbol which end of a potentiometer (volume, tone, drive control, etc.) should be connected to ground. Many beginners have a problem with this: After wiring in the control, it operates backwards! For example, maximum volume occurs when the control is set fully *counterclockwise.* I understand this annoyance, for it used to happen to me!

Also, the circuit symbol for meters shows that one terminal is plus and the other is minus. But, which is which? Some meters have the polarity marked on the cases: Others bear no identification. Fig. 3 shows which end of a control should go to ground, and the meter drawing indicates which terminal is the positive one. The positive meter lug always connects to the circuit point of *highest* potential, as shown by the examples in Fig. 3. Incorrect

Glossary

base — the internal part of a bipolar transistor that controls the flow of current.
bus — a conductor of electrical current that carries a potential from one point in a circuit to another, such as positive or negative voltage, or ground.
capacitor — a device that stores dc energy but prevents its flow; permits the passage of ac energy, however.
cathode — negative electrode from which electrons flow in a stream inside a vacuum tube.
collector — in a bipolar transistor, the region through which the primary flow of charge carriers leaves the base. Generally, the output terminal of the transistor.
diode — a device having an anode and cathode, and which allows current to flow only one way.
disc-ceramic — a type of capacitor containing a ceramic dielectric (nonconducting material).
drain — a field-effect transistor electrode that supplies the amplified output signal in a grounded-source or grounded-gate hookup.
emitter — the element in a bipolar transistor that injects electrons into the base, which can be modulated by the base input signal.
encapsulated — a component that is embedded in a hard protective substance, or in a metal case.
feedback — ac energy that follows a path from one part of a circuit to another, intentionally or otherwise.
filament (heater) — in a vacuum tube, metallic wire heated by electric current; may serve also as the cathode in some tubes.
gate — part of an electronic device such as a field-effect transistor that controls the passage of current.
grid — in a vacuum tube an electrode that controls current flow.
hand key — a device used for sending Morse code.
impedance — the total resistance in an electrical circuit to the flow of alternating current at a specific frequency; expressed in ohms.
impedance, low — minimal resistance to ac.
integrated circuit — an electronics component that contains many individual transistors, diodes, capacitors and resistors and is sealed permanently in a single block or unit (unrepairable); usually referred to as an "IC" or "chip"; the various internal components are connected together or "integrated."
mica — an insulating (or dielectric) material found in nature; a mineral silicate.
oscillator — a circuit that generates a particular frequency.
plate — in a vacuum tube, the anode (positive element; in capacitors, the internal metal conductors.
polarized — a component that has positive and negative terminals marked on the case; the polarity is sometimes indicated by the shape of the part — each end being slightly different.
potentiometer — a variable resistor, such as a volume control.
resistor — a component that opposes the flow of current; available in a wide range of ohmic values and power ratings.
schematic — a diagram using electrical symbols that illustrates a circuit plan or "scheme."
semiconductor — an electrical component that is made from solid crystal materials, such as silicon or germanium; modern diodes, transistors and ICs are semiconductors; conductivity is intentionally poor compared to metal conductors.
source — the element in a field-effect transistor that supplies electrons; similar to the emitter in a bipolar transistor or the cathode in a vacuum tube.
transistor — a triode or tetrode semiconductor device that is capable of performing amplification, oscillation and control functions.
trimmer — an adjustable component, such as a capacitor or resistor; generally used for fine adjustment and left in a preset position.
vacuum tube — a device used to generate or amplify signals; can also be used as a rectifier or to perform control functions.
VFO (variable-frequency oscillator) — an oscillator whose frequency can be varied over a wide range by mechanical or electrical means; normally adjustable from the front panel of the equipment.

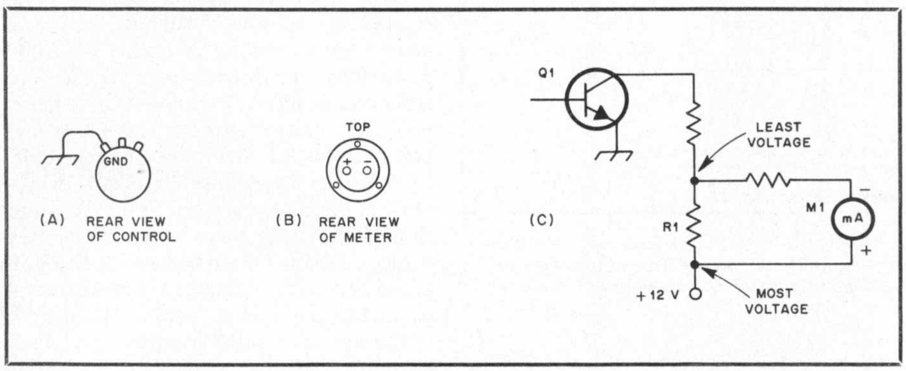

Fig. 3 — When wiring audio or tone controls, the ground end of the control is at the far left when viewing the control from the rear (A). Similarly, when viewing a meter from the back side (B), the positive terminal is at the left. The circuit at C shows that the negative terminal of a dc meter must be connected to the circuit point that has the lower of the two available potentials. The voltage drop across R1 in this example, caused by the current taken by Q1, makes the dc voltage lower at the top of R1 than it is at the low end of the resistor. This type of circuit can be used to monitor the current that Q1 draws.

polarization can destroy a meter at once. No one likes a meter with an S-shaped needle, jammed all the way to the left of the meter face! Ouch!

Some Final Words

The intent of this article is to help prepare you for the installments that follow in First Steps in Radio. How adept you become at following a schematic diagram easily and accurately will depend entirely on your tenacity in learning the symbology. Now is the proper time to apply yourself. This will make the lessons that follow a lot less difficult to digest. Practice drawing some simple circuits from memory. But, don't worry about the quality of your artwork. We aren't trying to follow in the footsteps of Rembrandt when drawing our diagrams; clarity is all that is required! QST

Strays

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