CABLE ANATOMY I: UNDERSTANDING THE MICROPHONE CABLE

What is impedance?

Impedance is the AC (alternating current) version of the DC (direct current) term ***resistance***, which is the ***opposition to electron current flow*** in a circuit and is expressed in ***ohms.*** Impedance (often abbreviated as "Z") includes ***capactive reactance*** and ***inductive reactance*** in addition to simple DC resistance. Reactance depends upon the ***frequency*** of the signal flowing in the circuit. Capactive reactance increases as frequency decreases: inductive reactance increases as frequency increases. Because of this frequency dependence, impedance is ***not*** directly measurable with a multimeter as DC resistance is.

What are the differences between high- and low-impedance microphones?

To answer this requires a little historical background. High-impedance microphones are capable of producing higher output voltages than low-impedance types. Until recently, "consumer" audio gear (small P.A. systems, home and semi-pro recording equipment, etc.) was always designed for high-Z mics because their relatively high output level required less amplification or ***gain.*** The lower output of low-Z mics required the equipment manufacturer to use ***input transformers*** in front of the mic preamplifiers to step up the strength of the signal, which substantially increased the cost of the circuitry. Hence, low-Z mics were rare outside of professional recording and broadcast studios.

In these "big-budget" facilities, low impedance lines offered several big advantages. A high-Z mic's high ***source impedance*** (approximately 10,000 ohms) combines with the ***capactive shunt reactance*** of the mic cable to form a low-pass filter which progressively cuts high frequencies. The severity of the loss is determined primarily by the length and construction of the cable. (See "Understanding the Instrument Cable.") The low source impedance (less than 200 ohms) of low-Z microphones proportionally reduces the high-frequency loss. Equally important, the high ***load impedances*** demanded by high-Z lines are much more susceptible to various forms of ***interference*** than low-Z lines, especially high-frequency noise and radio. Both of these high-Z liabilities made cable runs longer than 15-20 feet a problem.

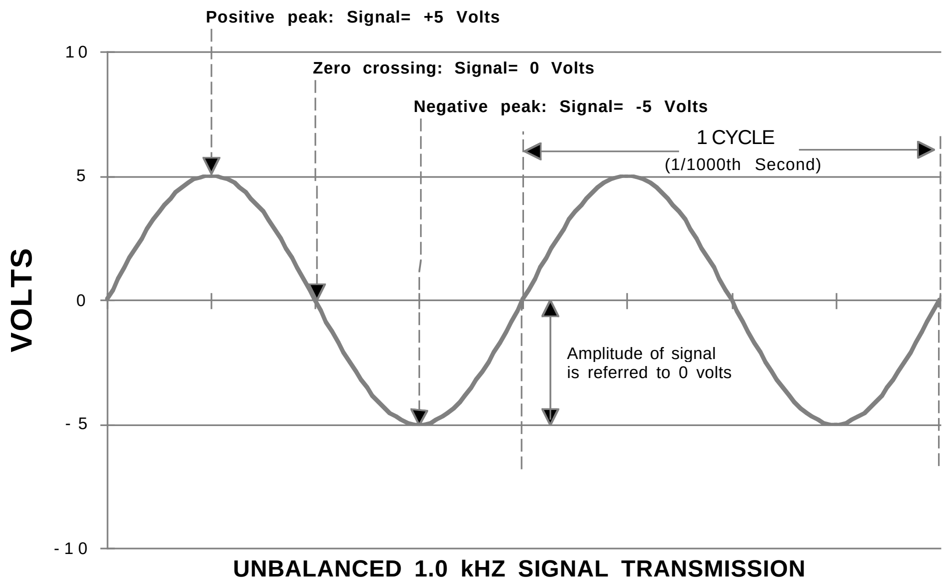
Isn't the use of balanced lines the biggest advantage of low-impedance microphones? What is a balanced line?

Balanced lines are wonderful, but they are sometimes given credit for benefits that they are not actually responsible for. ***Balanced, unbalanced, low-impedance*** and ***high-impedance*** are all ***individual*** properties. Many people erroneously refer to anything with a 3-pin XLR-type connector as "low impedance" and assume it to be "balanced." Others call any line connecting two pieces of equipment with 1/4" phone jacks "high-Z." In reality, a lot of equipment has unbalanced inputs and outputs that are carried on XLR connectors, and there are even more low-Z lines on phone jacks. Medical instrumentation uses a lot of high-impedance balanced lines for sensors, and most line-level unbalanced outputs are ***very*** low-impedance.

Electrical systems need a reference point for their voltages. Generally referred to as ***common*** or ***ground***, although it may not be actually connected with the earth, this reference remains at "zero volts" while the "hot" signal voltage "swings" positive (above) and negative (below) it. This is referred to as an ***unbalanced*** configuration. Physically, the common may be a wire, a trace on a printed-circuit board, a metal chassis—virtually anything that conducts electricity. Ideally it is a ***perfect conductor***—that is, it must have no resistance or impedance. In a cable connecting two pieces of equipment, the ***shield*** is used as signal common.

As the complexity and size of the system is increased, the imperfect conductivity of the common (ground) conductor inevitably causes problems. Since it is made of a real material, it must have some resistance, which must (Ohm's Law says) cause voltage drop when current flows through it, which means it cannot be at a perfect "zero volts" at both ends. The larger the system and the greater the distances between the source and load, the less effective this unbalanced configuration becomes.

The voltages of a balanced line are not referenced to the ground or common. Instead, the signal is carried on a pair of conductors with the signal applied to this pair di***fferentially***. The signals are electrical "mirror



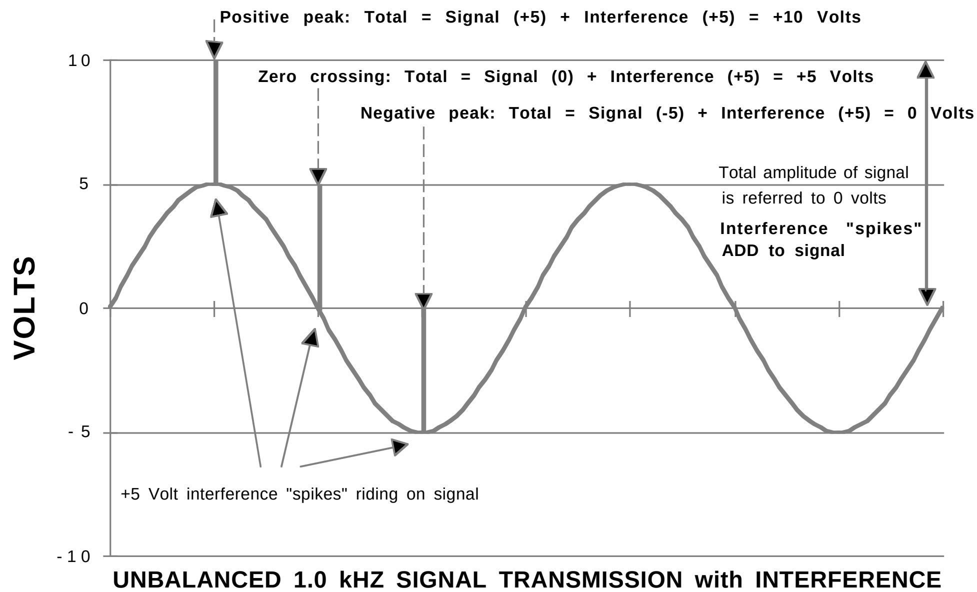
images" of each other—their ***levels*** are the same, but their ***polarities*** are ***opposite.*** In other words, as the applied signal "swings," one conductor will be ***negative*** with respect to the common, the other will be ***positive.*** These polarities alternate with the frequency of the signal, and the total signal level is the ***difference*** between the two individual voltages. For example, if one conductor is at +5 volts, the other will be at -5 volts, and the signal level is +5 volts ***minus*** -5 volts or 10 volts. If, for some reason, the two conductors were both at +5 volts ***simultaneously,*** the level would be +5 volts ***minus*** +5 volts, which is ***zero*** volts. Very tricky!

Because of this differential signal transmission, two very valuable things happen when using balanced lines. First of all, each piece of equipment can have its circuitry referenced to its own common, because the interconnection of the equipment does not require that the commons are connected in order to move the signal around. This eliminates the major cause of a lot of noisy audio gremlins, ***ground loops.*** Secondly, because the signal is differentially transmitted and received, any ***common-mode*** interference signal superimposed on the signal in the line will be carried by both sides at ***identical*** level and polarity. In other words, if the line has +5 volts of external noise induced, both conductors will have +5 volts of noise on them. This equals a total interference level of +5 volts ***minus*** +5 volts or ***zero volts. The interference cancels itself.*** This is called ***common-mode rejection.***

There are several ways to balance lines. (Actually, the term "balanced" is very often used incorrectly to refer to lines that are actually ***floating.*** Properly speaking, a balanced line is one which has equal impedance from each side to ground. An unbalanced signal may be derived from it by using one side of the pair as "hot" and ground as common. A floating line has ***no*** reference to ground, and must have on side of the line tied to common to "unfloat" it.) The input transformers once required by low-Z mic preamps also provided a ***floating*** input as long as neither side of the transformer's primary winding was tied to common. This is where the "low-impedance-is-balanced" misconception began. The use of balanced lines was actually just a by-product of the requirement for a transformer to step up the low signal level. Using modern low-noise integrated-circuit design, a low-Z mic preamp can be clean, quiet, balanced and a lot cheaper to build—without a transformer.

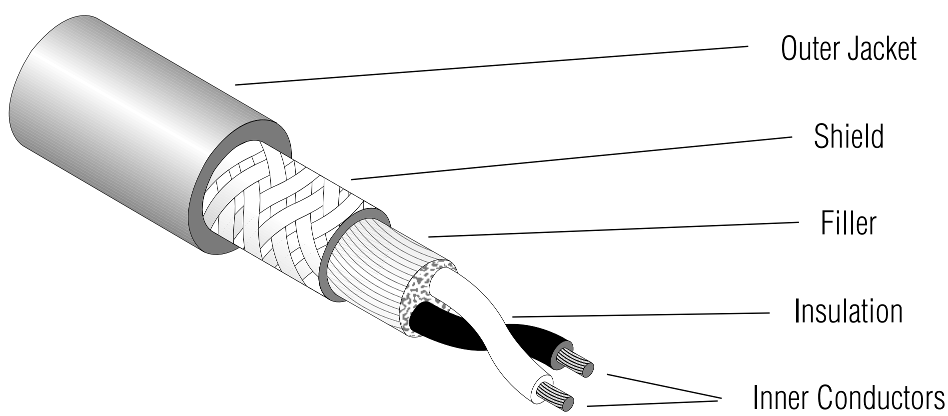
What are the basic parts of a high-Z microphone cable and what does each one do?

A high impedance mic has many of the traits of an electric guitar, so the cable used for it is generally a coaxial instrument cable. The "hot" center conductor is insulated with a high-quality dielectric; shielded electrostatically to reduce handling noise and triboelectric effects; shielded with a braid, serve, or foil which is also used as the current return path for the signal; and jacketed for protection. This type of cable is discussed in depth in "Understanding the Instrument Cable."



What are the basic parts of a low-impedance microphone cable and what does each one do?

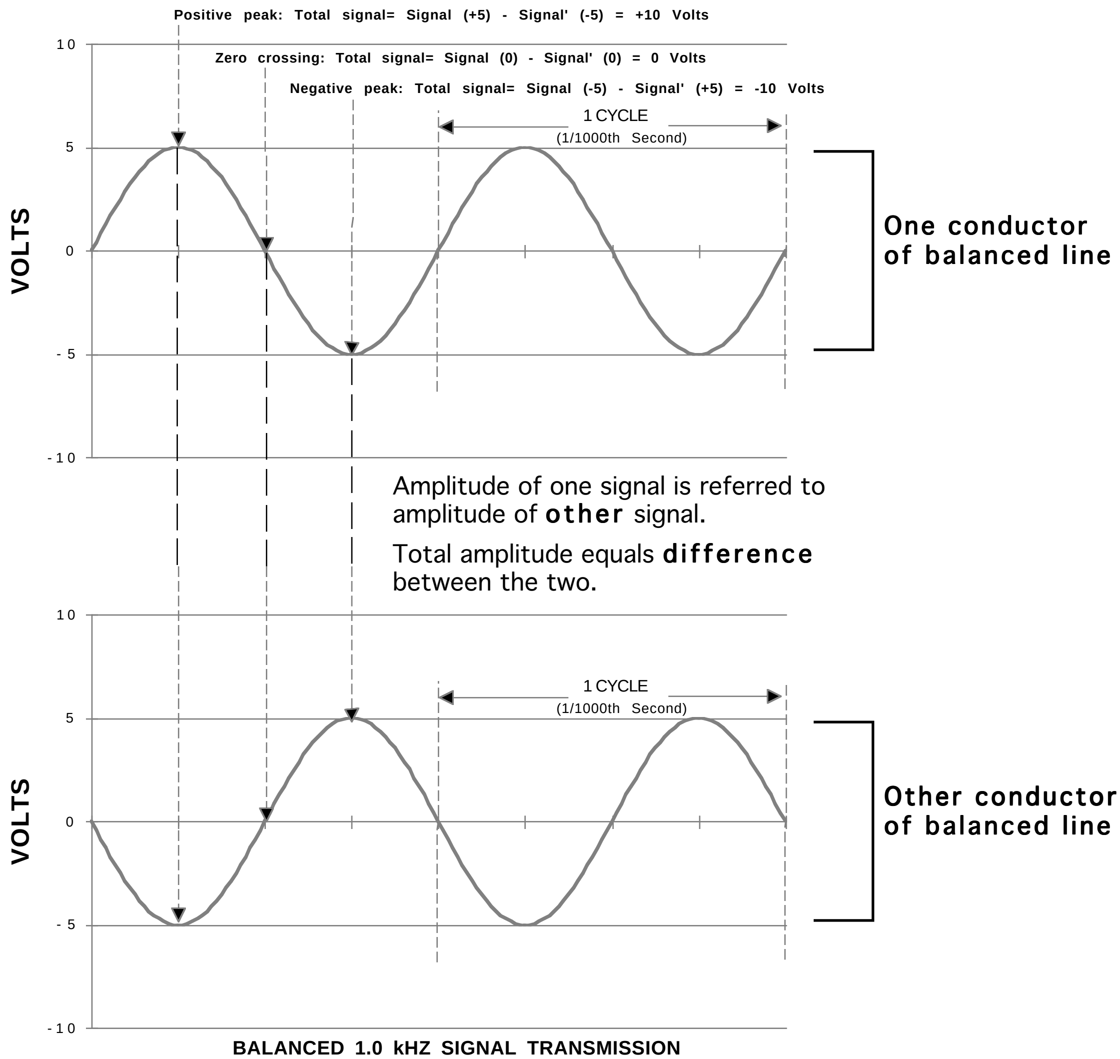
The basic cable construction for low-Z mic or balanced line applications is the ***shielded twisted pair.*** It consists of two copper ***conductors*** which are ***insulated,*** twisted together (often with ***fillers***), ***shielded*** with copper, and ***jacketed.***



What gauge and stranding should the two conductors be?

The amount of copper in any electrical cable is usually dictated by the amount of ***current*** it has to carry, or by the ***tensile strength*** it requires to perform without breaking. If we take the worst-case situation, where the cable is used for a line-level (+24 dBm) 600-ohm circuit, the current is a negligible ***13 milliamperes*** (that's 13 ***thousandths*** of an ampere). The ***power*** in such a circuit is ***100 milliwatts,*** or one-tenth of a watt. The current produced by a typical 150-ohm microphone connected to a 1,000-ohm preamp input is less than 10 ***microamperes*** (that's 10 ***millionths*** of an ampere), with power of less than a ***microwatt.***

By these figures it is apparent that not much copper is required to actually move signals around, except in applications demanding extremely long cable runs. Many low-impedance mic cables use 24 AWG conductors with excellent performance, and most multipair "snake" cables have 24 AWG (7 strands of 32 AWG) conductors. Other things being equal, more individual strands in each conductor mean better longevity and ***flex life.*** Since singers using hand-held microphones can put a cable through several hours of tugging, twisting, straining and other abuse, these situations call for finer stranding and often larger conductors, sometimes as large as 18 or 20 AWG. However, the sonic properties of the cable may be compromised by using large conductors.



Why are the two conductors twisted together?

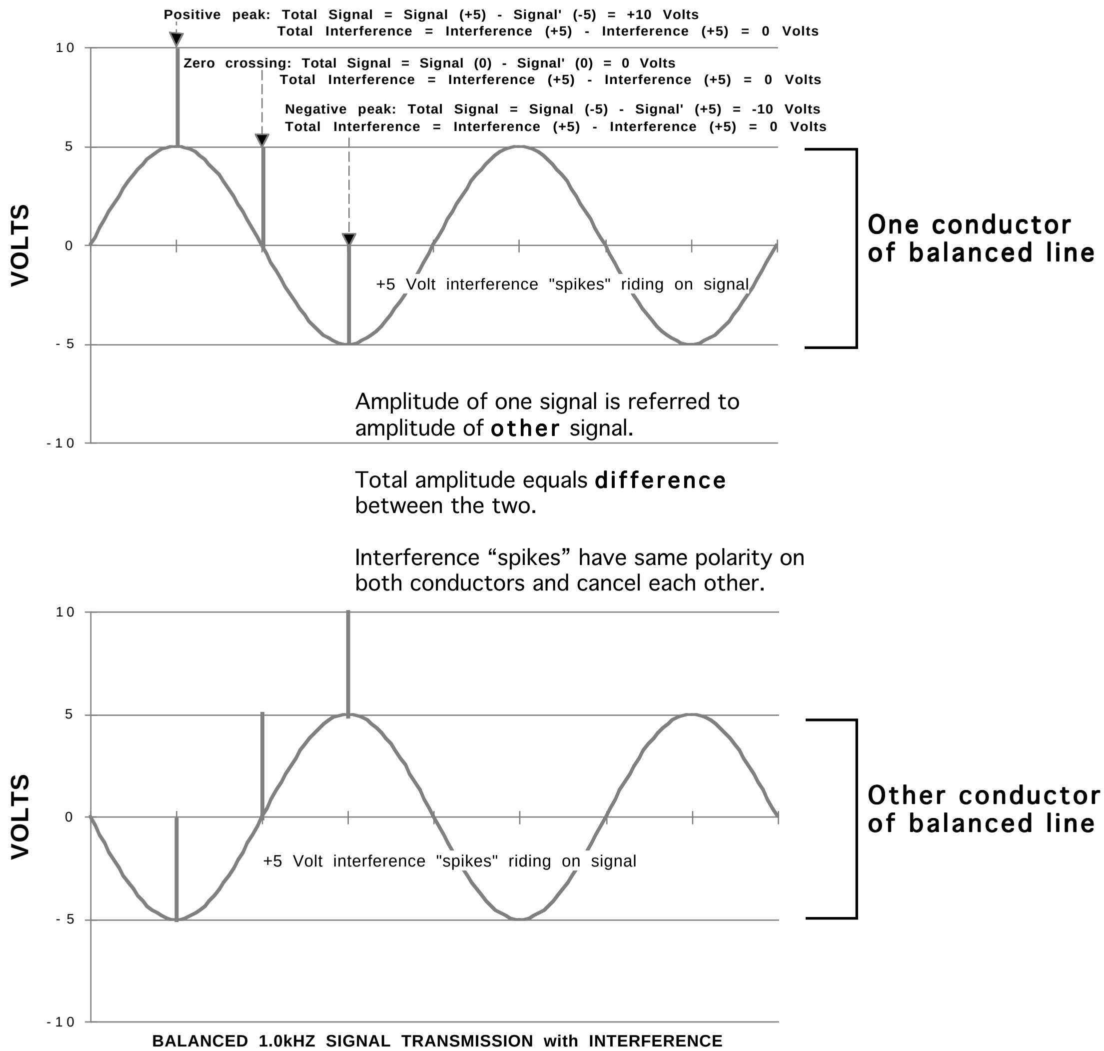
As previously explained, the interference-canceling common-mode rejection of the balanced line is based on the premise that the unwanted external noise is induced into both signal conductors ***equally.*** Minimizing the distance between the two conductors by twisting them together helps to equalize their reception of external interference and improve the ***common-mode rejection ratio (CMRR)*** of the line.

The two conductors also form a sort of "loop antenna" for stray magnetic fields. The farther apart the two conductors are the larger the "antenna" becomes, and the more interference it picks up from sources like transformers, fluorescent lighting ballasts, SCR-chopped AC lines to stage lighting, etc. Minimizing the ***loop area*** of the cable helps to reduce the unwanted hum and buzz from this type of interference, which the cable's shield is almost totally ineffective against.

The distance between the twists is called the ***lay*** of the pair. ***Shortening*** the lay (increasing the number of twists) improves its common-mode rejection, and also improves its flexibility. The typical pair lay in microphone cables is about 3/4-inch to 1-1/2 inches. Shortening the pair lay uses more wire and more machine time to produce the same overall finished length, so of course it increases the cost of the cable.

What is "star-quad" cable?

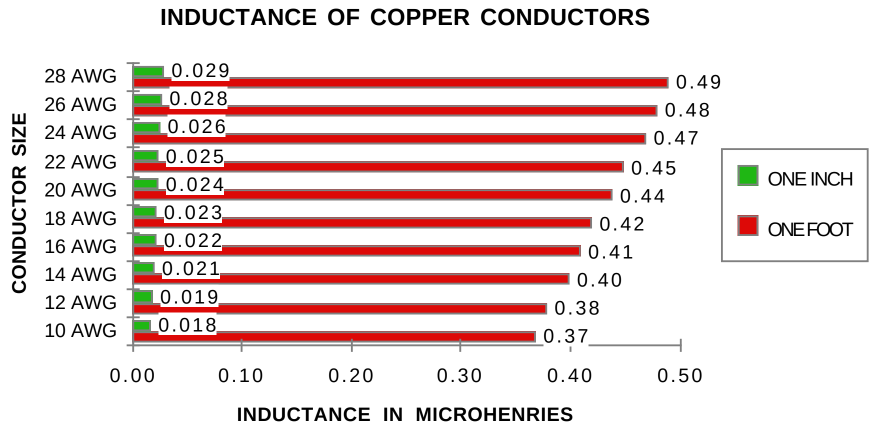
This four-conductor-shielded configuration can best be thought of as ***two twisted pairs twisted together.*** Using four small conductors in place of two large ones allows the loop area of the cable to be further reduced and its rejection of ***electromagnetic interference (EMI)*** is improved by a factor of ten (20 dB). This makes star-quad cable very popular for microphones and balanced lines used in applications such as television production, where huge amounts of power cable for lighting and camera equipment surround the performers.



Does star-quad actually sound better?

When used for low-impedance microphones, star-quad construction substantially reduces the ***inductive reactance*** of the cable. ***Inductance*** was previously mentioned in discussing ***impedance.*** An inductor can be thought of as a resistor whose resistance increases as frequency increases. Thus, series inductance has a ***low-pass filter*** characteristic, progressively attenuating high frequencies. While ***parallel capacitance,*** the enemy of high-frequency response in high-impedance instrument cable, is largely insignificant in low-impedance applications, ***series inductance*** (expressed in ***microHenries***, or uH) is not. The inductance of a round conductor is largely independent of its diameter or gauge, and is not directly proportional to its length, either. Parallel inductors behave like parallel resistors: paralleling two inductors of equal value doesn't double the inductance, it halves it. In cable construction, using two 25 AWG conductors connected in parallel to replace each of the conductors of a 22 AWG twisted pair will result in the same DC resistance, but approximately half the series inductance. This will result in improved high-frequency performance: better clarity without the need for equalization to boost the high end.

Also of significance is s***kin effect***, a phenomenon that causes current flow in a round conductor to be concentrated more to the surface of the conductor at higher frequencies, almost as if it were a hollow tube. This increases the apparent resistance of the conductor at high frequencies, and also brings significant ***phase shift.***



What is phase shift?

Phase shift is a term describing the displacement of two signals in ***time.*** When we described the two sides of a balanced line as being of opposite ***polarity,*** we could have said that they are ***180 degrees out of phase*** with each other. Each time an AC waveform completes a ***cycle*** from zero to positive peak to zero to negative peak and back to zero, it travels though 360 degrees (just like a circle). A simple 1 kHz (1,000 cycles per second) ***sine wave*** travels through this 360-degree rotation in one millisecond. If we consider its starting point to be zero, it will reach its positive peak one-quarter of a millisecond later, cross zero in another one-quarter of a millisecond, reach its negative peak a quarter-millisecond after that, and return to zero after a fourth quarter of a millisecond has elapsed. Thus, each quarter of a millisecond equals 90 degrees of phase difference.

When two identical signals are ***in phase*** with one another, their zero crossings and peaks are the same, and ***summing*** (combining) the two will ***double*** the amplitude of the signal. When they are 180 degrees out of phase, summing them will result in cancellation of both signals.

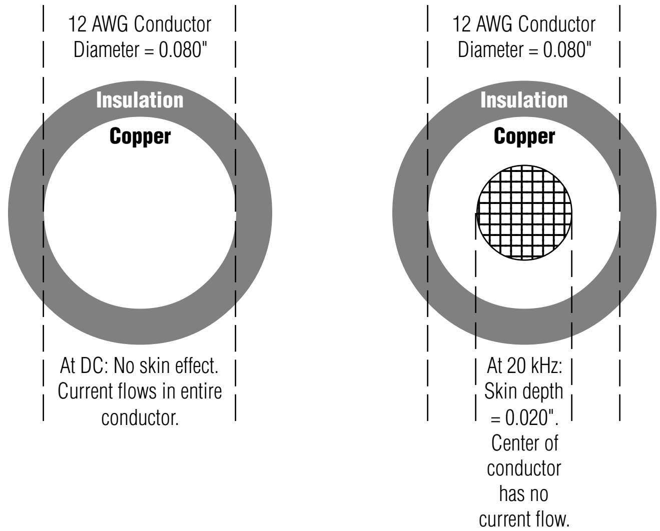
This property is very straightforward when considering simple sine waves. Sine waves consist only of a single ***fundamental*** frequency and have no ***harmonics.*** Harmonics are multiples of the fundamental, and are the elements of which ***complex waveforms*** are composed. An excellent example of complex waveforms is called music. The reason a middle C note on a piano sounds different from the same note played on a flute is because the two instruments generate different waveforms—the harmonics of the piano are present in different amounts and have different ***attack*** and ***decay*** characteristics than the harmonics of the flute.

When complex waveforms are traveling in a cable, it would be ideal if the ***amplitude*** and ***phase*** relationships they enter the cable with are the same as those they exit the cable with. When the effects of phase shift alter those relationships—when the upper harmonics that define the initial "pluck" of a string, for instance, are delayed with respect to the fundamental that forms the "body" of the note—a sort of subtle "smearing" begins to occur, and the sense of immediacy and realism of the music is diminished.

How can phase shift be minimized?

The ***phase lag*** caused by skin effect is one radian (about 57.3 degrees) per skin depth, and the effective skin depth of a conductor at a particular frequency is the same whether the conductor is very large or very small in diameter. For instance, the skin depth of a copper wire at 20 kHz is about .020 inches, while an 18 AWG conductor has a diameter of about .040 inches. This means that at frequencies from DC to 20 kHz, the full cross-sectional area of the conductor is utilized. Because the skin depth (.020") is never less than half the diameter of the conductor (.040"), there is never more than one radian of phase shift present.

In short, star-quad cables seem to offer lower inductance and lower phase shift, both of which are parameters that directly affect the clarity and coherence of high-frequency complex waveforms. Their inherently superior noise-rejection also reduces i***ntermodulation distortion***, a type which is particularly offensive because it produces "side-tones" not harmonically related to the fundamental. While the improvement may not be as dramatic as changing the microphone, an increasing number of audio professionals seem to be embracing the sonic benefits of star-quad construction.



What about the insulation used? Does it affect the sound?

Even though the effects of cable capacitance are much less than that encountered in high-impedance applications, the use of low-loss, high-quality (low ***dielectric constant***) insulation materials such as polyethylene and polypropylene are still preferred, especially when long cable runs are necessary. Because of the desire to keep cable diameter to approximately 1/4", the insulation thickness of a typical two-conductor microphone cable is generally about .020 inches, half that of a coaxial-type instrument cable. Because of this relatively thin wall, soldering requires good heat control to prevent melting. For very thin (.010") applications, ***cross-linked polyethylene*** insulation is sometimes used. The cross-linking process (similar to that used in manufacturing heat-shrinkable tubing) greatly reduces the problems of insulation meltdown and shrinkage during soldering.

Why does some cable have string-like fillers twisted with the conductors?

The primary use for fillers is to make the core of the cable round to eliminate ***convolution*** in the finished cable. A twisted-pair is not round, and without fillers the finished cable will have an undulating, "wavy" appearance unless a very thick jacket is applied, which will greatly affect its flexibility and make it very difficult to strip. A good example of convolution is found in the various thinly-jacketed twisted-pair cables used for pulling in conduit in permanent installations. Such cable is designed for economy and easy termination and so is not required to be round, only flexible and cheap.

Fillers also help to stabilize the cables shape and strengthen it, allowing some of the tugging, twisting and other stresses encountered to be absorbed by the filers rather than the conductors or shield. Some special miniature cables used for the "tie-clip" lavalier microphones use conductors that are literally copper strands wound around cores of synthetic kevlar fiber. This cable is less than 1/8-inch in diameter, yet is enormously strong. (Unfortunately, it is also very difficult to terminate because of the necessity of sorting out the unsolderable kevlar from the solderable copper strands.)

Why don't low-impedance cables require electrostatic shielding like high-impedance cables?

The "noise-reducing" semiconductive tape wrap or conductive PVC layers used on coaxial cable are used to "drain off" static electricity generated by the shield rubbing against the inner conductor insulation. When the source impedance is very high, these static charges will be heard as "crackling" noises as the cable is flexed and handled. A low source impedance has a damping effect on this type of static generation which minimizes its effect. There are cables available which use conductive textile or plastic shields for 100% coverage, with copper drain wires or very low-coverage copper braid added for ease of termination and low DC resistance. While this type of construction is very flexible, its shielding effectiveness suffers greatly as frequency increases, offering very little effect above 10 kHz because of its low conductivity.

What about handling noise?

The ***triboelectric*** effect that causes impact-related "slapping" noise as the cable hits the stage or is stepped upon during use is related to capacitance, specifically the change in capacitance that takes place as the insulation or dielectric is deformed. This causes it to behave as a crude ***piezoelectric*** transducer, a relative of an electret condenser microphone. Because such transducers are extremely high-impedance sources, the drastic impedance mismatch presented by a low-impedance microphone and its preamp or input transformer makes the extraneous noise generated by triboelectric effects negligible except in cases involving very low-level signals. In low-impedance applications, handling noise is best addressed by using soft, impact-absorbing insulation and jacket materials in a very solid construction with ample fillers to insure that the cable retains its shape. Note that it is totally invalid to evaluate the handling noise of a low-impedance mic cable without using a resistive termination to simulate the microphone element. A cable with no termination essentially presents an infinitely high source impedance, a situation that is beyond worst-case!

What special considerations should be given to shielding low-impedance cables?

Low-impedance microphone cables are shielded using the same basic methods as coaxial-type instrument cables. Woven copper braid generally offers the best high-frequency shielding performance and protection from radio-frequency interference (***RFI***). This is due to the very high electrical conductivity of the braid, and to its low-inductance, self-shorting configuration. Its disadvantages are primarily economic; it is the most expensive to manufacture and the hardest to terminate.

Spiral-wrapped copper serve shields are very inductive in nature, as they resemble a long coil of wire when extended. This can compromise high-frequency shielding and is not recommended when effective shielding above 100 kHz is required. Serve shields are relatively inexpensive and easy to terminate, making them a popular choice for medium-quality cables.

Foil-shielded cable is very heavily used for permanent installation work and for portable multipair "snake" cables. The extremely low cost, light weight and slim profile makes foil very advantageous in applications involving pulling cable into conduit. In these cases the conduit (if metallic and properly grounded) can greatly enhance the RFI and EMI shielding properties of the thin mylar/aluminum foil generally used. The 100% coverage of the foil shield, which should be of great benefit at radio frequencies, is somewhat compromised by the inductive nature of the copper drain wire typically used for terminating it. At low frequencies, performance is hampered by the relatively low conductivity of the foil/drain configuration. In applications involving repeated flexing and coiling, the metallized mylar tape will begin to lose its aluminum particles, opening up gaps in the shielding. This can be a particular problem with multipair cable used for touring systems, where the shield breakdown may lead to increased crosstalk between channels and to annoying radio pickup problems.

Does the use of 48-volt phantom power affect the performance of the shield?

The current typically drawn by a phantom-powered condensor microphone is generally limited by 6.81 kohm resistors, resulting in a current of less than 15 mA total. This is not a significant factor unless the shield begins to break down mechanically due to use: tearing or fraying are possible, which could create intermittant changes in shield resistance. This has lead a few professionals to prefer the use of three-conductor microphone cables, with the common carried by a drain wire in addition to the shield.

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