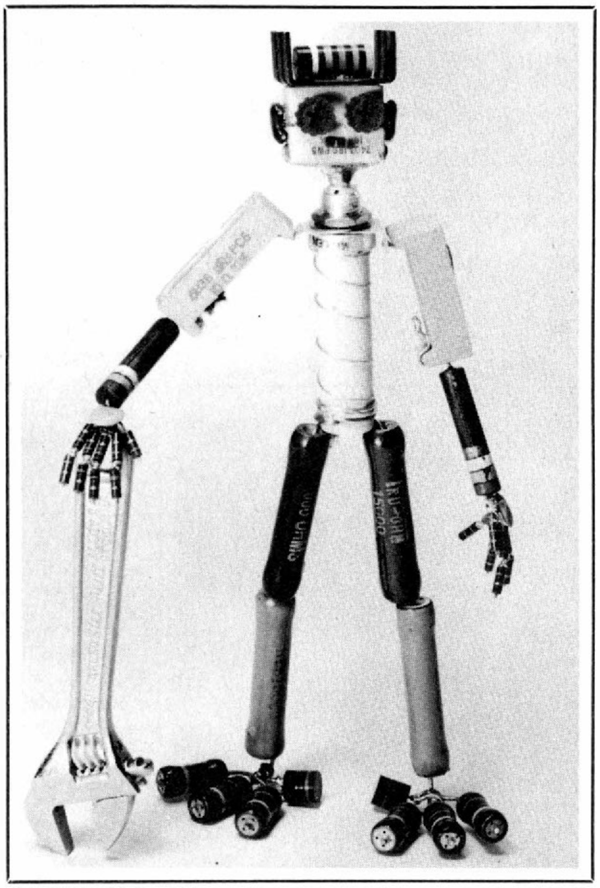
• *First Steps In Radio*

Understanding Resistors

Part 3: Without resistors we would be unable to build electrical circuits. What part do they play in a circuit? How are they rated? What do the color bands mean?

By Doug DeMaw,* W1FB



What is a resistor? Well, it is an electronic component that functions precisely as the name implies — it *resists* alternating or direct current. Resistors come in many sizes, shapes, power ratings and tolerances. Some have the value (resistance is specified in ohms) stamped on the case, while others have a group of color bands that help us to learn the resistance value. Let's learn more about resistors.

The Nature of Resistors

We can think of the resistor as an imperfect conductor. On the other hand, a perfect conductor would have *no resistance* at all. Therefore, if we had a test instrument that could accurately read ac or dc resistance to a finite value (zero ohms, in this case), the instrument would indicate zero ohms when the test set was arranged to read the resistance from one end of the conductor to the other (see Fig. 1). Perfect or nearly perfect conductors are necessary in many electronic circuits, but we also need to have poor conductors — namely resistors — in many parts of our radio circuits. This is where the resistor does its job.

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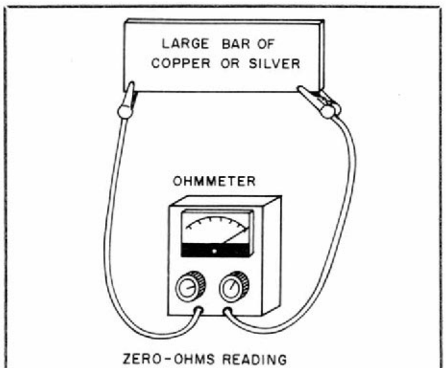


Fig. 1 — A perfect conductor would show a zero resistance. A large bar of highly conductive metal might represent a perfect conductor.

In electronics work we usually measure the resistance of a material with an instrument known as an *ohmmeter*. Many hams and experimenters own a VOM (volt-ohmmeter) that is used for this purpose. A VOM also measures ac and dc voltage, and may include a function for measuring dc. Inexpensive VOMs can be obtained from Radio Shack, Heathkit and similar outlets that sell components for experimenters. You should acquire a VOM for use in learning radio theory (lab experiments) and for design and repair work after you become experienced in Amateur Radio.

Power Classification

The greater the current that flows through a resistor the higher the power (wattage) rating must be. Resistors are available with ratings from as low as 1/8 watt to hundreds of watts. If the power rating of a resistor is too low for a particular circuit, it will get hot and burn out, sometimes quickly and other times gradually, depending on how much lower the rating is than the circuit application requires. When power is dissipated (as within a resistor) there will be heat. This is demonstrated clearly by an electric heater or toaster. The heating element in such appliances is a gigantic power resistor made from nichrome wire. This wire has a resistance that causes power to be dissipated as current passes through the wire. The wire glows from a red color to an almost yellowish color in some instances.

We could not tolerate having our radio-circuit resistors get that hot, so they are designed to operate cool or slightly warm to the touch. Choosing the correct power rating is, therefore, essential (more on this

Table 1
Resistor Color Codes†

Band Color	*Number (First Two Bands)*	*Zeros (Last Band)*
Black	0	—
Brown	1	0
Red	2	00
Orange	3	000
Yellow	4	0,000
Green	5	00,000
Blue	6	000,000
Purple	7	0,000,000
Gray	8	00,000,000
White	9	000,000,000

†Used on small carbon-composition units

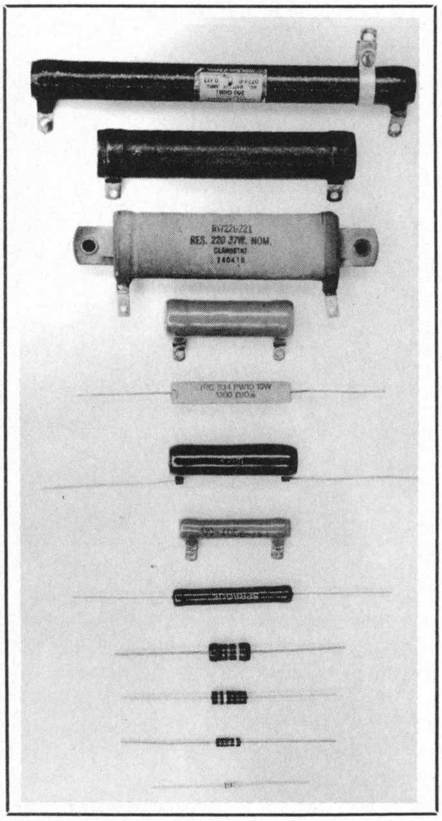


Fig. 2 — Photograph of various types of common resistors. The high-wattage types start at the top and the low-power resistors are at the bottom.

later). Fig. 2 shows a number of resistors of various wattage ratings. Low-power radio circuits (such as pocket-size transistor radios) use very tiny resistors ¼-watt sizes) because very little current flows in those circuits. On the other hand, we may find huge power resistors in large items of equipment, such as power supplies, that deliver large currents.

How to Read a Resistor Color Code

If we are to work with resistors we must learn how to determine their values from the color bands that are printed on them. Table 1 lists the colors found on resistors and shows what each color band represents numerically. You will want to memorize these numerical designators to be able to recognize and select them easily later on. There is usually a fourth color band on small carbon-composition resistors. It indicates the tolerance of the resistor in ohms — the percentage the actual resistance can vary, plus or minus.

Fig. 3 shows some examples of resistors with color bands, and provides the ohmic value of each. Remember that the term "k" means *thousand* and "M" stands for *million.* Thus, a 2.2-kΩ (kilohm — the omega symbol stands for ohms) resistor has 2200 ohms of resistance. Similarly, if the resistor is a 2.2-M (megohm) unit, the resistance is 2,200,000 ohms. Resistors are available with ratings from a fraction of an ohm to millions of ohms, but they come in *standard values* only. That is, resistors are not available for every possible ohmic round-number value.

Table 2 lists the standard values of primary interest to amateurs. If we need a special resistance value that falls between the standard value we can purchase, we must use a combination of resistors in parallel or series to obtain the needed value. More on that later. Alternatively, we may use a variable resistor (one for which the value can be changed by mechanical adjustment over a specified ohmic range). A volume control on a radio is an example of a variable resistor (also known as a potentiometer or "pot").

Physical Forms

Various formats are used in the manufacture of resistors. Some have wire leads (pigtails) that come out of the ends of the resistor bodies. Others have a tab at each end to which we may solder our circuit connections. The variety with tabs are called "power resistors" and are quite large. Some integrated circuits (ICs) contain microscopic arrays of resistors. Connection to those resistors is by means of the pins on the IC body.

There are many kinds of variable resistors. Some have sliders that make contact with the wire from which the resistor is made. As the slider is moved from one end of the resistor to the other, the effective resistance is changed. Panel-mounted variable resistors are used as volume and tone controls, as well as for a host of other functions, such as adjustment controls on TV sets. Other circuits contain variable resistors that must be adjusted by means of a screwdriver. These are called "trimmer resistors" or "Trimpots,"® which are generally set for a specific resistance just

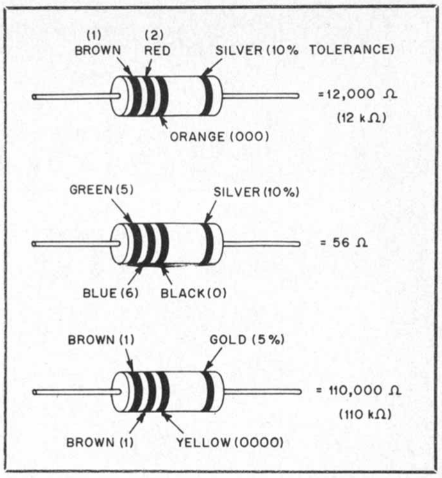


Fig. 3 — Three color-code examples to illustrate how to determine the value of a resistor that is banded.

Table 2
Standard Resistance Values

Resistors with ±10% tolerance are available only in values shown in bold type. Resistors with ±5% tolerance are available in all values shown.

Ohms

1.0	3.6	**12**	43	**150**	510	**1800**	6200	**22000**	75000
1.1	**3.9**	13	**47**	160	**560**	2000	**6800**	24000	**82000**
1.2	4.3	**15**	51	**180**	620	**2200**	7500	**27000**	91000
1.3	**4.7**	16	**56**	200	**680**	2400	**8200**	30000	**100000**
1.5	5.1	**18**	62	**220**	750	**2700**	9100	**33000**	110000
1.6	**5.6**	20	**68**	240	**820**	3000	**10000**	36000	**120000**
1.8	6.2	**22**	75	**270**	910	**3300**	11000	**39000**	130000
2.0	**6.8**	24	**82**	300	**1000**	3600	**12000**	43000	**150000**
2.2	7.5	**27**	91	**330**	1100	**3900**	13000	**47000**	160000
2.4	**8.2**	30	**100**	360	**1200**	4300	**15000**	51000	**180000**
2.7	9.1	**33**	110	**390**	1300	**4700**	16000	**56000**	200000
3.0	**10.0**	36	**120**	430	**1500**	5100	**18000**	62000	**220000**
3.3	11.0	**39**	130	**470**	1600	**5600**	20000	**68000**	

Megohms

0.24	0.62	1.6	4.3	11.0
0.27	**0.68**	**1.8**	**4.7**	**12.0**
0.30	0.75	2.0	5.1	13.0
0.33	**0.82**	**2.2**	**5.6**	**15.0**
0.36	0.91	2.4	6.2	16.0
0.39	**1.0**	**2.7**	**6.8**	**18.0**
0.43	1.1	3.0	7.5	20.0
0.47	**1.2**	**3.3**	**8.2**	**22.0**
0.51	1.3	3.6	9.1	
0.56	**1.5**	**3.9**	**10.0**	

once, then left in that position. Fig. 4 shows a number of variable resistors.

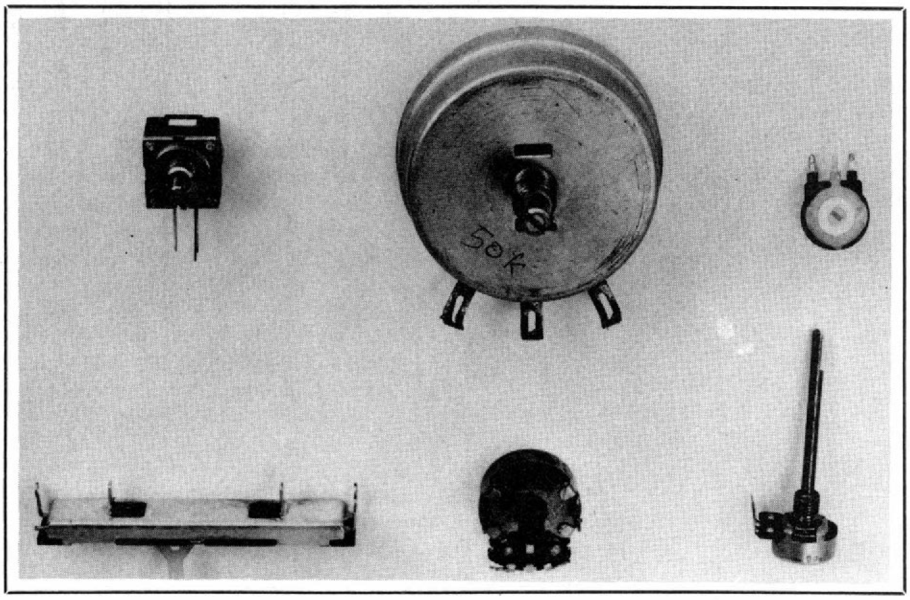


Fig. 4 — Photograph of assorted variable resistors. Some can be adjusted by means of a knob, while others require a screwdriver to change the effective resistance value.

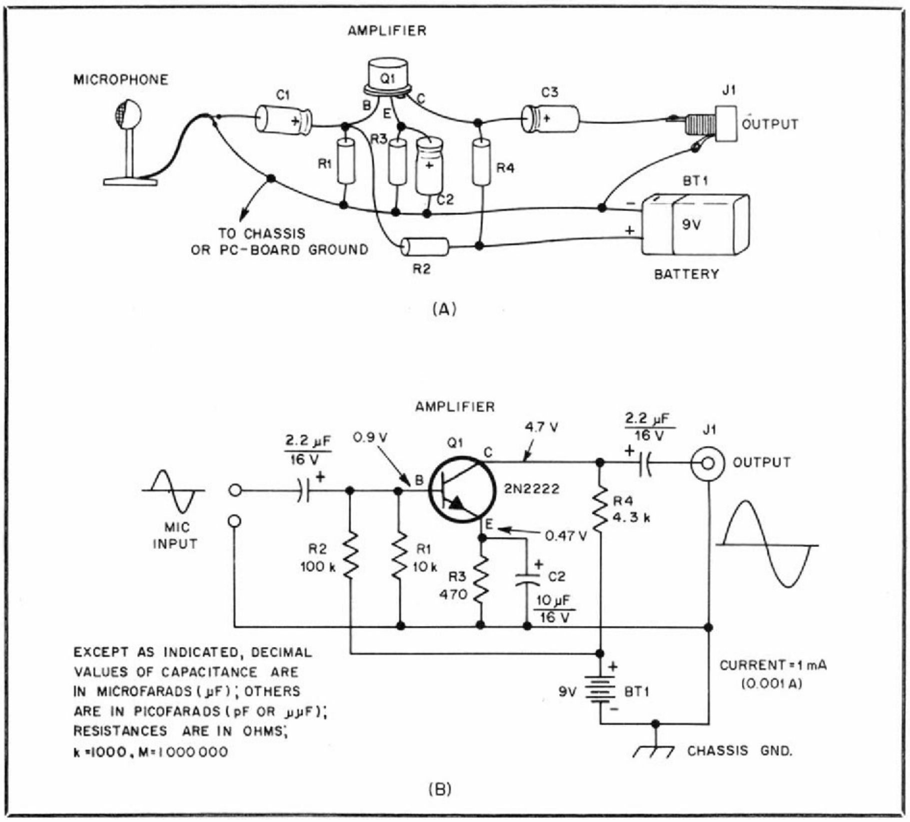


Fig. 5 — Pictorial (A) and schematic (B) examples of a simple one-stage audio amplifier. This set of examples is presented for text-discussion purposes.

Putting the Resistor to Work

Let's imagine that we built a small transistorized audio amplifier designed to increase the output from a microphone. We would need some resistors to perform electrical tasks within the circuit. The diagram in Fig. 5 illustrates our use of resistors. The illustration at drawing A is a refresher of sorts on how to read a diagram (see Part 2). It shows the physical aspects of our little microphone amplifier. Examine the schematic diagram at B of Fig. 5. Note that at the top end of R4 we have a lower voltage than is found at the battery terminals. That is because R4 is a resistor, and when the transistor (Q1) draws current through R4 it will cause what is known as a *voltage drop*. The higher the current flow, or the greater the resistance of R4, the greater the voltage drop across the resistor.

This can be used to advantage in many circuits where the battery or power-supply voltage is too high for a particular transistor, tube or IC. The proper value of resistor is used to ensure that the transistor is protected from excessive voltage or current. Too much voltage (and the increased current) can cause the transistor to overheat and be destroyed, or the excessive voltage might puncture the inner elements of the transistor and destroy it.

In order for us to select a correct value of resistance for R4, we need to know the amount of current in that branch of our circuit. That exercise is beyond the purpose of this discussion, but we mention it now for tutorial purposes. Once we know the current value in such a circuit (we'll assume it is 1 mA in Fig. 5), we can choose a resistor value to provide the desired operating voltage. We will use Ohm's Law, which shows the relationship between resistance, voltage and current in simple algebra:

$$R = \frac{E}{I} \text{ ohms} \qquad \text{(Eq. 1)}$$

where E is the desired voltage drop, and I is the circuit current in amperes (note that 1 mA equals 0.001 A). Hence, if we have a 9-V battery and desire 4.7 volts at the collector of Q1 (Fig. 5B), our resistor must drop 4.3 volts. Its resistance will be determined by

$$R = \frac{4.3 \text{ V}}{0.001 \text{ A}} = 4300 \text{ ohms} \qquad \text{(Eq. 2)}$$

If we subtract 4.3 (the voltage drop across R4) from 9 volts, we have 4.7 volts at the collector.

R4 serves still another purpose in our circuit. Since it resists the passage or flow of dc and ac, it will hold back our amplified voice signal (composed of ac energy) and prevent it from being lost into ground via the battery. Instead, the audio energy is directed to the output jack (J1) through capacitor C3. If R4 were too low in resistance we would lose a large part of the audio signal before it reached J1.

R1 and R2 are used at the input of our Fig. 5 circuit for the purpose of establishing a small operating voltage (approximately 0.9 V) at the base of Q1. Those resistors also isolate the signal from our microphone so it is routed to Q1 rather than to ground via BT1.

Our circuit needs a small voltage at the emitter of Q1, so we are using R3 to develop what is called *self bias* (emitter bias). The 0.001-A current of the transistor also flows to ground through R3. This creates a

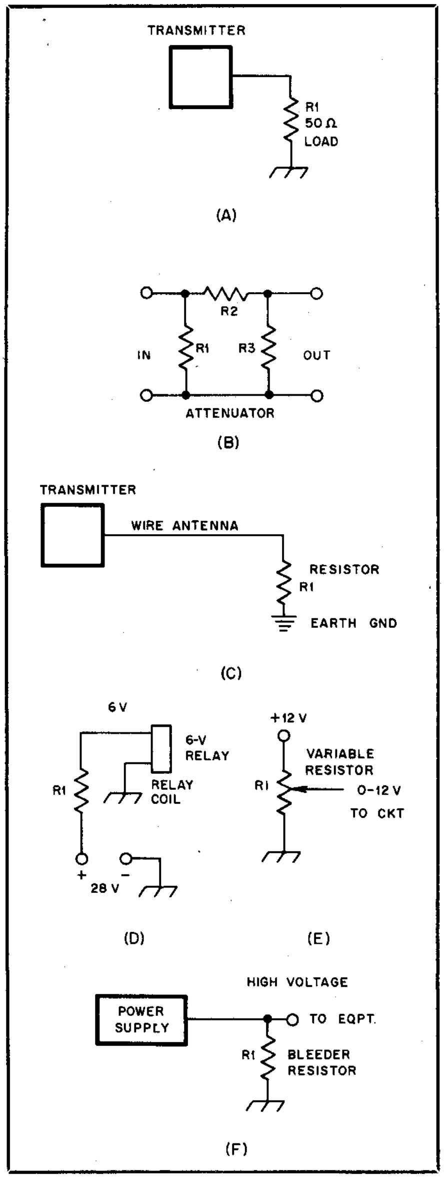


Fig. 6 — Various applications for resistors (see text).

voltage drop across the resistor, which in this case is 0.47 V. This can be calculated from another form of Ohm's Law:

$$E = IR = 0.001\ A \times 470\ \Omega = 0.47\ V \quad \text{(Eq. 3)}$$

where I is in amperes (A) and R is in ohms.

If you have a voltmeter available I suggest you obtain the parts for the circuit in Fig. 5 and tack it together for experimental use. Try various resistance values at R4 to see how the collector voltage at Q1 changes. Of course, as the resistance is made greater, the current drawn by Q1 will fall. But, once you measure the voltage drop across R4 you will be able to calculate the current of Q1. Since Ohm's Law is the basis of electrical work, and may appear on license exams, you should practice your calculations now. You can learn what the current flow is from still another version of Ohm's Law:

$$I = \frac{E}{R} \text{ amperes} \quad \text{(Eq. 4)}$$

where E is the drop across the resistor in volts and R is the resistor value in ohms. Furthermore, if you build the test circuit neatly on a printed-circuit or "perf" board, you can try it with your microphone by placing it between your mike and the input of an audio hi-fi amplifier.

I believe strongly in "learning by doing." I hope you will get involved with the simple lab experiments suggested in this series. They will bolster your "book larnin."

Some Other Uses for Resistors

The applications for resistors are so numerous, and at times detailed, that we could fill an entire book discussing them all. But for the sake of brevity let's examine a few examples of where we might apply resistors in routine amateur work.

Fig. 6A shows a transmitter to which we have connected a 50-ohm resistor (R1). This is called a *dummy load* or *dummy antenna*. If R1 is the same resistance as the transmitter output (usually 50 ohms), and if it can safely handle the transmitter output power, we may use R1 in place of an antenna during transmitter tests. We thereby prevent our signal from going out over the air and possibly interfering with another amateur.

Fig. 6B shows three resistors used in an *attenuator* circuit. Attenuators can be designed to reduce the power by almost any amount we desire. The example shows a circuit that will reduce the input power to a desired output power level. The amount of power reduction (attenuation) depends on the resistance values selected for resistors R1, R2 and R3. In other words, if we had a low-power transmitter we wanted to use to drive a high-power amplifier, but the small transmitter put out too much power, we could use an attenuator. It would be placed between the transmitter and amplifier. In our example, because the attenuator in Fig. 6B cuts power in half, we would get 30 watts into the amplifier if the transmitter put out 60 watts.

Resistors are sometimes used in antenna systems, as shown in Fig. 6C. R1 can be used to make the antenna present a particular resistance to the transmitter and receiver. An antenna of this type is called a *terminated antenna,* because the resistor is used at the far end (termination).

Sometimes we hams buy surplus relays for our projects. They may have the wrong voltage rating for the power supply we have on hand. Fig. 6D shows how we might lower the relay operating voltage if it requires a lower potential than that of our power supply. To find the value of R1 we can measure the resistance of the relay coil with an ohmmeter, then apply Ohm's Law in accordance with the voltage drop needed.

Earlier in this article we talked about variable resistors. An example of one is given in Fig. 6E. The resistor has a movable contact that can be varied for any voltage from 0 to 12.

Finally, in Fig. 6F we see a resistor being used as a *bleeder.* Power supplies that provide dangerous voltage potentials (hundreds or thousands of volts) are equipped with bleeder resistors. Your ham license exam may have a question about this. The resistor permits the power-supply voltage to trickle or bleed off slowly (seconds) when the supply is turned off. This protects the operator against an accidental shock (which could be lethal) from the charge stored in the filter capacitors. R1 has a sufficiently high resistance to prevent it from taxing the power supply (drawing excessive current) during normal operation.

The Wattage Rating of Resistors

Each resistor we use must be chosen in accordance with the power that will be dissipated within it. If it isn't, we can burn up a resistor rather quickly! Resistors come with various wattage ratings, and for most low-current, low-voltage operations (such as in transistor radios) we will use ¼- or ½-watt units. The wattage rating of a resistor signifies the *maximum* safe power it will dissipate without changing value or burning out. As a safety margin it is wise to use the next higher rating than the circuit demands. In other words, if ½ watt of power was dissipated in a resistor, a ½-watt unit and would be warm to the touch and you'd want to use a 1-watt unit.

We can learn the power consumption in a circuit branch if we know any two of the voltage, current or resistance values.

$$P = E \times I = I^2R = \frac{E^2}{R} \quad \text{(Eq. 5)}$$

where P = power in watts, E is in volts, I is current in amperes and R is in ohms. Thus, if the branch of our circuit that contains a resistor has a current flow of 50 mA (0.05 A) and the resistor is 470 ohms, the power dissipated in the resistor will be 1.175 watts, from

$$P = I^2R = 0.05^2 \times 470\ \Omega = 1.175\ W \quad \text{(Eq. 6)}$$

This tells us that a 2-watt resistor should be installed in that part of the circuit.

Resistor Combinations

At the start of our discussion I mentioned combining resistors in series or parallel to obtain special values of resistance. How might we do this and know the resultant value of resistance? Simply by doing a bit of basic math with a calculator or slide rule, or by longhand.

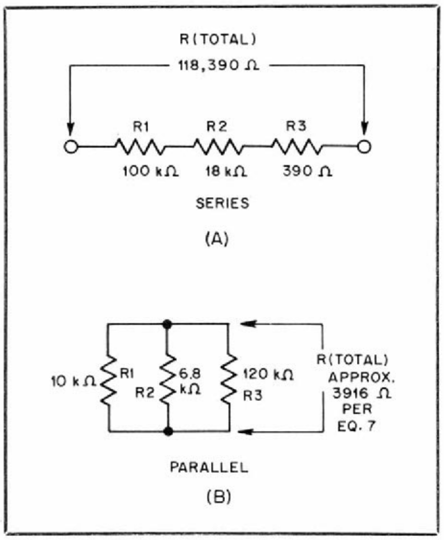
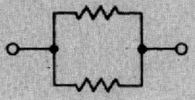


Fig. 7 — Resistors in series result in the combined ohmic value of the string (A). When resistors are wired in parallel (B) we must use Eq. 7 to learn the resultant total resistance.

Glossary

bias — a voltage, normally on the input lead of an active device (tube or transistor), to make the active device operate in a desired region. Bias sets the resting voltage when no signal is present.

parallel — a way of connecting two or more components together in a side-by-side manner. The current is divided between the two or more branches formed. For example, the following two resistors are connected in parallel:



relay — a switch that can be remotely controlled by an electrical signal. The control signal goes to a coil that magnetically pulls an armature, which in turn causes the switch to move from its normal position.

series — a way of connecting two or more components together in a string so the same current goes through each. For example, these two resistors are connected in series:

When we connect resistors in series (Fig. 7A) we merely add the values of the individual resistors. But, when we place the resistors in parallel we must use Eq. 7.

$$R(\text{total}) = \frac{1}{\frac{1}{R1} + \frac{1}{R2} + \frac{1}{R3} \cdots} \text{ ohms (Eq. 7)}$$

Fig. 7B shows a combination of series resistors and the net value of resistance, as determined from Eq. 7. When resistors are used in this manner they occupy considerably more room in the circuit than if a single unit were employed. But, using series or parallel combinations is often necessary to obtain a critical value of fixed resistance.

Final Comments

I hope you now have a basic understanding of what resistors are and why they are necessary. Next month we will discuss capacitors in the same fashion. Meanwhile, let me encourage you to obtain some small hand tools, a soldering iron, a VOM and some rosin-core solder. This will enable you to do experiments as we progress through this learning series.

I should say in closing that special resistance values can often be obtained from *precision resistors* that can be purchased on special order. They are costly and are thus not apt to be a product you will ever want to buy! Also, close-tolerance resistors (1%) are available at increased cost from most large parts distributors. For most practical applications, precise values are unnecessary — both to the circuit and to your pocketbook. QST

New Products

MOTOROLA MC14442 CMOS ANALOG-TO-DIGITAL CONVERTER

☐ A new CMOS 8-bit analog-to-digital converter (A/D) is now available from Motorola. The MC14442 is a 28-pin, CMOS, parallel-bus-compatible successive-approximation A/D converter with additional digital input capability. This low-power, microprocessor-compatible converter operates from a single 5-V supply and provides interface to the CPU data bus used by all M68XX-family parts.

The 8-bit conversion is done in 32 machine cycles and allows up to 11 analog inputs and up to 6 digital inputs. Resolution is 8 bits with a relative accuracy of ± ½ LSB across voltage and from −40 to 85 °C. No external trimming required. All the necessary logic for software configuration, channel selection, conversion control and bus interfacing is included.

The MC14442 has a 32-microsecond conversion time at f_E = 1.0 MHz. The MC14442 A/D has TTL-compatible inputs with a 5-V (±10%) supply and is fully programmable.

These units are available now with pricing in quantities of 100 and up being $14.23 (plastic package) and $18.41 (ceramic package). Contact your local Motorola sales office or distributor for further information. — *Paul K. Pagel, N1FB*

Strays

MORE ON THE NAVY KNOB

☐ In January 1984 *QST* there is a Stray on the Navy knob ("The Navy Knob — From Whence It Came," p. 25). The article did not state why the black button was placed underneath the knob, however.

When these keys were used for radio, they were dangerous because they were hot with both RF and the power source that was being used. If an operator wasn't careful while handling the key, he could get burned. By adding the black button, the operator could avoid the burns. — *Everett Power, K6JY, Oakland, California*

WHAT A COMBINATION!

☐ Let me offer an amateur's solution for a universal problem: remembering lock combinations. On the back of the lock, paint or engrave prefixes for countries in the CQ zone corresponding to the lock combination. For example, a lock with a combination of 14-25-38 would get G-JA-ZS. I defy any non-DXing cryptographer to figure that one out! — *Jim Stahl, K8MR, Cleveland Heights, Ohio*

GOING TO BE STATIONED IN OKINAWA?

☐ U.S. military personnel who are going to be stationed in Okinawa can write to the Radio Society of Okinawa for licensing information and help in setting up. The club's address is P.O. Box 217, Torii Station, APO SF 96331.

QST congratulates . . .

☐ Kenneth M. Miller, K6IR, of Rockville, Maryland, on being elected to the Radio Club of America Board of Directors.