Work-Ready Electronics

Synchronizing Curriculum to the Rapidly Changing Workplace

Module: Wiring and Cabling

WORKREADY ELECTRONICS

Wiring and Cabling Technology

Wiring and cabling are a major part of all electrical and electronic technology work yet we often fail to consider just how important they are. Despite their importance, little is done to teach this critical subject. In fact, most wiring and cabling knowledge tends to come from experience rather than education.

However, because electronics has become so large and complex, some formal knowledge of wiring and cabling is necessary. Since textbooks basically omit this subject and most courses neglect it, this module can serve as an introduction.

Wiring and Cabling Are Everywhere!

Before beginning this module, consider the scope of wiring and cabling. It includes AC power wiring, DC power wiring, audio system wiring, video wiring, security system wiring, telephone system wiring, computer network wiring, and wiring for cable TV. Wiring is everywhere. And in fact, we have rewired the world several times already. It began with telegraph and telephone wiring in the late 19th century, then power wiring, and today, computer network and Internet wiring. More recently, fiber optic cable wiring has become the wiring of choice of many modern electronic communications systems.

This module summarizes all of the most widely used types of wires and cables, their function, and characteristics. This module also covers wire and cable installation, testing, and troubleshooting.

Module Prerequisites

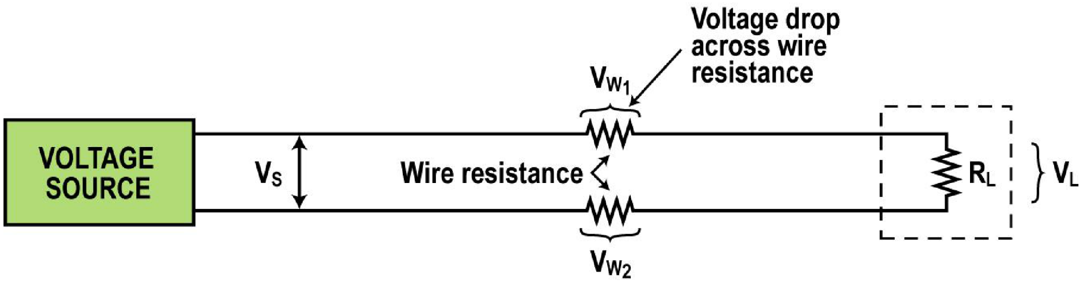
To complete this module successfully, you should have knowledge and background in both DC and AC circuit fundamentals.

What Technicians Need to Know

- How to identify and distinguish between the various types of wiring and cabling applications
- How to identify the different types of wire, sizes, insulation, and specifications
- How to select a wire type and size for a given application
- How to distinguish between a cable and a transmission line
- Types of wire and cables used in DC and AC power connections, audio electronics, video electronics, radio/wireless/RF applications, and computer networks
- How to test and troubleshoot wire and cables

Wire and Power Wiring

Purpose of Wiring



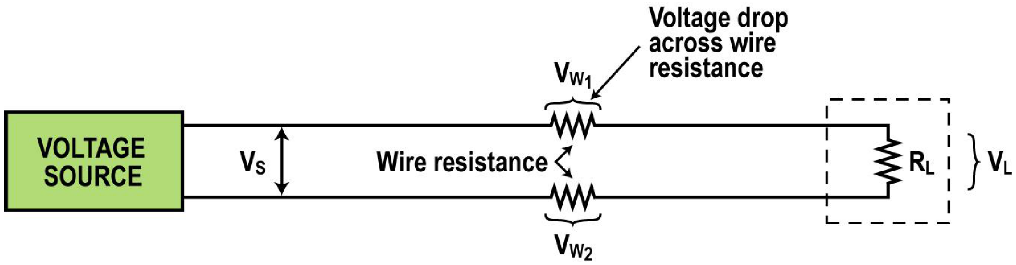
$$V_L = V_S - V_{W_1} - V_{W_2}$$

It is probably overstating the obvious, but just so that it is clear, wiring is used to carry a voltage to a load and to conduct the current produced by that voltage in the load.

The wire, of course, must be a good conductor. That is, it must have a low resistance and not add opposition to the current flow.

The wire size should be such that its resistance is low enough that the wire does not dissipate too much power. The goal is to transfer the power from the voltage source to the load with minimal loss in the connecting wires.

Wire Size

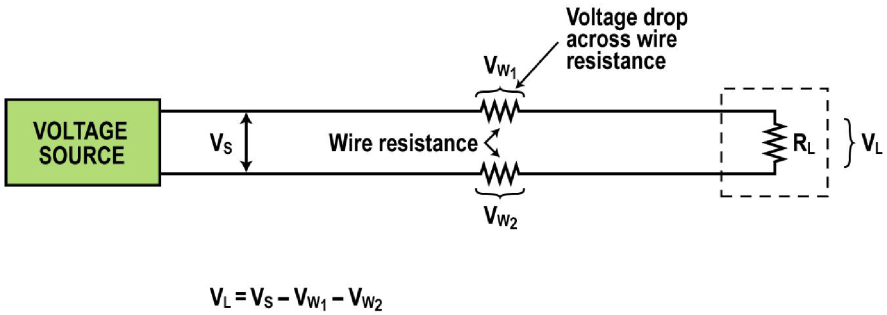


$$V_L = V_S - V_{W_1} - V_{W_2}$$

Wires that are too small have high resistance and will rob voltage from the load due to voltage drops while also dissipating power as heat. If the current and/or the resistance is too high, the wires can overheat and cause a fire.

Normally, we do not think in terms of wire having resistance but it does. Choosing a wire size that gives minimum resistance for the application is a critical choice in designing wiring.

Wiring as a Component



As you can see in the figure, the interconnecting wires have resistance. Together with the load R_L they form a series circuit connected to a voltage source V_S. Ideally we want V_L to be the same as V_S. However, the current flowing in the circuit produces voltage drops across the wires V_{W1} and V_{W2}.

Based on Kirchhoff's voltage law, the load voltage is going to be the source voltage less the wire voltage drops:

$$V_L = V_S - V_{W1} - V_{W2}$$

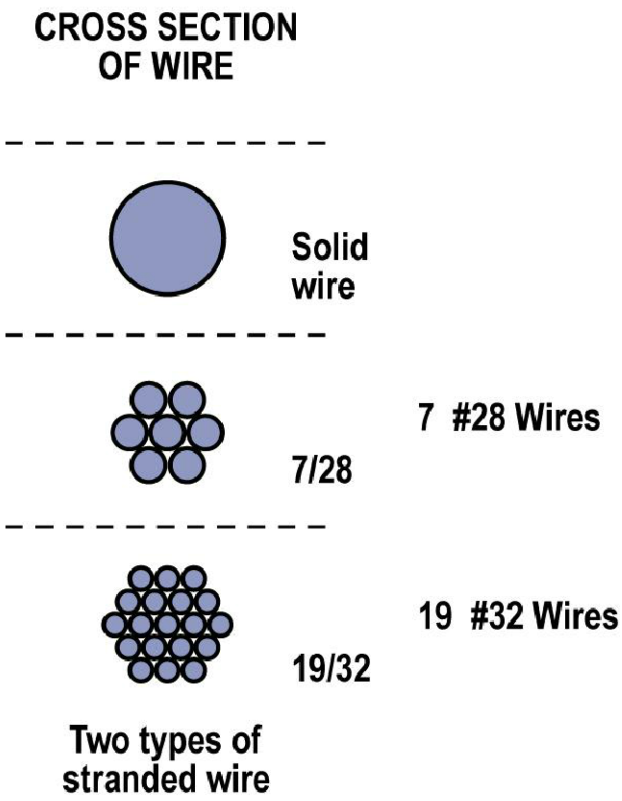
For this reason, it is critical to make the wire resistance as low as practical to ensure that most of the source voltage gets to the load.

Types of Wire

Virtually all wire used in electrical and electronics is copper. The two basic types are solid and stranded.

Solid wire, as its name implies, is a solid piece of copper with a circular cross section. It is supplied in a wide range of diameters.

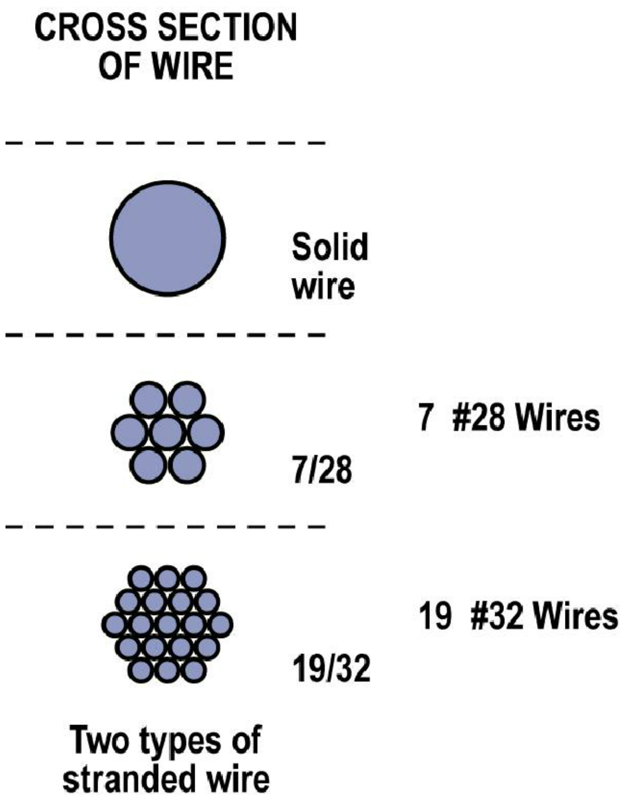
Stranded wire is made up of many small diameter solid copper wires twisted together. The cross section is circular. Most stranded wires are tinned meaning that they are coated with solder, a tin-lead alloy.



Solid Wire

The main difference between the solid and stranded types is its degree of flexibility. A solid wire is quite rigid. The larger the diameter, the less flexible it is. This makes solid wire hard to work with especially when it is being installed.

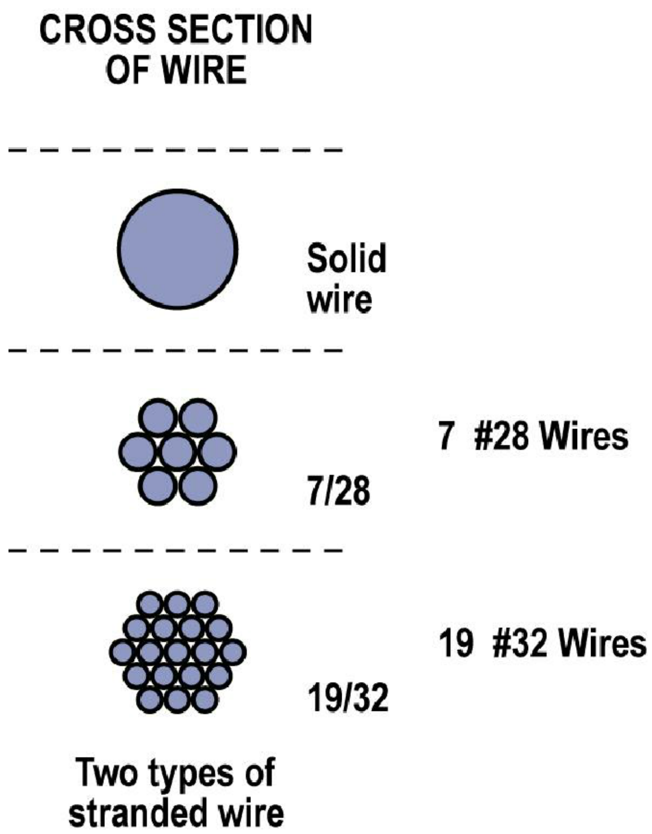
Solid wire is designed for applications where the wiring is to be fixed in place and not moved. Electrical wiring in a home or building is a good example. Excessive movement or flexing of a solid wire puts stress on it. If a solid wire is constantly bent or flexed, it will soon break.



Stranded Wire

Stranded wire is far more flexible. The very thin wires making up the conductor can be bent and flexed with much less stress. It is less likely to break after repeated bending or flexing.

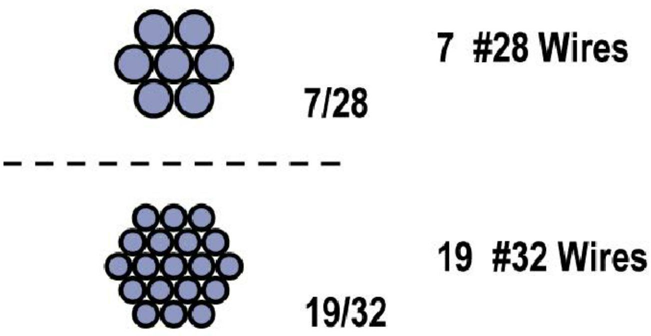
Because it is flexible, stranded wire is also easier to install.



Use of Stranded Wire

Stranded wires are used where cables are constantly or even occasionally being moved or rerouted. AC power cords, keyboard and mouse cables, speaker cables, and microphone cables are good examples.

In the figure, the designation 7/28 simply means that the wire is made up of seven size #28 wires while the designation 19/32 indicates nineteen size #32 wires.



Two types of stranded wire

Insulation

Most wire is covered with some kind of insulation. This insulation keeps the wire conductor from touching other wires or other metallic objects that could cause a short or an electric shock. Early wires used paper insulation or a fine thread. Today, most insulation is some kind of thermo-plastic. Polyvinylchloride (PVC) is probably the most common type but other plastics like Teflon are also used. Rubber was once a common insulation but is rarely used today.

The type of insulation needed is dependent upon the wire environment. There are three basic categories: dry, damp, and wet. Dry means that the wires are never exposed to wetness or dampness. Damp refers to wires that may encounter some moisture like dew or humidity. Wet means that wires are sometimes or always in contact with water or wetness as they would be when underground or exposed to the weather.

Another factor affecting the type of insulation is temperature. Temperature variation is caused by the environment as well as the self-heating effect produced by wires that carry high current.

Bare Wires

There are some cases where the wire does not have an outer insulation. These are called bare wires.

However, some bare wires are typically insulated with a thin enamel or varnish coating that does provide a minimum of insulation to protect wires from touching other objects.

Bare wires are typically used for grounding where a piece of equipment or an electrical system is connected to earth ground.

Enamelled or varnished wires are typically used in winding transformers, inductors, motors, and generators.

Wire antennas are also made of either bare or enamelled wire.

Wire Size

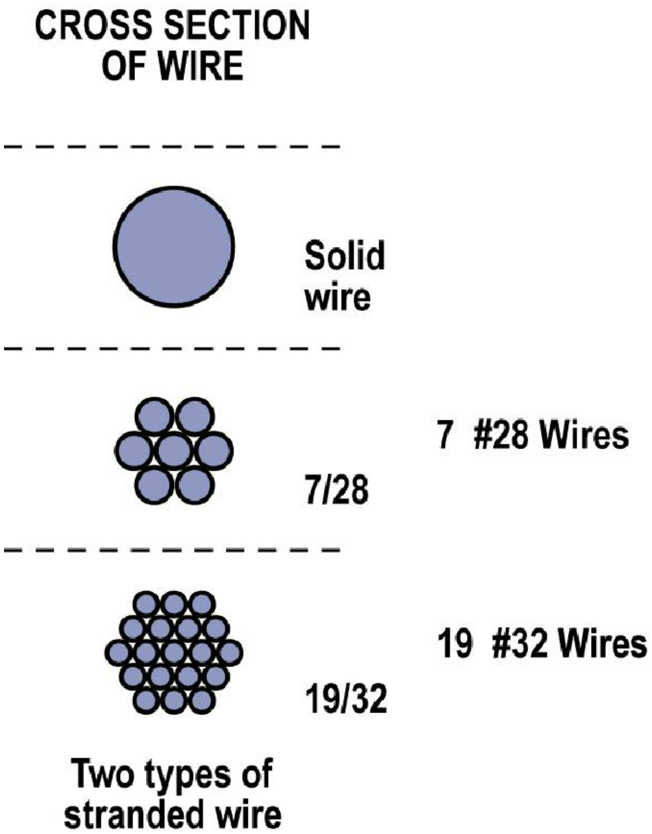
Wire size is designated by its diameter whether it is solid or stranded. All wire has a round (circular) cross section. The larger the wire, the greater the diameter.

In practice, we do not use the actual diameter to designate a particular wire. Instead, we use a standard wire size indicator system known as the American Wire Gauge (AWG).

Standard diameter wires are assigned a wire size number from 0000 to 30 where the smaller the number, the larger the wire. For example, size 8 wire has a large diameter while size 30 is very thin. The wire size applies to both solid and stranded wire.

Wire Size Designation

Stranded wires are usually designated by the number and size of the wire strands. For example a #18 AWG stranded wire may be made up of sixteen (16) smaller #30 wires. You will see this designated as (16 x 30). The figure shows two other examples.



Common Wire Sizes

The table in the next slide shows common wire sizes used in electronics and their diameter. Wire diameter is usually specified in mils where a mil is one thousandth of an inch (.001 inch).

Another measure of wire size is the area of the cross section of the wire. While area is usually given in square inches or square centimeters (CM), that measure is not used for wire. Instead, area is given in circular mils where a mil is one thousandth of an inch and circular mils is the mils value squared.

The CM area is simply the square of the diameter in mils. A 4 mil diameter wire has an area of 4^2 or 16 CM.

Another thing to notice is that only even wire sizes are given. There are both odd and even AWG sizes but only the even numbered sizes are commonly used.

Standard Wire Size Table

AWG #	Diameter (mils)	Circular Mils	Ohms/1000 ft
8	128.5	16,510	0.64
10	101.9	10,380	1.02
12	80.81	6530	1.62
14	64.08	4107	2.58
18	40.30	1624	6.51
22	25.35	642	16.46
24	20.10	404	26.17
28	12.64	160	66.17
30	10.03	101	105.2

The resistance is given at 25° C.

Wire Resistance

The second most important specification of a wire behind size is its resistance value. Copper is often used because the resistance of copper is very low. This is a desirable trait of any interconnecting conductor.

However, the resistance is not zero as would be the ideal case. Instead, all copper wire has a finite resistance based upon its size. The resistance is usually given in ohms per 1000 feet of wire. The table in the previous slide also shows the resistance values of common copper wire sizes.

To find the amount of resistance per foot of wire, simply divide the value given by 1000. For example, a #28 wire has a resistance of 66.17 ohms per 1000 feet. The resistance per foot is 66.17/1000 = 0.06617 ohms per foot.

Wire Resistance and Length

The resistance of any wire depends upon its length as well. The overall formula for finding the resistance of a wire is:

$$R = \rho A/l$$

where ρ is rho, a constant that indicates the conductivity of the wire. For copper, ρ is 10.4.

A is the area in circular mils and l is the length in feet or inches.

The best way to determine the overall resistance is to first use the wire tables to find the resistance per foot for the given wire size then simply multiply that value by the actual length of the wire in feet.

As an example, the resistance of 30 feet of #14 wire would be

Resistance per foot is = 2.58/1000 = .00258 ohms

Resistance for 30 feet = 30 x .00258 = 0.0774 ohms

The Importance of Wire Resistance

Wire adds resistance to any circuit or connection. Usually the resistance is very low and is usually ignored for very short wires. We just assume the resistance is negligible and of no consequence. However, when the wire is very long, the resistance can reduce the level of the voltage or signal it is transporting by introducing a voltage divider effect. This effect may be minimized by using larger wire or making the wire shorter.

Wire resistance is especially important in power wiring, wiring that carries AC or DC voltages to equipment. Current flowing in a wire causes power to be dissipated in the wire because power is dissipated in any resistance. This power causes heat to be produced. If the heat is too great, it can melt insulation or even cause fires. For that reason, it is important to use a wire size that minimizes resistance. The National Electrical Code (NEC) was developed to indicate the best wire size for a given length and amount of current to be carried.

Determining Wire Size

Wire size determines how much current the wire or cable can handle safely. As stated earlier, when current flows through the wire, power is dissipated in the wire resistance and produces heat. The amount of heat produced is dependent upon the square of the current.

Remember the familiar power formula $P = I^2R$. Doubling the current causes the power and the heat produced to quadruple.

Wire size also affects the amount of voltage dropped across it. The longer the wire or the greater the current, the more the voltage drop. This is voltage that does not reach the load.

If you know the wire resistance per foot and the length, you can determine the voltage drop. Usually the guideline is to use a wire size that limits the voltage drop over the length of the wire to less than 2 or 3% of the total applied input voltage.

Estimating Wire Size

One common way of determining wire size is to use standardized tables developed for use in the National Electrical Code (NEC). These tables give the "ampacity" of a wire, that is the maximum amount of current a given wire size can handle. These tables are set up for different voltage levels and temperatures, types of insulation, and other conditions.

For instance, a #14 copper wire with standard plastic insulation can carry up to 20 amperes at a temperature up to 140° Fahrenheit (60° Celsius). It is important to use these tables to determine the minimum wire size suitable for the application.

DC Power Wiring

When wiring power supplies and electronic circuits, stranded wire is used. Again the wire size is critical to ensure minimum voltage drop and minimum temperature and power dissipation.

Listed below are some of the most common wire sizes, their resistance per 1000 feet, and the maximum current capability given at 20° C.

AWG #	Ohms/1000 ft	Max. Current (Amps)
14	2.58	5.87
18	6.51	2.31
22	16.2	0.914
24	26.17	0.577
28	66.17	0.227

As an example, to carry 1.5 amperes, you would select #18.

AC Power Wiring

Another technique estimates wire size based on voltage drop. The formula is:

Circular mils = (length of wire x amperes x 22)/voltage drop

Assume an applied voltage of 120 volts and a load that takes 3 amperes. The wire length is 150 feet. Assume a voltage drop of no more than 2% or 0.02 x 120 = 2.4 volts. Keep in mind that this voltage drop will occur across two wires. The constant in the formula above (22) factors in that condition.

Circular mils = (150)(3)22/2.4 = 4125

We need a wire with a circular mil area greater than 4125. Looking back at the wire table (frame 19), you can see that a #12 is needed. The #14 wire is close with 4107 CM but it is better to use the next largest wire for safety and a lower drop.

Hook-Up Wire

The wire used for general purpose power wiring and other interconnections is called hook-up wire. It is generally stranded wire although solid wire is sometimes used.

Hook-up wire comes in sizes as large as #14 AWG to #30 AWG. Most of the wire is tinned copper. Size #22 is the most common.

The insulation is usually PVC and comes in a variety of solid colors as well as white with different color stripes.

A special type of hook-up wire used for wire wrap applications is also available. This is a #30 solid silver plated copper wire with a polyvindene fluoride insulation called Kynar. The wire is tightly wrapped around a square cross section connector. The corners of the square conductor cut into the wire making a good electrical connection without solder. It is sometimes used in prototyping digital circuits.

Test your knowledge

Wiring and Cabling Knowledge Probe 1

Wire and Power Wiring

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