More Dollars Than Sense?

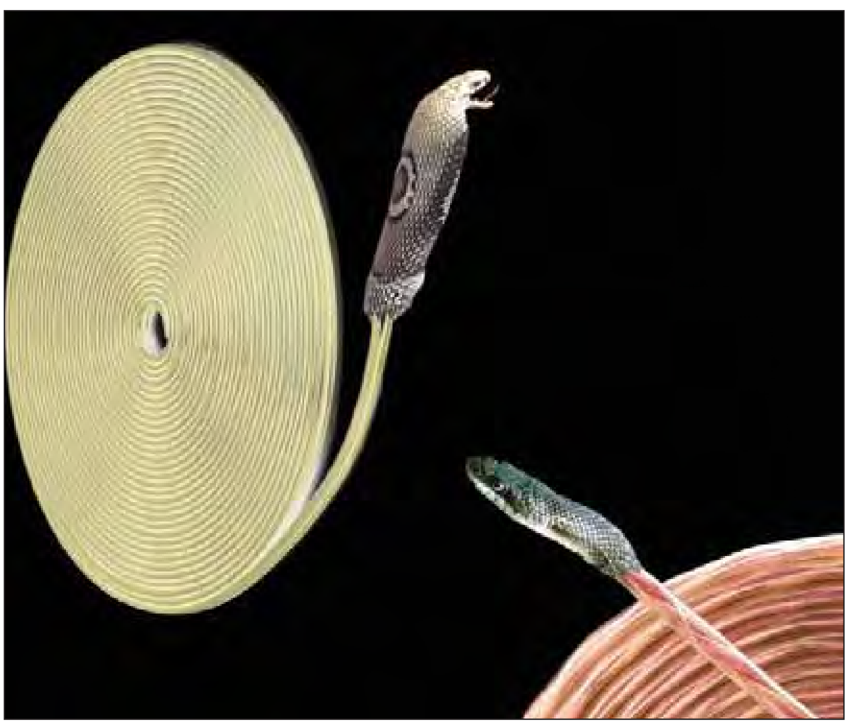
The truth about loudspeaker wire

By John Roberts

Too many good folks have been separated from their hard-earned money by hyperbolic claims about loudspeaker wire. There will always be people with more dollars than sense, but they don't last very long in professional audio. I speculate there aren't many (if any) of you who would pay thousands or even tens of dollars per foot for speaker wire.

A very basic practice in merchandising is called differentiation. Marketers must come up with reasons for why you should buy their wire. To claim that their wire is better, they must first identify, in some cases invent, a difference.

This search for a selling proposition has sometimes focused on "skin effect." It's a real effect and describes how at very high frequencies, electrons travel in the outer layer or "skin" of signal conductors. Another related property is that high frequency signals travel faster than low frequencies through the same cable.



These phenomena are dealt with appropriately in very high frequency applications with several techniques. "Litz" wire is made up of a large number of very small conductors braided or woven into one cable, producing a large surface area or "skin" for a given cross sectional area.

Another approach for high-power high-frequency power transfer is to use a hollow conductor, resembling a section of copper tubing. If the electrons are going to ignore the center of the conductor, why pay for it?

This is not an issue for audio professionals, working at mere audio frequencies of 20 Hz to 20 kHz. Perhaps it would be if we were sending audio over many miles, like the telephone company in its pre-digital days. They had to periodically correct for waveform smear. But at the speed that electricity travels, our typical path distances are much too short to be an issue.

OUT OF PERSPECTIVE

Wire is not very sexy or easy to create real marketing hooks for, but it can actually make an audible difference. The dominant mechanism is simple resistance. It's perhaps ironic that the "snake oil" marketers of speaker wire will exaggerate some real but insignificant parameter far out of perspective while compromising the real deal.

Forget the hype, what's important for speaker wire is that it exhibit low impedance that is resistive in nature. If the wire has a significant impedance component (reactance) that changes over the audio frequency spectrum, this can form a simple divider with the loudspeaker's resistive impedance, causing a frequency response error.

In addition, since loudspeaker

impedance will vary quite a bit over frequency, even a perfectly resistive speaker wire will cause errors. The magnitude of this frequency response error will increase proportionately as the wire's resistance increases.

Purveyors of "funny wire" don't bother to make claims about useful metrics like resistance since that is already defined by the wire size or gauge (known as "American Wire Gauge" or AWG for short). That would be like advertising how many quarts were in their gallons!

However, frequency response errors caused by wire resistance are one of the very real things that people actually do hear. I find this following anecdote instructive. From a discussion with one individual who was certain that he heard a significant improvement when using his "Snake-O Special" speaker wire (name changed because I don't remember it), I determined that the wire gauge he was using was marginal for the length of his run. The wideband loss of volume caused by a wire's resistance will be very difficult to hear without a side-by-side comparison.

But the difference in amount of loss caused by the speaker's changing impedance at different frequencies can easily cause a frequency response error that is probably what he heard.

It's easy to imagine how a rising impedance at high frequency could cause a pleasant sounding treble boost. Just listen to how clean and clear these "Snake-O Specials" sound!

There are several strategies to manage these real losses from wire resistance. The obvious one is to throw more copper at the problem. Heavier gauge wire with lower resistance will exhibit lower losses for a given run length. Another fairly obvious approach is to locate the amplifiers as close as possible to the loudspeakers to keep the run length as short as possible. A third, less obvious, approach is to scale up the intermediate signal voltages.

CONSTANT VOLTAGE

There are cases, such as in large distributed sound systems, where neither of the first two approaches is cost effective. You can't afford to put a separate amplifier at every speaker location, and sending sound sources over long distances with acceptable losses would require very heavy gauge wire. The solution borrows a strategy from high-voltage power distribution systems such as the one used by utilities to bring electrical power to our homes.

The power developed within a given load increases with the square of the terminal voltage (E^2/R). However, wire's losses only increase linearly with current flow, because the voltage developed across the wire is a simple function of its resistance times that current. Power engineers determined that by raising the voltage carried by transmission lines; they could increase the power being carried exponentially while simultaneously reducing the losses due to current flow.

The utility company accomplishes this magic with step-up/step-down transformers. By "transforming" a typical 100-amp at 240-volts residential service up to tens of thousands of volts at the transmission line, is reduced to the far more manageable level of one amp or so. Wire losses are one percent of what they would otherwise be.

Similar manipulations go on in "constant voltage" distributed sound systems but rather than stepping up the voltage to thousands of volts the standard for U.S. systems is 70-volt, with Europe using a slightly higher 100-volt standard. The rest of the world tries to conform to one of those two standards.

Of course, the audio signal isn't actually held constant. The voltage at rated power is. Both five watts and 500 watts constant voltage systems deliver the same nominal voltage for distribution.

The goal in any effective distribution system is to deliver as much power as possible to do useful work in the load and waste as little as possible heating up the wire. In a simple distributed sound system sending a few watts of announcements across a few hundred feet of factory floor, the typical low voltage system could drop as much power in the speaker wire as would reach the loudspeakers. By stepping up to 70 volts and back down again at each speaker the balance of power delivered versus lost is more respectable.

To put numbers to this concept, say we are trying to deliver one watt each to two loudspeakers located 100 feet distant from an amplifier using 24 AWG wire. Because we must count wire losses from the feed coming and going, 200 feet total of 24 AWG exhibits resistance of approximately five ohms.

To realize one watt at each loudspeaker, there would need to be more

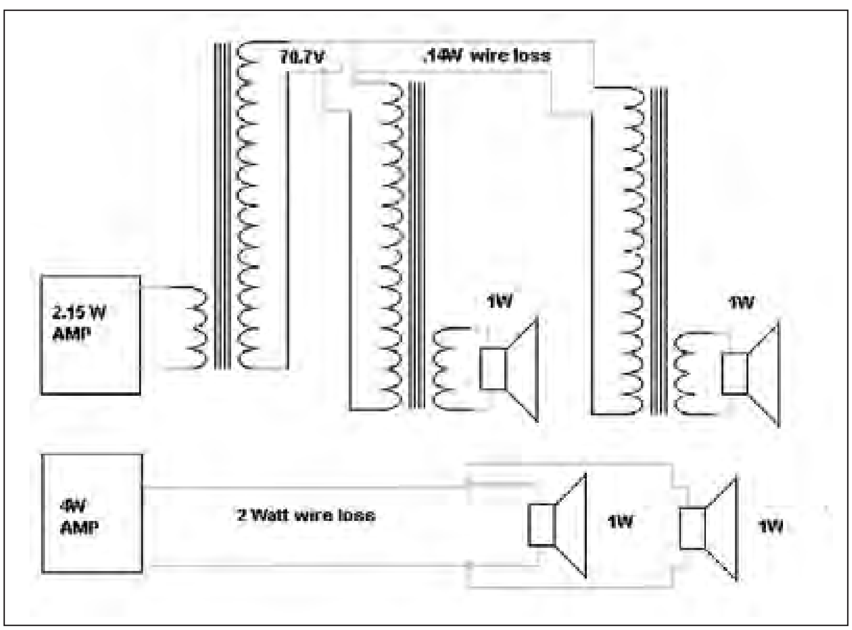


Figure 1: Two different ways of realizing one watt at two speakers.

than four watts into the wire at the amplifier end. (Over two watts gets wasted as heat in the wire). If we first step up the audio to a nominal 70-volt level the current drops to such a low level that the same wire would only waste 0.14 watts while delivering the same one watt each to the two speakers. (See **Figure 1**)

As useful as constant (high) voltage systems are for managing wire losses, they don't make sense for point-to-point runs in sound reinforcement systems. The main drawback is the size of the step-up and step-down transformers required.

To put this in perspective, the size of the transformer has to double every time you drop the frequency an octave. To cleanly pass 20 Hz both step-up and step-down audio transformers would have to be three times the size of a conventional amplifier's 60 Hz power supply transformer.

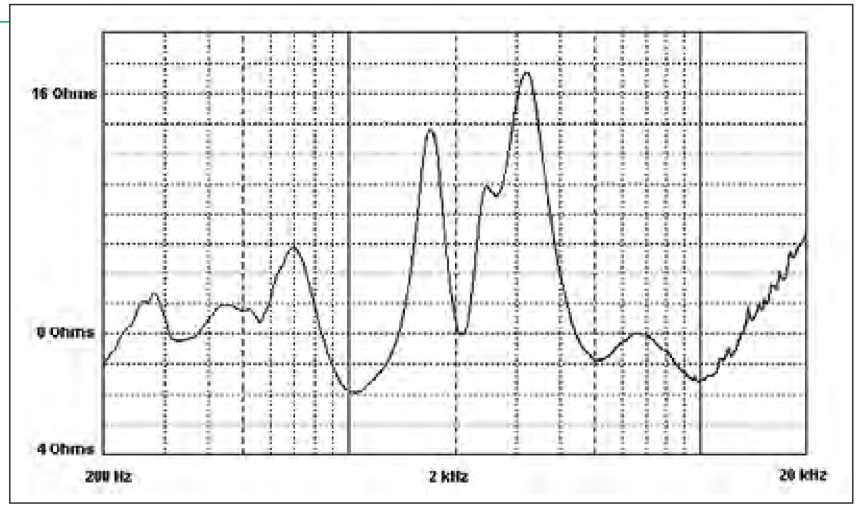


Figure 3: While more complex than the loudspeaker in Figure 1, this covers a similar impedance range, with a maximum around 16 ohms.

KEEP IT SHORT

The good news for most live sound applications is that we don't have to tolerate extremely long wire runs. By locating power amplifiers near the loudspeakers we can keep wire runs reasonably short. At these shorter distances we can easily afford heavier gauge wire.

While power losses are now manageable, it is worthwhile investigating the next dominant consideration in sizing speaker wire. Frequency response errors will be caused by the voltage divider created between the wire's fixed resistance and the loudspeakers changing impedance versus frequency.

Figure 2 and **Figure 3** show two representative loudspeaker impedance plots, pulled from the Internet. These are not offered as either worst case or typical.

From the impedance plot in **Figure 2**, if we ignore the extreme low frequency, this loudspeaker exhibits a maximum impedance greater than 17 ohms, with a significant region of the upper bass down around five ohms. Meanwhile, **Figure 3**, while more complex, covers a similar impedance range, with a maximum around 16 ohms and a minimum around six ohms.

To derive a frequency response error we need to compare the drop at maximum impedance to the drop at minimum impedance. The equations below calculate that drop for a given wire resistance. Note: to simplify this analysis we will assume all loudspeaker impedances to be resistive.

While not strictly accurate, loudspeaker impedances will typically be resistive at impedance minimums and any errors caused by load phase angle at the impedance maximums will not be significant for the sake of this analysis.

Minimum Voltage drop= V max = Z max /(Z max +Z wire)

Maximum Voltage drop= V min = Z min /(Z min + Z wire)

Frequency Response deviation= FR max = -20 Log10 (V min/ V max)

Solving for 1-, 0.5-, and 0.1-ohm wire resistance we get:

Loudspeaker	1 ohm	0.5 ohm	0.1 ohm
Spkr 1 (17/5)	-1.09 dB	-.57 dB	-.12 dB
Spkr 2 (16/6)	-.81 dB	-.42 dB	-.09 dB

Another related consequence is how wire resistance degrades effective damping factor. While damping factor is usually thought of as a power amplifier characteristic, in reality the wire selection can easily dominate actual damping available at the loudspeaker.

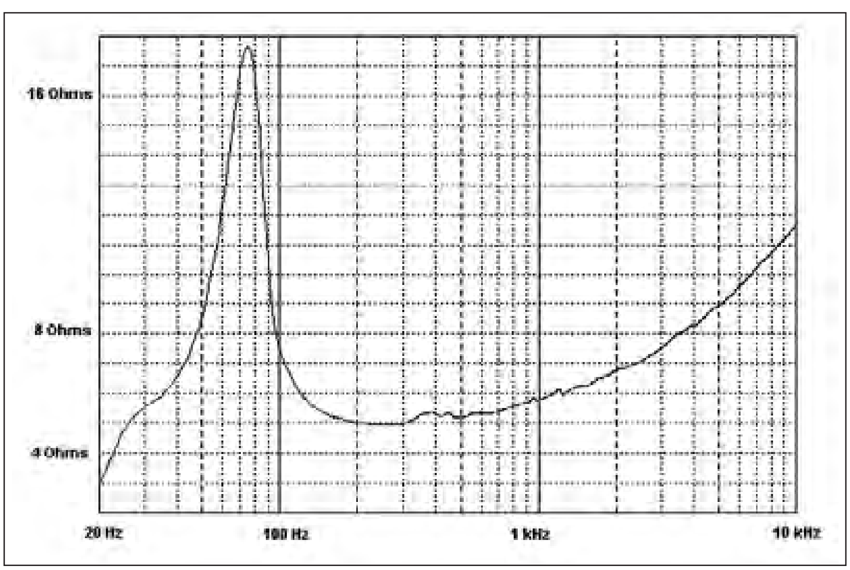


Figure 2: This loudspeaker exhibits a maximum impedance greater than 17 ohms.

In the previous examples, the one-ohm wire would by itself cause a rather weak damping factor of five or six (regardless of the amplifier's rated damping factor). Using the 0.1-ohm wire predicts a more respectable 50 to 60 damping factor, with some small additional degradation due to the amplifier's output impedance.

Damping factor deserves a more extensive discussion, but for this exercise we will assume that the amplifier's output impedance is small with respect to our wire's resistance.

GAUGING GAUGE

It's difficult to predict a precise threshold for audibility of frequency response errors. Controlled listening tests have suggested that differences as small as a few tenths of a dB can be audible. To satisfy the dual goals of minimizing frequency response errors and not degrading damping factor for the example loudspeakers selected, I am comfortable with targeting a total wire resistance on the order of 0.1 ohm.

Wire's resistance varies linearly with length. To keep the total resistance below our target limit of 0.1 ohm we must first project the length of our desired wire run, and then select a wire gauge whose resistance per unit length keeps us within the total resistance budget.

Don't overlook that the wire length is actually twice the run distance as we must consider the feed to and return from the loudspeaker as effectively in series. We must also add in contact resistance for the connections at all ends.

Lets look at how this works out for a practical example of a 20-foot run. First, we double that to 40 feet to establish the true signal path length. Then we need to account for contact resistance. I've seen Neutrik Speakon (or copies of that connector) rated as low as one mOhm (1/1000th ohm) per contact when new, and guaranteed < two mOhm over life.

What's important for speaker wire is that it exhibit low impedance that is resistive in nature

Because there are four connections in our total path lets budget .008 ohms for connections. Subtracting this 0.008 ohms from our 0.1-ohm target leaves us .092 ohms for wire. Dividing this 0.092 ohms by the 40-foot length calculates out to 0.0023 ohms per foot.

Plugging this into the equation for wire gauge:

AWG = 10 _log 10 R +10 (R is per 1000 feet)

We get:

AWG = 10x log 10 (2.3) +10 = 13.6 gauge

This is a little cumbersome, but once you have established an appropriate gauge for a nominal run length with your specific system. This gauge can be scaled up or down for other run lengths.

Wire resistance changes linearly with length. It changes non-linearly with gauge. A convenient property of wire gauge is that the wire's resistance will double for every three-step increase in gauge (AWG). Conversely the resistance will drop in half for a three-step decrease in gauge.

Based on this same example and rounding off to 14 AWG, we can expect similar performance from a 40-foot run using 11 AWG wire, and a 10-foot run would only need 17 AWG. This numbering convention gets a little unusual below "0" AWG.

One step below (larger than) "0" is "00", and "000" is two steps larger than "0". I don't expect to see speaker wire this large, as they would be very difficult to effectively interface with amplifiers and loudspeakers.

Using this example to size wire for your system will get you in the ball park, but it will be more accurate to use actual impedance specifications for your loudspeakers. Manufacturers of professional loudspeakers routinely publish this information.

Remember, use only the impedance max/min deviation within the audio bandwidth of interest. It doesn't matter what a tweeter's DC resistance is or a woofer's 20 kHz impedance, since you won't be listening to them there.

You also may want to tighten or relax the acceptable frequency response deviation. Better yet, look at your loudspeaker's typical frequency response and determine if the response errors caused by your wire losses are additive or corrective.

While I don't suggest trying to dial in corrective equalization using wire losses, if the error is making your system flatter you can afford to be less aggressive in sizing your wire AWG as long as you keep damping and power losses under control. ■

John Roberts is a long-time professional audio product and system designer and has been writing outstanding technical articles over the past two decades. Reach him at(johnhrob@netpathway.com.

Distinctions: Ohms Law

It's not unusual for newcomers to pro audio (as well as a few old timers) to misuse words or hold incorrect understandings of fundamental relationships. In many cases these are harmless, but precision in language especially when dealing with technical matters is always preferred.

Here I offer a distinction related to the topic at hand. How many out there think they know Ohm's Law? (O.K. - put your hands down.) Until recently, I thought I did too: I=E/R, and its several very useful variants.

However it turns out that Ohm's Law is really a material property, namely "a resistance that doesn't change with applied voltage". Such materials are appropriately known as "Ohmic". This compares to semi-conductors whose resistance changes in dramatic and non-linear fashions as the voltage changes, or complete non-conductors.

The equations popularly known (and taught) as Ohm's Law are more properly the definition of resistance. Mislabeling this is a harmless affectation but precision is always good general practice. Who knows, you might win a bar bet with this tidbit if you find yourself surrounded by a group of audio "know it alls." That is, if you can get them to believe you.

-J.R.