All About Wire

This article discusses some of the different types of wire commonly used in audio equipment, and provides some practical advice about when to use each type. **By Pete Millett**

On the surface, the function of wire seems pretty simple: get electrons from point A to point B. But there are many choices to be made when wiring audio equipment. A multitude of different wire types, sizes, and materials is available to the builder.

THE SINGLE CONDUCTOR

Single-conductor wire is what most people think of as "normal" wire. The single metal conductor can be made of one piece of metal called "solid" wire, or from many smaller wires wrapped together, which is called "stranded" wire. Single-conductor wire may be bare metal (un-insulated) or covered in a nonconductive material. (I discuss the materials used for the conductor and insulation in more detail later.)

Electrically, there is not much difference between solid and stranded wire. The main difference is mechanical. Solid wire is, well, solid, while stranded wire is more flexible. *Photo 1* shows solid and stranded wires with the insulation removed.

In old-fashioned point-to-point wiring, like that used in tube equipment, solid wire is generally used. It is easier to terminate to solder lugs (like those on tube sockets) since it doesn't fray out into a million little wires, at least one of which will never go into the hole you choose. Solid wire also holds its shape, so you can dress it into position and it will stay there.

On the other hand, stranded wire is more flexible, especially in larger sizes. It also survives being bent back and forth without breaking, so any wiring that involves motion should be done with stranded wire, which is also used when the wire is to be terminated into crimp or insulation displacement (IDC) connections. Solid wire doesn't generally make a reliable connection this way except in very small wire sizes and with connectors specially designed for it (such as telephone connectors).

A typical piece of audio equipment may use both solid and stranded wire. For example, AC power wiring is usually done with stranded wire, since it is more flexible in the larger size required for AC wiring, and can be terminated with crimp terminals. Point-to-point wiring, such as between tube

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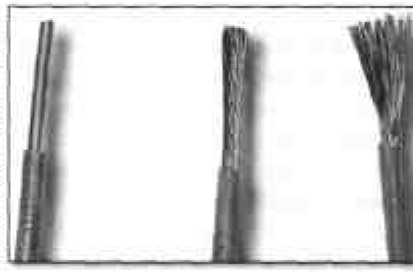

PHOTO 1: Solid (left) and stranded wire with the insulation removed.

PHOTO 2: Different wire sizes. From left: 12AWG, 16AWG, 24AWG, 30AWG.

TABLE 1
COMMON WIRE SIZES AND THEIR CHARACTERISTICS

AWG	DIA. (INCHES)	AREA (SQ. INCHES)	RESISTANCE (MILLIOHMS/ FOOT, COPPER 20°C)	RESISTANCE (MILLIOHMS/ FOOT, SILVER 20°C)	MAX CURRENT, AMPS (BARE COPPER WIRE)
4	0.2043	0.03278	0.2485	0.229	199
6	0.162	0.02061	0.3952	0.364	125
8	0.1285	0.01297	0.6281	0.579	79
10	0.1019	0.00816	0.9988	0.921	49.6
12	0.0808	0.00513	1.59	1.46	31.2
14	0.0641	0.00323	2.52	2.33	19.6
16	0.0508	0.00203	4.02	3.7	12.3
18	0.0403	0.00128	6.39	5.89	7.75
20	0.032	0.000804	10.1	9.34	4.89
22	0.0253	0.000503	16.2	14.9	3.04
24	0.0201	0.000317	25.7	23.7	1.93
26	0.0159	0.000199	41	37.8	1.2
28	0.0126	0.000125	65.3	60.2	0.761
30	0.01	0.0000785	103	95.6	0.477
32	0.008	0.0000503	162	149	0.304

TABLE 2
COMMON AUDIO EQUIPMENT APPLICATIONS OF DIFFERENT WIRE SIZES

WIRE SIZE (AWG)	APPLICATION
24-26	Low-level audio signals, power wiring <500mA
20-22	Power wiring <1.5A
16-18	AC line wiring (usually stranded) <5A, speaker wiring <40W, power wiring <5A
12-14	AC line wiring (usually stranded) <10A, speaker wiring >40W, power wiring <10A

sockets or terminal strips, may use solid insulated wire.

For under-chassis wiring inside a typical audio project, the choice between solid and stranded wire is mostly a matter of builder preference. Either one works fine.

WIRE SIZE

Wire is manufactured in sizes as thin as a hair to several inches in diameter. The size affects its electrical characteristics, such as resistance and ability to pass large currents, as well as its mechanical characteristics. Smaller wire has a higher electrical resistance, and very small wire is difficult to work with. At the other extreme, large wires take up space, are difficult to bend and fit into chassis, and are expensive.

Wire size is commonly specified with a number called "gauge." "American Wire Gauge," or "AWG," is the standard normally used for electronic wiring. The larger the number, the smaller the wire. *Table 1* shows the diameter and characteristics of a range of wire sizes that covers most of what is used in wiring normal electronic equipment. Note that commonly available wire sizes are only in even numbers; the odd-numbered sizes do exist, but are not commonly found. *Photo 2* shows differently sized wires for comparison.

Two factors influence what size of wire you use inside a piece of electronic equipment. Electrically, a wire needs to be large enough so that its resistance is low enough not to influence the circuit or be heated significantly by the power dissipated in the resistance. Mechanically, you need a wire that is neither so small that it's fragile and hard to terminate, nor so big that it is difficult to bend into shape.

For low-level signals, where the current is measured in milliamps, the wire size is chosen more for ease of use than for electrical characteristics. Usually, a size between 22AWG and 28AWG is chosen somewhat arbitrarily.

For power wiring (both power-supply and high-level signals like speaker wiring), you must choose the wire size based on the amount of current that must be passed. There are many rules-of-thumb for determining the current capacity of a given wire size—some based on temperature rise, others on voltage drop. Generally, it is best to be conservative and use a wire size that is a couple of sizes bigger than what is absolutely necessary.

The maximum currents listed in *Table 1* are based on temperature rise of bare wire. Consider these absolute maximums for wiring in audio equipment, and it would be best to use wire two sizes larger than this minimum.

BLACK MAGIC

Some audiophiles seem to have a nearly neurotic obsession about wire. The science and engineering says, within reason, wire is wire. Yet, there is a proliferation of exotic materials and technologies: from silver hook-up wire and silver-wound transformers to long-grain ultra-pure oxygen-free copper wire with some exotic polymer insulation. So, what's up with this?

Though I am an engineer by profession, I've learned not to dismiss all of this "black magic" as hallucination and marketing hype. As much as engineers and scientists hate to admit it, there are things that can be heard but not measured.

Can I hear the difference between identical tube amps—one wired with silver hook-up wire at $20 per foot, and one with Radio Shack copper wire? Nope. But I'm not quite willing to say that nobody can. If there's one thing I've learned in this business, it's to keep an open mind.

Things become even more complicated when you start looking at speaker wire and interconnect cables, which can cost you anywhere from a couple of bucks up to thousands of dollars. There are certainly measurable and audible differences between cables, but, to my ear, they don't necessarily relate to the price tag.

I've heard so much discussion about how solid wire sounds so much better than stranded wire (something about "strand interaction?"), and how PVC insulated wire sounds better than Teflon® (and vice-versa), and how you just have to use silver solder, that it makes my head spin.

So how do you resolve all this? Well, you don't. Build and buy what sounds good and makes sense to you. Experiment and make your own decisions—don't be swayed by the magazines and the marketeers.—**PM**

Table 2 lists some common wire sizes used for hook-up wire in audio equipment.

CONDUCTOR MATERIALS

Almost any metal can be used to construct wire, as can combinations of more than one metal. For example, wire designed to be strung between telephone poles sometimes uses a steel core for strength, with copper layered around it for good electrical conductivity. In the wiring of electronic equipment, though, the electrical characteristics of the material are more important than mechanical characteristics, so they determine what metal is used.

Of the commonly available metals, the best electrical conductor is silver, followed by copper and gold. Gold is far too expensive to consider for electronic wiring—you'd need to be a very wealthy person (not to mention one in need of psychiatric help) to wire a project using gold wire!

Silver wire is sometimes used in high-end audio projects. Although it is a better conductor than copper, its resistance is only about 8% less than copper, which is much less expensive. Even though from an engineering perspective there is no reason to use silver as a wiring material, many audiophiles swear by it (see sidebar).

So, copper is the material of choice for almost all electronic wiring. However, there are different types of copper as well!

Pure copper is a very soft metal, so it is often alloyed with other metals to alter its mechanical properties. There is also always some level of impurities left in the metal, so even "pure" copper has some amount of other metals—and non-metallic materials—in it. As far as the electrical properties are concerned, purer copper is better.

There has been much discussion about "ultra-pure" and "oxygen-free" copper being needed to wire audio equipment. Certainly, impurities such as copper oxides are detrimental to the electrical properties of the wire, but they are very difficult to quantify.

Copper's problem is that it reacts with air and forms an oxide layer on its surface, which turns the shiny copper color to a dull brown. Copper oxide is not a good conductor, and it can make connections and solder joints work poorly. Because of this, most wire used in electronics has another metal—usually either tin or silver—plated on the outer surface of the wire. This plating dramatically improves the solderability of the wire and reduces the chance of a connection becoming open over time. Unless you have a specific reason to use unplated wire, you should always use wire that has tin or silver plating.

INSULATION

Most wire used in electronic equipment has a coating over the metal to insulate it, or to prevent it from making electrical contact with other wires, a chassis, or you!

There are applications that use uninsulated wire. Short connections, such as between adjacent lugs on a tube socket, are often done with uninsulated wire, which is fine, as long as the connection is short enough that there is no danger of the wire bending and making contact where it's not supposed to. Likewise, grounded connections, such as bussing together the grounded side of a bunch of phono jacks, are often done with uninsulated wire, which is commonly called "bus" wire.

Many different materials are used to insulate electronic wire. The two basic parameters to consider in an insulation material are its breakdown voltage (how high a voltage the insulation can withstand before failing), and its temperature rating (how hot the insulation can become before it melts or otherwise breaks down).

Various plastic and rubber materials have been used for hook-up wire in electronic equipment over the years. Today, for electronic wiring, the most commonly available insulation materials are PVC (polyvinyl chloride) and Teflon®. For special applications requir-

TABLE 3
COMMON UL AND MIL WIRE TYPES

WIRE TYPE	INSULATION	APPLICATION
UL1007	PVC, 300V, 80°C, 0.016"	General use hook-up wire
UL1015	PVC, 600V, 105°C, 0.031"	Higher voltages and temperatures—thicker insulation
UL1429 MIL-W-16878/1	Irradiated PVC, 600V, 105°C, 0.010"	Thinner, tougher insulation, resistant to soldering
UL1213 MIL-W-16874/4	Teflon®, 600V, 200°C, 0.010"	High reliability, high temperatures
MIL-W-16878/5	Teflon®, 1000V, 200°C, 0.014"	High voltage, high temperature
MIL-W-76B	PVC, 1000V, 80°C, 0.015"	High voltage

ing very high voltages, temperatures, or flexibility, there are many other materials available as well, but they are seldom used by the hobbyist.

The most common type of electronic wire, usually called "hook-up" wire, is normally insulated with PVC, which is a good—not great—electrical insulator, and is inexpensive. It's easy to work with because it strips easily. Its biggest downside is that it doesn't withstand high temperatures well. It melts easily when soldering, so you must be careful (and quick) when soldering connections. It comes in different thicknesses, which are rated for different voltages. Common PVC hook-up wire is rated for 300 or 600V, which is adequate for everything except some tube circuits.

The other type of wire used often in audio equipment is Teflon® insulated wire. Teflon® is a better electrical insulator than PVC and can withstand much higher temperatures. It is also very resistant to flame, and for these reasons Teflon® insulation has always been the preferred material in high-reliability and military applications. Teflon® has a distinctive slippery feel to it, and is usually shiny, as opposed to PVC, which is duller.

Teflon® insulated wire has a couple of disadvantages. It tends to be expensive (though in the quantity you would need for a typical audio project, the cost is probably not too great a deterrent), and it is also harder to strip the insulation from the wire. Unless you use a good, sharp wire stripper, Teflon® tends not to cut cleanly and to draw out in long stringy pieces.

So, which one should you use? It really comes down to personal preference. I like the fact that Teflon® doesn't melt easily, so you can solder a connection without worrying about the insulation, and you can run the insulation right up to the solder joint. But it's hard to find Teflon® wire in any type other than the silver-plated, stranded wire commonly used in military applications—if you prefer solid wire, it may be a bit more difficult to find.

Table 3 lists several commonly available types of insulated wire and their military (MIL) and UL designations.

MULTI-CONDUCTOR CABLES AND SHIELDED CABLE

More than one insulated conductor can be enclosed inside a common jacket to form a multiconductor cable. There are many different types of cables, many used in constructing audio equipment.

Shielded Wire and Coaxial Cables

A single conductor can be surrounded by braided wires or metal foil to form a coaxial, shielded cable, which is used in many audio interconnect cables. The signal travels through the center conductor, with the outer shield acting as the return or ground conductor. The grounded outer shield helps prevent noise from being coupled into the audio signal traveling within.

You should always use shielded cable for very low-level audio signals, such as those from a microphone or phono cartridge, to prevent noise or hum from being coupled into the signal from nearby power cords, transformers, or other components. You should also use it inside equipment, such as in an amplifier chassis, if the signal cable must be rout-

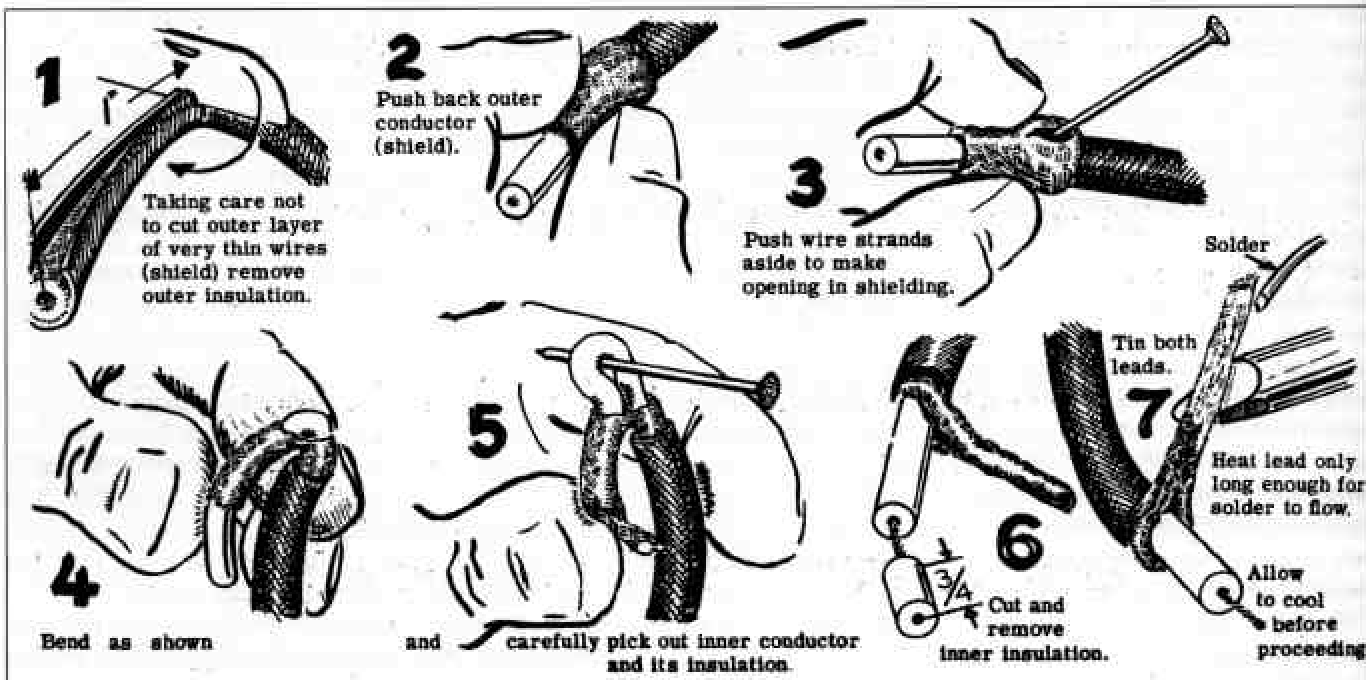

FIGURE 1: Cable termination (from Heathkit booklet #595-294).

ed near a power transformer or other potential source of noise.

When you use shielded cable, you need to consider that there is significant capacitance between the center conductor and the (normally grounded) shield. This can cause problems in sensitive circuits, such as phono cartridge inputs. This capacitance can cause degradation of the high-frequency response of your system. For this reason, it is best to use only cable that is specifically designed for audio use, and to avoid cables designed for digital or radio-frequency used in audio circuits.

Braided shielded cables can be difficult to terminate, since the shields are usually made up of many small wires. The best approach is to try to unbraid all the tiny wires, and then twist them together and tin them with solder before trying to connect them to anything (*Fig. 1*). You can use heat-shrink tubing over the twisted shield wires and over the end of the cable jacket for a neat appearance and to prevent stray shield wires from causing a short circuit (*Fig. 2*).

Foil-shielded cables normally have a wire running along the inside of the foil, called a "drain" wire. When terminating this type of cable, you simply cut off the foil shield and terminate the drain wire as you would any other wire.

Another common technique is to use a shielded cable with two conductors inside. At one end (usually the output of the cable) the shield is connected together with one of the conductors to ground, and at the other end the shield is left unconnected. This prevents the flow of current through the shield, which can sometimes introduce noise into the signal inside.

FIGURE 2: Cable modification (from Heathkit booklet #595-186).

Photo 3 shows some different shielded wires designed for audio use.

Multi-Conductor Cable and Twisted-Pair Cable

A multiconductor cable is made up of several single conductors randomly oriented inside a common jacket. Twisted-pair cable is similar, except the wires are arranged in pairs that are twisted around each other. Multi-conductor cables may also have an overall shield around all the wires, as described above.

Multiconductor cables are not often used in audio equipment, except in pro-sound reinforcement and studio applications, where many signals must be transported. They are sometimes used between components, such as between an amplifier and a separate power supply.

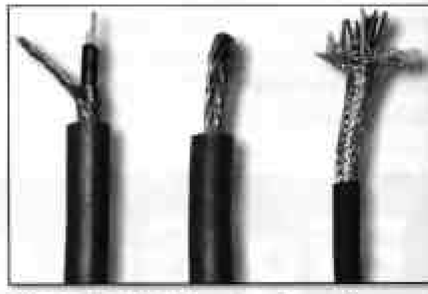

PHOTO 3: Shielded cables for audio.

Twisted pairs are sometimes used—with or without a jacket surrounding the pair of wires—inside equipment. Twisting a signal wire together with a return (or grounded) wire helps reject some noise, though it is not as effective as a shielded wire. Conversely, wires carrying AC power, like filament connections, are often twisted together to provide cancellation of the magnetic field emanating from the wires. This reduces the coupling of AC hum into surrounding signal circuits. [Tight twists can be achieved by clamping one end of a pair in a bench vise, twisting and soldering the other ends of the pair together, and twisting them with a bent nail in the chuck of an electric drill.—Ed.] ❖