

CABLE ANATOMY I: UNDERSTANDING THE INSTRUMENT CABLE

Are instrument cables used for high-impedance or low-impedance lines?

Generally, the *source impedance* is the determining factor in cable selection. Instrument cables are used for a wide range of sources. Many keyboard instruments, mixers, and signal processors have very low (50 to 600 ohm) source impedances. On the other hand, typical electric guitar or bass pickups are very *inductive*, very high impedance (20,000 ohms and above) sources. Typical *load impedances* are greater than 10,000 ohms, which limits the electrical *current* flow to a very small amount on the order of *a few thousandths of an ampere* (milliamps).

How much power does an instrument cable have to carry?

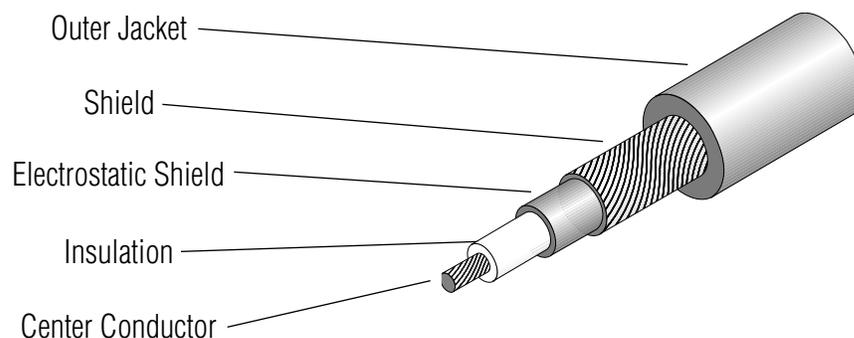
The *voltages* encountered range from a few *millivolts*, in the case of the electric guitar, to levels over *ten volts* delivered by line-level sources such as mixers. By Ohm's Law this represents *power* levels of *less than a thousandth of a watt*.

What kind of frequency response does an instrument cable need? What are the lowest and highest frequencies produced by the source?

The *bandwidth* spans the entire audible range of frequencies, from the 41 Hz (and below) of bass guitar and synthesizer to the 20 kHz harmonics of keyboards and cymbals. Recording applications demand wide bandwidth to preserve the "sizzle" of a hot performance. Even an electric guitar has a bandwidth of about 82 Hz to above 5 kHz.

How big does an instrument cable need to be? Will a bigger cable sound better? Will a bigger cable last longer?

In order to be compatible with standard 1/4-inch phone plugs the diameter of the cable is effectively limited to a maximum *diameter* of about .265". Larger cable diameters demand larger plug barrels, which sometimes won't fit jacks that are located close together or in tight places. In terms of both sound and durability, "it's not how big you make it, but how you make it big."



What are the basic parts of an instrument cable and what does each one do?

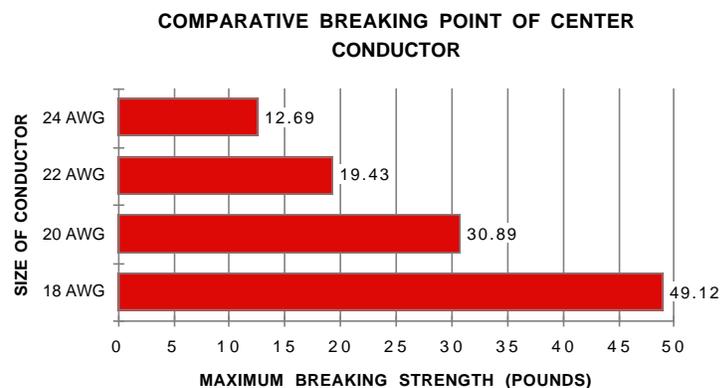
The *coaxial* configuration is generally used for unbalanced instrument cables. At its simplest it consists of a *center conductor*, which carries current from the source, separated by *insulation* from a surrounding *shield*, which is also the current return conductor necessary to complete the circuit. These three components are augmented by an *electrostatic shield* to reduce handling noise and an *outer jacket* for protection and appearance.

What is a stranded center conductor? Why is it important?

A stranded conductor is composed of a number of *strands* of copper wire bunched together to form a larger wire. *Solid* conductors having only one strand are the *cheapest* and *easiest* to work with when *assembling* cables, because they do not require the *twisting* and *tinning* that stranded types need to prepare them for soldering. The *problem* with a solid conductor is that it quickly *fatigues and breaks* when it is bent or flexed. This makes *stranded conductors a must* for cables that are frequently moved around, especially when they are attached to human beings playing music. Finely stranded conductors *increase the cost* of the cable because of the increased production time and the expensive and sophisticated machinery required to assemble very small and fragile strands into a single conductor. The stranding of the center conductor is only one of a number of factors that influence the overall *flexibility* of a given cable, but it is generally true that finer stranding increases the flexibility and the *flex life* of the cable.

What is wire gauge? What gauge wire is used in instrument cables?

The diameter of copper wire is typically given in AWG (American Wire Gauge), with the *larger numbers signifying smaller size*. For instance, a 20 AWG (or “20 gauge”) wire is smaller than an 18 AWG wire. Generally, instrument cable center conductors are in the range of 18 to 24 AWG, with strands of 32 to 36 AWG. Many American wire mills simply cannot work with wire smaller than 36 AWG because their equipment is too antiquated. The Japanese manufacturers *Canare* and *Mogami* have been leaders in the use of very fine (40 AWG) copper stranding.



What gauge should the center conductor of an instrument cable be?

Since the current involved in instrument applications is negligible, the amount of copper in the center conductor has only a very slight effect on the strength of the signal reaching the amplifier. In practice, the center conductor's size is determined primarily by (1) the necessity of obtaining a maximum diameter of .265" or less while (2) providing sufficient *tensile strength* to withstand the rigors of performance without breaking. The 20 AWG center conductor has become quite standard, normally in the form of 26 strands of 34 conductor has become quite standard, normally in the form of 26 strands of 34 AWG (26/34) or 41 strands of 36 AWG (41/36). A 20 AWG conductor has a breaking point of approximately 31 lbs. Reducing conductor size to 22 AWG reduces breaking point to about 19 lbs. (a reduction of 39%); increasing it to 18 AWG increases the strength to over 49 lbs. (an increase of 58%). The most common cause of failure for instrument cables is broken center conductors.

What are the differences between tinned copper and bare copper stranded conductors?

Sometimes the individual strands of the center conductor are run through a bath of molten tin before assembling them into a wire. *Tinned copper* wire is often easier to solder, especially if a lengthy (months to years) shelf life is required, because the tin coat prevents copper oxides from forming. If the cable is to be used immediately upon manufacture pre-tinned strands are not required and add unnecessary expense. Furthermore, an electrical phenomenon known as *skin effect* makes the use of tinned conductors a potential threat to the high-frequency signal-carrying properties of the cable. However, the *aging effects* of the formation of copper oxides on *untinned conductors* may also cause a gradual deterioration of performance.

What is skin effect and how does it affect tinned copper?

Briefly, skin effect is caused by the magnetic field generated by the current flow in the cable causing *electron flow* to be *concentrated* more and more on the *outer surface* of the conductor as frequency increases. If this outer surface is coated with tin, which has higher *resistance* than copper, the cable will have a falling high-frequency response and act as an *attenuator*.

What is oxygen-free and linear-crystal copper? How do they affect sound in cables?

There is a continuing debate concerning the use of *oxygen-free* and *linear-crystal* copper wire. These types of wire contain lower levels of oxide impurities and fewer crystal boundaries than standard copper. Since these impurities form tiny semiconductors within the cable, the theory is that the cable itself introduces signal *distortion*, especially of low-level “detail” information. These claims have been very difficult to document with scientific test equipment, but numerous listening tests suggest there is something to them.

What materials are used for insulation of the center conductor?

The *insulation* that surrounds the center conductor can be made from *thermoset* (rubber, E.P.D.M., neoprene, Hypalon) or *thermoplastic* (polyethylene, polypropylene, PVC, FPE) materials. The thermoset materials are extruded over the conductor and then heat-cured to *vulcanize* them. This process yields a very high melting point which makes soldering very easy, but the vulcanizing stage adds to the cost and introduces unpredictable shrinkage which can make it very difficult to maintain the desired *wall thickness*. Thermoplastic insulations are cheaper to process but will return to a liquid state when overheated, requiring great care during soldering when used to insulate large conductors. In the past decade the insulation of choice for instrument cable has largely shifted from rubber or E.P.D.M. to *high-density polyethylene*, with cost being a major factor.

How does the insulation affect flexibility?

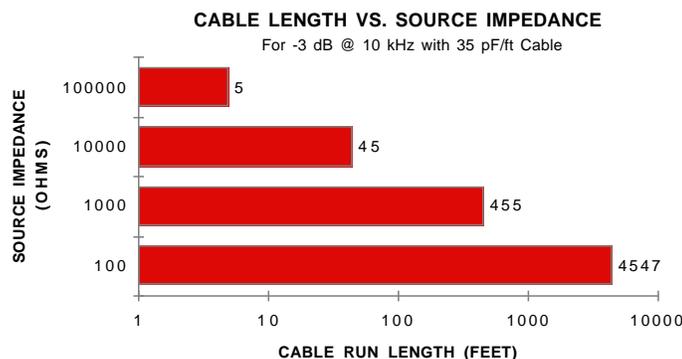
The insulation material and its thickness can be very dominant in *determining the flexibility* of the cable. A finely-stranded conductor insulated with a stiff compound will behave much like a solid conductor, as will a conductor insulated with a very thick layer of a more flexible compound. The thinner the insulation is, the more flexibility it allows in the overall cable.

How thick does the insulation need to be?

The basic electrical requirement for insulation thickness is called *dielectric strength* and is determined by the cable’s *working voltage*. The *voltages* involved in instrument cable applications are very low and very little dielectric strength is necessary to prevent the insulation from breaking down. However, a very important consideration when the cable is to be used for instruments like electric guitars is the amount of *capacitance* between the center conductor and shield.

What is capacitance and what does it do?

Capacitance is the ability to store an electrical charge. In cables, capacitance between the center conductor and shield is expressed in *picofarads per foot* (pF/ft.), with lower values indicating less capacitance. Combined with the source impedance, cable capacitance forms a *low-pass filter* between the instrument and amplifier; that is, it *cuts high frequencies*, much as the instrument’s tone control does.

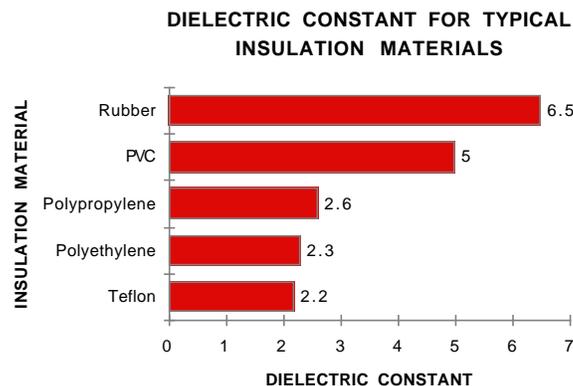


Why is low-capacitance cable an advantage? How can cable capacitance be eliminated? How long of a cable can I run before I lose high frequencies?

Lower cable capacitance allows more of the natural “brightness,” “presence,” or “bite” of an instrument to reach the amp, which in turn allows the treble controls to be run lower, reducing “hiss” and other unwanted noise. High-frequency loss from the cable becomes audible and objectionable depending on the source, the amplification and other circumstances. *Raising the source impedance* or *increasing the length of the cable* increases the loss; there is no point at which high-frequency loss suddenly appears or disappears. Guitars typically have much higher source impedances at higher frequencies because of the *inductive* nature of their pickups, which aggravates the effect of cable capacitance. A guitar will often sound noticeably “muddier” when run through a 40-foot cable, whereas keyboard instruments, samplers, mixers and other line-level devices with low source impedances can usually drive cable runs of hundreds of feet without problems.

How is low-capacitance cable made?

Given that the overall outside diameter of the cable is limited by the plugs that must be used, cable capacitance is largely the result of trade-offs between conductor size (and hence strength), insulation material (cost) and insulation thickness (size and flexibility). The term *dielectric constant* is used to rank the insulation quality of a material. Some materials are great insulators but impractical for use as wire insulation—glass, for instance! As far as practical materials are concerned, the thermoplastics are generally far superior to the thermoset family. For instance, *polyethylene* has a dielectric constant of 2.3, while that of rubber is 6.5. This allows a cable with polyethylene insulation to have perhaps one-third of the capacitance of a cable insulated with the same thickness of rubber. This can make an audible increase in the clarity of the sound.



What is the best all-around insulation material for instrument cables?

Polyethylene is very economical and dielectrically hard to improve upon (teflon is slightly better, but its cost is far greater, and its flexibility is far from ideal). Its only drawback is a low melting point which requires a skilled touch with the soldering iron to avoid problems in production.

What does the electrostatic shield do?

As the cable is flexed and bent, the copper shield rubs against the insulation, generating *static electricity*. The electrostatic shield acts as a semi-conducting barrier between the copper shield and the center insulation which *discharges* these static electrical charges. Without it any movement of the cable would result in obnoxious “crackling” noises being generated.

What are electrostatic shields made of?

Electrostatic shields first appeared in cable as a layer of rayon braid. Nowadays carbon-impregnated dacron “*noise-reducing tape*” is a common element in any good high-impedance cable. Increasing in popularity are *conductive-plastic* (carbon-loaded PVC) electrostatic shields. Conductive PVC is extrudable just like an insulation, which guarantees 100% coverage of the insulation with a very consistent thickness and a very low

coefficient of friction. The superior *conductivity* of C-PVC makes it much more effective than the semiconductive tape in bleeding off the small electrical charges that cause “the crackles.” Extruded C-PVC is also thinner and more flexible than dacron tape, which is applied longitudinally and restricts the “bendability” of the cable. Although conductive plastic (with a copper drain wire) has been used to completely replace copper braid or serve shields, its effectiveness falls off above 10 kHz.

Why are some cables microphonic?

As was noted previously, the center conductor, insulation and shield of a coaxial cable form a capacitor; and, as many a microphone manufacturer will tell you, when the plates of a capacitor are deflected, a voltage is generated. (This is the basis of the condenser microphone!) Similarly, when the plates (conductor and shield) of our “cable-capacitor” are deflected (for instance, by stepping on it or allowing it to strike a hard floor), a voltage is also generated. Unfortunately, this voltage generally pops out of the amplifier as a distinct “whap,” and can be very hard on ears and loudspeakers alike. Effects of this type are called *triboelectric* noise.

How can cable noise be reduced?

The electrostatic shield’s charge-draining properties help greatly to diminish triboelectric effects. Triboelectric impact noise is also reduced by decreasing the capacitance of the cable with thicker and softer insulation because the deflection of the conductor is proportionally reduced. This is the main reason that the single-conductor coaxial configuration remains superior to the “*twisted pair*” for high-impedance uses—it allows thicker insulation for a given overall diameter. Triboelectric effects are accentuated by high source impedances, and are at their worst when the source is an *open circuit*—for instance, a cable plugged into an amplifier with no instrument at the sending end. Testing for this type of noise requires *termination* of the cable with a shielded resistance to simulate the source impedance of a real instrument.

What does the shield do?

The copper *shield* of a coaxial cable acts as the return conductor for the signal current and as a *barrier* to prevent interference from reaching the “hot” center conductor. Unwanted types of interference encountered and blocked with varying degrees of success by cable shielding include radio frequency (*RFI*) (CB and AM radio), electromagnetic (*EMI*) (power transformers) and electrostatic (*ESI*) (SCR dimmers, relays, fluorescent lights).

What makes one shield better than another?

To be most effective the cable shield is tied to a *ground*—usually a metal amplifier or mixer chassis that is in turn grounded to the AC power line. Cable shielding effectiveness against high-frequency interference fields is accomplished by minimizing the *transfer impedance* of the shield. At frequencies below 100 kHz, the transfer impedance is equal to the DC resistance—hence, more copper equals better shielding. Above 100 kHz the *skin effect* previously referred to comes into play and increases the transfer impedance, reducing the shielding effectiveness. Another important parameter to consider is the *optical coverage* of the shield, which is simply a percentage expressing how complete the coverage of the center conductor by the shield is.

What are the characteristics of the three basic types of cable shields? Which is best?

A *braided* shield is applied by braiding bunches of copper strands called *picks* around the insulated, electrostatically shielded center conductor. The braided shield offers a number of advantages. Its coverage can be varied from less than 50% to nearly 97% by changing the angle, the number of picks and the rate at which they are applied. It is very consistent in its coverage, and remains so as the cable is flexed and bent. This can be crucial in shielding the signal from interference caused by radio-frequency sources, which have very short wavelengths that can enter very small “holes” in the shield. This RF-shielding superiority is further enhanced by very low *inductance*, causing the braid to present a very low transfer impedance to high frequencies. This is very important when the shield is supposed to be conducting interference harmlessly to ground. Drawbacks of the

braid shield include restricted flexibility, high manufacturing costs because of the relatively slow speed at which the shield-braiding machinery works, and the laborious “picking and pigtailing” operations required during termination.

A *serve* shield, also known as a *spiral-wrapped* shield, is applied by wrapping a flat layer of copper strands around the center in a single direction (either clockwise or counter-clockwise). The serve shield is very flexible, providing very little restriction to the “bendability” of the cable. Although its tensile strength is much less than that of braid, the serve’s superior flexibility often makes it more reliable in “real-world” instrument applications. Tightly braided shields can be literally shredded by being kinked and pulled, as often happens in performance situations, while a spiral-wrapped serve shield will simply stretch without breaking down. Of course, such treatment opens up gaps in the shield which can allow interference to enter. The inductance of the serve shield is also a liability when RFI is a problem; because it literally is a coil of wire, it has a transfer impedance that rises with frequency and is not as effective in shunting interference to ground as a braid. The serve shield is most effective at frequencies below 100 kHz. From a cost viewpoint, the serve requires less copper, is much faster and hence cheaper to manufacture, and is quicker and easier to terminate than a braided shield. It also allows a smaller overall cable diameter, as it is only composed of a single layer of very small (typically 36 AWG) strands. These characteristics make copper serve a very common choice for audio cables.

The *foil* shield is composed of a thin layer of mylar-backed aluminum foil in contact with a copper *drain wire* used to terminate it. The foil shield/drain wire combination is very cheap, but it severely limits flexibility and indeed breaks down under repeated flexing. The advantage of the 100% coverage offered by foil is largely compromised by its high transfer impedance (aluminum being a poorer conductor of electricity than copper), especially at low frequencies.

What type of shield works best against 60-cycle hum from power transformers and AC cables?

The sad truth is that the most offensive “hum-producing” frequencies (60 and 120 Hz) generally emitted by transformers and heavy power cables are too low in frequency to be stopped by anything but a solid tube of ferrous (magnetic) metal—iron, steel, nickel, etc.—none of which contribute to the flexibility of a cable! For *magnetically-coupled* interference, the only solution is to present as small a *loop area* as possible. This is one of the reasons that the *twisted-pair* configuration generally used in *balanced-line* applications became popular. Fortunately the high input impedances generally found in unbalanced circuits minimize the effects of such interference. *Don’t* run instrument cables parallel to extension cords. *Don’t* coil up the excess length of a “too-long” cable and stuff it through the carrying handle of an amp—this makes a great inductive pickup loop for 60 Hz hum!

What does the outer jacket do? What is it made of?

The jacket is both armor and advertisement; it protects the cable from damage and enhances the marketability of the assembly. As armor, the jacket must resist abrasion, impact, moisture and sometimes hostile chemicals (Bud Light, for instance). As advertisement, it may be distinctively colored or printed with the name of the manufacturer or dealer for product identification. The materials used for jacketing are the same type as those used for the inner insulation (thermoset or thermoplastic), but the choice is dictated less by electrical criteria and more by *physical durability* and *cosmetic acceptability*.

What is the best cable jacketing material?

For years rubber or neoprene were preferred for their superior abrasion resistance and flexibility, but modern thermoplastic technology has produced a number of PVC compounds that are soft and flexible but also very tough. As previously noted, thermoplastic processing is cheaper, faster and more predictable than that for thermoset materials. Only very specialized situations requiring oil or ozone resistance or extremes of temperature and climate demand neoprene or Hypalon jacketing.

The use of PVC has two other major advantages. PVC is not as elastic as rubber or neoprene, and this lack of “stretch” lends additional tensile strength to the resulting assembly by taking some of the strain that would otherwise be borne solely by the center conductor. This has made a dramatic improvement in the reliability of currently manufactured instrument cables.

The other important property of PVC is its almost limitless colorability. Once found only in gray or “chrome vinyl,” PVC-jacketed cable now ranges from basic black through brilliant primary colors to outrageous “neon” shades of pink and green.

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