Fred E. Davis

SPEAKER CABLES

TESTING FOR AUDIBILITY

The function of a speaker cable seems intuitively obvious: Simply transmit the output of an amplifier to the speaker without alteration. This might appear to be a trivial task, yet there are nearly endless cable styles, sizes, conductor and insulation materials, strand winding techniques, etc. All promise the same result, even though they may incorporate opposing electrical characteristics. Does connecting a speaker to an amplifier require such complexity? Can changing cables really make dramatic improvements in system sound, or are perhaps fraudulent marketing tactics preying on an unknowing, nontechnical public?

Speaker cable seems to be one of those issues that leave very few standing on middle ground. People are either strong supporters of esoteric cables or steadfast skeptics. Everyone seems to have an opinion, but how many of those opinions are based on fact rather than assumption?

Only two reports have appeared in engineering journals in this country [1, 2]. These present objective analyses of cable behavior at audio frequencies from an engineering perspective. Over the years, numerous articles have appeared in popular audio magazines, hi-fi newsletters, and engineering trade journals [3 to 18]. Some are quite good, but others are mere repetitions of advertising claims. There are even articles and debates on computer networks [19]. Several manufacturers have published "white papers" to extol the benefits of their cable's design [20 to 23]. I note, with some skepticism, that little is sacred to marketing, including the laws of physics. Some papers do present interesting data but draw conclusions from elsewhere.

About the time audio enthusiasts discovered that 18 AWG (American Wire Gauge) lamp cord worked better than the common 22 AWG "speaker wire," very heavy specialty cables were introduced. Every three steps of AWG indicate a change of twice or half the cross-sectional area. For example,

Fred E. Davis is currently a senior engineer with ReSeal International, designing thermal-control, packaging, and delivery systems for flowable materials. As a consulting engineer, he has been involved in a variety of electronics applications including machine vision, biomedical and nuclear instrumentation, recording studio and video electronics, industrial controls, computer hardware and software, and consumer electronics. More important, he loves music.

Illustration: Danuta Jarecka

an 18 AWG wire has twice the area of 21 AWG, and 12 AWG has four times the area of 18 AWG.

At that point in time, more complex views of cables emerged, suggesting that speaker cables performed better if they had less capacitance or more inductance; that skin effect (frequency-dependent variation in the signal's penetration of the conductor), phase shift, and dispersion were veiling high frequencies, or that cables behaved like transmission lines. Other concepts included the need for vibration damping to isolate the cables, the use of directional arrows (so the alternating current would know which direction sounds best), and the need to "burn in" speaker cables to attain peak performance. In his papers [2 to 5], R. A. Greiner writes that speaker cables are not transmission lines (audio frequency wavelengths are much too long compared to the length of the cables), that phase shift and dispersion effects are too small to be audible (typically less than 0.1° per foot at 20 kHz, and differences of less than 0.006 μS per foot for most cables between 100 Hz and 10 kHz), and that the skin effect has only a small effect on heavy conductors (skin depth in copper at 20 kHz is 0.020 inch).

It is no secret that speaker systems present a complex load to the amplifier [24, 25]. While an isolated speaker driver is predominantly inductive (except around resonance), the complex impedance of most speaker systems, which have multiple drivers and passive crossovers, exhibits negative and positive phase angles within the audible range, indicating capacitive reactance as well as inductive reactance. Complex impedance is the combined effect of resistance and capacitive and/or inductive reactance. (Some issues of *Audio* that contain interesting Nyquist or polar-impedance plots of speakers' complex impedances are November 1990, page 100, and August 1990, page 95. Also see sidebar, "Speaker Impedance and Reactance.") Otala and Huttunen [25] show that given complex waveforms, some commercial speakers require up to 6.6 times more current than an 8-ohm resistor for the same signal, suggesting a dynamic impedance as low as 1.2 ohms.

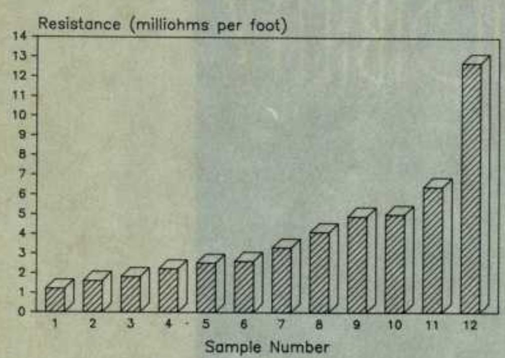


Fig. 1— Resistance for all cable samples (respectively: cable A, jumper, cable B, cable C, cable D, 138-064, #12 zip, cable E, cable F, cable G, 191-036, and #18 zip).

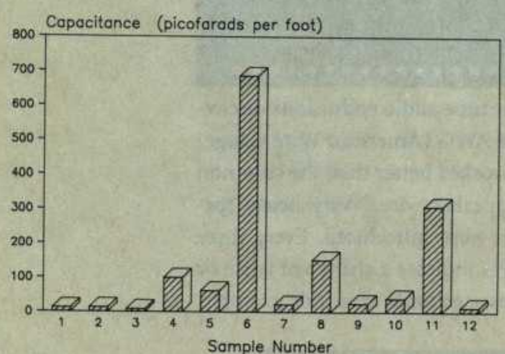


Fig. 2— Capacitance for all samples.

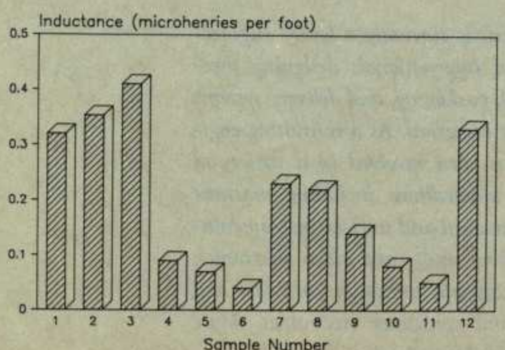


Fig. 3— Inductance for all samples.

The ideal speaker cable should transfer all audio frequencies into any loudspeaker load with flat response. Real cables will always show some loss due to resistance, but better cables will minimize this loss and still transfer all frequencies unscathed. One frequently overlooked concept is that the amplifier, cable, and loudspeaker form one electrical network. Too often, the amplifier, loudspeaker, and cable are considered as if they were separate components, when in fact they are closely coupled in a single system.

There are two primary mechanisms for a speaker cable to alter the signal to the speaker. One is that the electrical properties of the cable (especially frequency-dependent reactive properties) will directly alter the signal reaching the speaker. The other occurs when the cable either causes or allows the amplifier to generate spurious signals or distortions [14]. For example, if an amplifier that cannot drive capacitive loads has a highly capacitive cable attached to it, then the amplifier will oscillate. Another example: An amplifier sensitive to reactive loads is connected to a reactive speaker with a low-resistance, low-reactance cable. The amplifier will see a load it cannot handle and become unstable. These are faults of the amplifier design and will not be much addressed here. They are, however, far from uncommon.

I will primarily address the electrical properties and effects of cables. The main reason is that electrical measurements are not subject to the vagaries of our ears, either tin or golden.

Every cable possesses a combination of the fundamental electrical properties of resistance, inductance, and capacitance. The measured characteristics of 12 cables will be discussed, as will some basic electronics relating to cables and audio. The performance of the cables with real speakers will be examined first, and then two amplifiers will be included to present the electrical response of the complete systems.

I tested a variety of commonly and uncommonly available wire. Most of the samples were 10 feet in length. Some are very expensive (not the most expensive available, but still over $130 per foot), others are cheap (about 24¢ per foot), and some are not sold as speaker cables at all. This is not an exhaustive examination of every speaker cable available, but it does represent a wide variety of styles. A brief description of each cable follows, presented in order of ascending resistance. When known, the organization of the strands is shown in parentheses as "(quantity × gauge)." Unspecified gauges were estimated from conductor diameter and resistance. Brand names and models of some cables have been abbreviated; others have been deleted in the interests of not adversely affecting the business of any manufacturer, whatever the merits of the design.

(1) **Cable A.** Thousands of bare copper strands (39 AWG) in two parallel conductors, each about 0.25 inch in diameter and spaced about 0.5 inch between centers of the conductors. Approximately 5 AWG. Extremely flexible for such a heavy conductor. This is an older cable but is typical of the very-heavy-conductor style.

(2) **Jumper.** Automotive jumper cables from the garage. Two parallel 0.375-inch-diameter conductors of approximately 7 AWG (19 × 20). They are great for starting the car and come with handy, attached alligator clips, but how well will they work with speakers?

(3) **Cable B.** Independent conductors, about 0.625 inch in diameter each, with complex layer construction. Inside a very thick layer of insulation is a 0.189-inch-diameter conductor. This conductor is composed of several groups of tightly twisted, very thin (about 39 AWG) enamelled wires wound in helices around a heavier (about 20 AWG) enamelled wire. (A similar construction is used by at least two other brands.) All conductors are soldered together at each end, terminated with large, crimped lugs. Approximately 8 AWG.

(4) **Cable C.** Six conductors (each approximately 13 AWG) composed of many small (approximately 30 AWG) enamelled copper wires, lightly twisted over a stranded plastic core, altogether about 0.5 inch diameter. Equivalent to about 9 AWG.

(5) **Cable D.** Sixteen independent wires, woven together in a flat cable. Teflon insulation. Each individual wire is equivalent to 19 AWG and is composed of seven strands, varying in size from 31 to 24 AWG. Equivalent to approximately 10 AWG.

(6) **138-064.** (Full name: Spectra-Strip 843-138-2601-064 ribbon cable, manufactured by Amphenol.) Made of 32 twisted pairs of 26 AWG wire (7 × 34), arranged in a flat ribbon. Intended for high-speed transmission of digital data. For these tests, each conductor was made of 32 wires, one wire from each pair. Equivalent to about 11 AWG.

(7) **#12 zip.** (Full name: Belden 9718.) Belden's 12 AWG (65 × 30) speaker wire with clear PVC insulation and parallel construction like zip (lamp) cord (sample 12). Electrically, it is very similar to jacketed, twisted-pair cables—such as Manhattan 35059 and Belden 8477—which are commonly used in professional sound reinforcement.

(8) **Cable E.** A large, 0.7-inch-diameter cable using a construction technique of multiple conductors of different gauge and length, like sample 3. The manufacturer claims this will permit "all frequencies to travel through a given length of . . . cable at exactly the same rate of speed." Each main conductor is composed of three groups of multiple gauges, with a coaxial cable connected in an unknown fashion (hidden by potting compound) inside a proprietary coupler at the amplifier end. At $130 per foot, the most expensive cable tested. Approximately equivalent to 12 AWG.

(9) **Cable F.** Very similar to sample 5, except eight independent wires, woven in a flat cable. Teflon insulation. Each individual wire is equivalent to just over 19 AWG and is composed of seven strands of variable gauge, from 31 to 24 AWG. Approximately equivalent to 13 AWG.

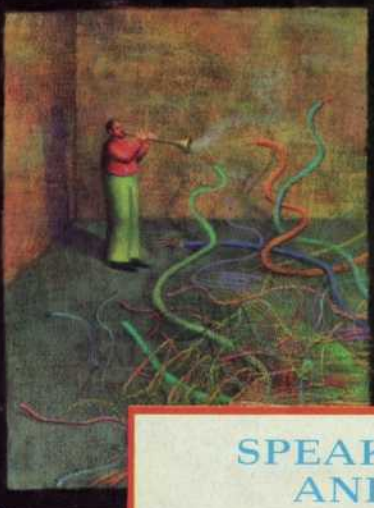
(10) **Cable G.** An unusual cable made from eight independent wires of 23 AWG (7 × 31) braided together. PVC insulation. Equivalent to 14 AWG.

(11) **191-036.** (Full name: Spectra-Strip 843-191-2811-036 ribbon cable, manufactured by Amphenol.) Made of 36 wires of

A speaker cable's job seems simple—

so how can different designs affect the sound?

The ideal speaker cable should transfer all audio frequencies into any speaker load, with flat response.



28 AWG (7 × 36), arranged in a flat ribbon. Intended for digital interconnections (such as floppy disk drives). For these tests, 18 alternate wires were connected for each conductor. Equivalent to about 15 AWG.

(12) **#18 zip.** (Full name: Belden 19123.) An 18 AWG (41 × 34) zip (lamp) cord. Brown PVC insulation, and parallel construction.

Resistance

Measured cable resistance, in milliohms per foot, is shown in Fig. 1; note that this includes the resistance of both conductors. Conventional wisdom would indicate that since a speaker's impedance is low (often 4 ohms, sometimes less), the cable's resistance should be much lower. In the pursuit of lower resistance, some practical limits are frequently exceeded at the expense of performance, due to added inductance.

The skin effect is a frequency-dependent change in resistance. The depth through which most of the current flows will be lower with lower frequencies and closer to the surface at higher frequencies. In copper at 20 kHz, this depth is about 0.020 inch. Therefore, conductors thicker than 0.040 inch in diameter (larger than about 20 AWG) will begin to show an increasing resistance at 20 kHz. Cable A (sample 1, 5 AWG) has a 342% increase in resistance between 20 Hz and 20 kHz. At first this seems quite astounding, but compared to an 8 ohm-load it represents a change of only 0.36%, which is not readily audible (especially given our lack of hearing sensitivity at 20 kHz). The skin effect, although quite real and measurable, will have insignificant audible effect.

Capacitance

In parallel with the amplifier and speaker, capacitance is the second most commonly discussed cable parameter. Yet, paradoxically, it has the least direct effect. The capacitance of most cables is very small (usually about 1/10,000 of the inductance) and will have little direct effect on the signal. Figure 2 shows measured cable capacitance, in picofarads per foot.

Inductance

Figure 3 shows cable inductance, in microhenries per foot. Inductance is rarely mentioned in discussions of speaker cables, yet its audible effect often exceeds that of resistance. Like resistance, it is in series between the amplifier and speaker. Inductive reactance will cause an inductor to oppose the flow of an alternating current, much like a resistor. Inductive reactance is directly proportional to frequency, so the higher the frequency, the higher the inductive reactance. For example, cable A (sample 1, 5 AWG) has an inductive reactance of 0.4 ohm at 20 kHz. Notice that this is about 10 times greater than the a.c. resistance including the skin effect (0.041 ohm). When 8-ohm loads are driven at 20 kHz through 10 feet of this cable, the combined inductive reactance and skin effects would produce a drop of 0.43 dB.

Impedance

The combination of a cable's resistance, capacitance, and inductance will determine the equivalent series impedance of the cable across the audio spectrum. Simply speaking, better cables will have a low im-

SPEAKER IMPEDANCE AND REACTANCE

If the phase angle or polar-impedance (Nyquist) plot for a loudspeaker is not available, you can still get a reasonable idea of how reactive that speaker is by examining a plot of its impedance amplitude. The manufacturer should be able to supply you with your speaker's impedance curve if it is not in your owner's manual. Another potential source is a magazine review; check your local library. (Note that in the plots of speaker phase angle published in *Stereophile* magazine prior to November 1991 with an "Ap" symbol in the upper right corner, the true phase angle is inverted.) You can also easily measure your speaker's impedance. (See "Quick-Build a Speaker Impedance Checker" by M. J. Salvati, *Audio,* August 1979.)

A rising impedance amplitude with increasing frequency is a result of inductive reactance with a positive phase angle. A falling impedance with increasing frequency is a result of capacitive reactance with a negative phase angle. The amplitude of the reactive component is proportional to the slope of the impedance magnitude. A very steep slope indicates a large reactive component; a gentle slope indicates a small reactive component. Note that the same interpretations can be made for speaker cables by using their impedance plots (Figs. 4 and 5). Those cables that have the largest change in impedance will be the most reactive and have the greatest phase shift.

pedance at all audible frequencies; this, in turn, permits flatter transmission of signals from amp to speaker.

The measured impedances of the sample cables are shown in Figs. 4 and 5. Those cables with the most constant impedance were the flat, or ribbon, types with higher capacitance and lower inductance (Fig. 4, 138-064; Fig. 5, 191-036). Other multiconductor cables, such as cables C and D (Fig. 4) and the lighter cables F and G (Fig. 5), display a small impedance rise. Of the simple two-conductor cables tested, the #12 zip (Fig. 5) performed the best, since both heavier and lighter gauges showed greater high-frequency impedance. The low resistance of the heavy, two-conductor cable A and the jumper (Fig. 4) are little help at 20 kHz, where inductive reactance has raised the impedance beyond the impedance level of even much lighter gauges. Cable F, which has a complex layer construction, duplicates almost exactly the impedance characteristics of #12 zip (Fig. 5).

Cables with the greatest change in impedance will also show the greatest phase shift. (See sidebar, "Speaker Impedance and Reactance.") The heavy, two-conductor cables will have approximately 3° of phase shift at 20 kHz, an amount that is inaudible and thus not a problem [26, 27].

Higher cable capacitance will tend to reduce the combined reactive component of a cable, thus lowering the cable's impedance at high frequencies and improving the high-frequency response. This effect is contrary to the popular belief that high frequencies will be attenuated more with higher cable capacitance [18, 21]. Erroneous conclusions are usually drawn from a mathematical model of cable performance that comprises series resistance and shunt capacitance but omits series inductance. Increasing capacitance counters the inductive effects from the cable and amplifier. Sample 6, 138-064, showed the highest capacitance, lowest inductance, and flattest impedance. Well-designed amplifiers are not affected by this amount of cable capacitance, but some amplifiers, especially older designs, may become unstable.

Cable/Speaker Interactions

The speakers I used for these tests, designated A and B, have fairly typical impedance and phase characteristics, as can be seen in Figs. 6 and 7. I took measurements at the same frequencies that I used in the tests of cable impedance. (Please note that the lines connecting the data points in these two graphs are intended to simplify reading the plot and do not reflect valid data between the sample frequencies.) Speaker A, an AR Model LST/2, is a three-way design with an acoustic-suspension woofer, three dome midranges, and three dome tweeters. It exhibits mostly capacitive reactance (negative phase angle) at the frequencies sampled between 127 Hz and 12 kHz; its lowest impedance, 4.8 ohms, occurs above 8 kHz. Speaker B, a Burhoe Model Green, is a two-way system with a bass-reflex enclosure and dome tweeter. It shows much more inductive reactance (positive phase angle) around 1 kHz than speaker A, and its capacitive reactance peaks at around 8 kHz. Its lowest impedance is 5.8 ohms, around 500 Hz.

Obviously, a loudspeaker can only perform up to the quality level of the electrical input to its terminals, so the best cable will have the flattest frequency transmission despite loudspeaker impedance or phase angle. Cable electrical response was measured using these two commercial loudspeakers as loads; results are shown in Figs. 8 and 9 with speaker A and in Fig. 10 with speaker B.

The low-inductance, multiconductor cables show the most linear response (cable

Fig. 4— Impedance of samples 1 through 6.

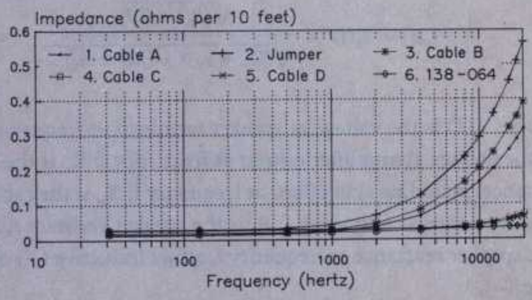


Fig. 5— Impedance of samples 7 through 12.

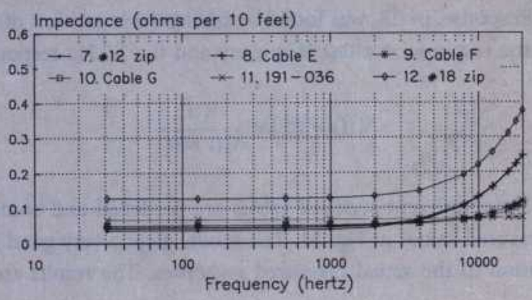


Fig. 6— Impedance and phase response of speaker A. (Note: Here and in Fig. 7, lines connecting data points do not reflect valid data; see text.)

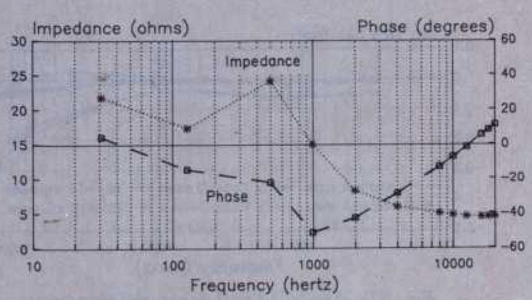
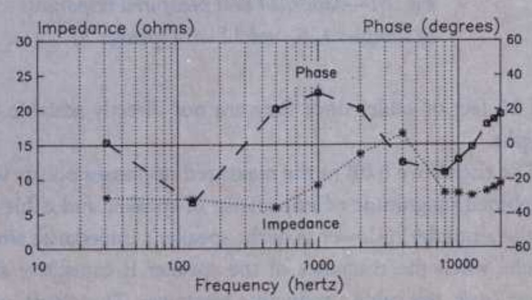


Fig. 7— Impedance and phase response of speaker B.



SPEAKER CABLE MODELS

The cable and speaker should be treated as lumped circuit elements in electrical models. The cable response model presented here is simple and is based on the ratio of the vector sum of the speaker's resistive and reactive components to the vector sum of both speaker and cable resistive and reactive components together. The cable is modelled at each frequency as a resistance in series with an inductive reactance, using the measured values of resistance and inductance. The skin effect was calculated and applied to the resistance where appropriate. The capacitive component of the cables modelled is too small to have much influence at audible frequencies, and is thus omitted from the model. The speaker is modelled at each frequency as a resistance in series with a reactance that can be either inductive or capacitive. The expression for the cable response at the speaker terminals for a given frequency is:

$$V_s(f) = V_a(f) \times \frac{\sqrt{(R_s^2 + X_s^2)}}{\sqrt{(R_w + R_s)^2 + (X_w \pm X_s)^2}}$$

where $V_s(f)$ is the voltage at speaker terminals at frequency f; $V_a(f)$ is the voltage at amplifier output at frequency f; R_w is the cable resistance, including skin effect, at frequency f; X_w is the cable inductive reactance at frequency f; R_s is the speaker resistance, and X_s is the speaker reactance at frequency f, either inductive (+) or capacitive (−).

Response, in dB, was found by taking the logarithm of the ratio of the response at a test frequency and the 1-kHz response:

$$V_s(f) = 20 \log \frac{V_s(f)}{V_s(1\ \text{kHz})}$$

Three different styles of cables are modelled and compared to measured values in Fig. B1. The model gives a very good approximation to the actual measured responses. The results are for the

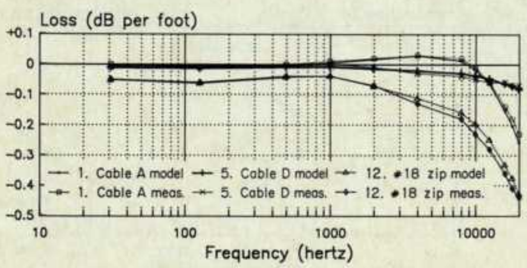


Fig. B1—Modelled and measured responses of samples 1, 5, and 12 with speaker A.

full 10 feet of cable, since they are not directly scalable to other lengths.

The rise above 0 dB in the measured responses occurs when the combined magnitude of impedance of speaker and cable (as seen by the amplifier) is lower than the speaker's impedance alone. This results when the reactance of the speaker is capacitive and subtracts from the cable's inductive reactance. The result is a lower total reactive component, which reduces the magnitude of the impedance seen by the amplifier. The current through the cable and speaker is higher than the speaker's impedance alone would require. This higher current results in a voltage across the speaker terminals that is higher than the amplifier's output. Low-inductance cables will provide a more ideal response, since cables whose inductive reactance is much less than the speaker's capacitive reactance will reduce this "hump" effect and add only a little more than the speaker's complex impedance to what the amplifier sees as a load. When the effective impedance of cable and speaker is lower, it should not prove difficult for a well-designed amplifier because

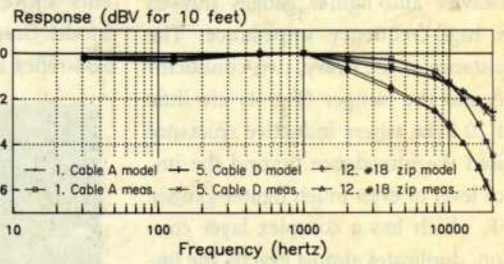


Fig. B2—Modelled and measured system response for amp B with speaker A, samples 1, 5, and 12.

the effect is small with short cables (approximately 0.6% for the worst case in these tests, sample 2, jumper cable). The lowest impedance seen by the amplifier and the greatest rise in speaker voltage as a result of this effect occurs at resonance, when the inductive reactance of the cable is equal to the capacitive reactance of the speaker. The impedance will then be limited by the resistive components of both cable and speaker. For example, speaker A would require just over 40 feet of sample 7, #12 zip, to provide enough inductance to achieve resonance at 10 kHz, where the resistance seen by the amplifier would be about 4.84 ohms.

The effect of the amplifier can be added to the cable response model by including the additional resistance and reactance of the amplifier's output:

$$V_s'(f) = V_a'(f) \times \frac{\sqrt{(R_s^2 + X_s^2)}}{\sqrt{(R_a + R_w + R_s)^2 + (X_a + X_w \pm X_s)^2}}$$

where $V_s'(f)$ is the voltage at speaker terminals at frequency f, $V_a'(f)$ is the internal amplifier voltage at frequency f, R_a is the amplifier output resistance, and X_a is the amplifier output inductive reactance at frequency f.

Figure B2 illustrates the results of this model, using amp B's voltage response with speaker A's impedance and phase (converted to dB relative to the 1-kHz response, as before). The model fits extremely well with the measured data. Because the model is very simple and amplifier dynamic responses are more complex, it will not fit as closely with all amplifiers. The model infers that, overall, the flattest response will occur by keeping the reactance of the amplifier and cable as low as possible.

C, cable D, and 138-064 in Fig. 8; cable F, cable G, and 191-036 in Fig. 9, and 138-064 in Fig. 10). Also note the relatively flat response of the 12 AWG cable with both speakers (#12 zip in Figs. 9 and 10) when compared to other two-wire cables (cables A and B in Figs. 8 and 10). These graphs also show another common effect, the high-frequency loss with the higher inductance two-conductor cables.

The interaction of a cable's inductive reactance with the speaker's capacitive reactance can be seen in Figs. 8 and 10. Notice where the response rises above 0 dB (Fig. 8, between 1 and 9 kHz; Fig. 10, between 3 and 12 kHz). At this point, the speaker's terminal voltage has exceeded the amplifier's output. (See sidebar, "Speaker Cable Models," for an explanation of this effect.)

Amplifier Effects

The frequency response and damping factor of the two test amplifiers are shown in Fig. 11. Damping factor is a measure of the amplifier's ability to deliver a given voltage without being affected by the load impedance. It is inversely proportional to the amplifier's output impedance. A damping factor that falls (i.e., rising output impedance) with increasing frequency is usually due to inductive reactance. For amp A, a Mark Levinson ML-11, the frequency response falls off at each end of the spectrum, and it has a drop in damping factor above 1 kHz. Amp B, a Nikko Alpha 230, has a flat frequency response and a high, almost linear damping factor.

Now let's look at the effects of amplifiers and cables. We've already seen how added cable inductance will cause deviations in frequency response due to interactions with the speaker's reactive components. Therefore, it would be desirable to minimize reactive effects from the amplifier as well. But why would an amplifier's output be reactive? Amplifier design theory is beyond the scope of this article. In short, most designers add inductance (typically 0.5 to 10 μH) between the output of the amp's last stage and its output terminals to isolate it from capacitive loads that could cause instability. This inductance is always in series with the cable's inductance, and in some amps can exceed the cable's inductance. (Amps A and B include such a network.) The greater the inductance, the greater the increase in output impedance (and the lower the damping factor) with increasing frequency. The damping factor of an amp can also shape the frequency response [7, 10, 14]. The response of the system becomes more sensitive to the speaker's impedance with increasing output impedance of the amplifier.

Matching the source and load impedances at radio frequencies is important to reduce reflections of the signal. But this is not a problem at audio frequencies, because the rise-time of the amplifier (which is much faster than the musical content of the signal) is far slower than the propagation time of the audio signals in the cable.

The response of every cable was tested with the same speaker load but two different amplifiers. Figures 12 and 13 present the response of all 12 cables with speaker A and amp A, while Figs. 14 and 15 present the response of all 12 cables using speaker A and amp B. Note that the "dBV" scale is different from the scale in the cable response plots in order to accommodate the increased range. These graphs illustrate the combined response of speaker, cable, and amplifier. Immediately obvious is that the response of amp A overwhelms the individual cable effects (Figs. 12 and 13). Damping factor for amp A and the impedance of speaker A are both low in the same frequency range, which makes the net re-

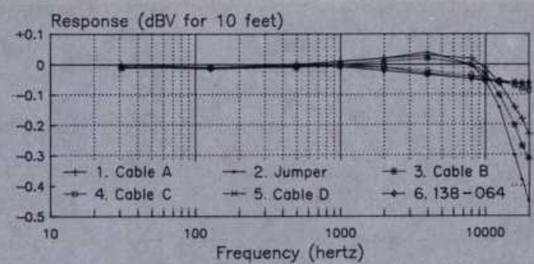


Fig. 8—Frequency response of samples 1 through 6 with speaker A.

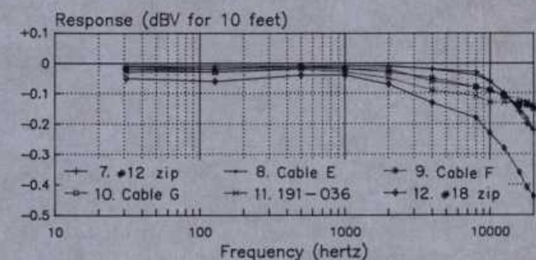


Fig. 9—Frequency response of samples 7 through 12 with speaker A.

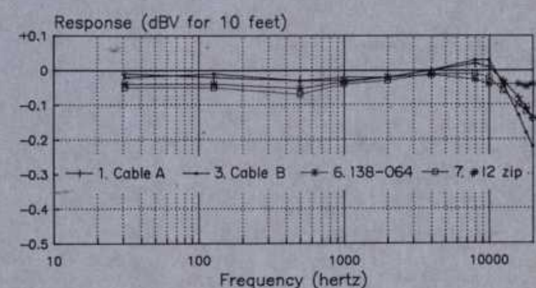


Fig. 10—Frequency response of samples 1, 3, 6, and 7 with speaker B.

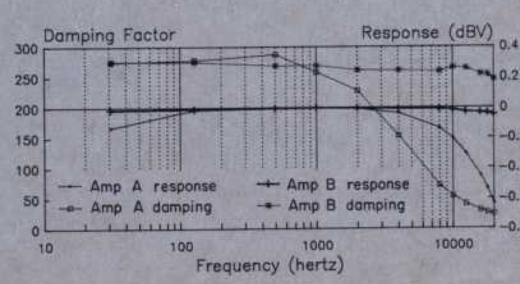


Fig. 11—Frequency response and damping factor of amps A and B.

sponse worse. The response with amp B (Figs. 14 and 15) closely resembles the response of the cable and speaker alone (Figs. 8 and 9). The high damping factor of amp B maintains better control of reactive effects with the more inductive cables and is less affected by variations in load impedance, thereby producing a flatter response (Fig. 14).

Audibility

Cable differences are measurably different, but are those differences audible? The answer is a definite maybe. It depends on many factors, some of which include: Cable type and length, frequency response and other characteristics of your system, speaker/listener placement and room characteristics, choice of musical material, and your hearing ability. Under carefully controlled listening conditions, differences of as little as 0.2 dB over an octave can be reliably detected by some listeners [28].

In informal listening tests (primarily using amp B and speaker A but also including a variety of others), I found the difference between standard, two-wire cables to be indistinguishable, even when comparing 12 AWG to 18 AWG (a 400% difference in resistance!). This was not surprising, since the cables' impedance curves are almost identical, with only an offset in resistance (Fig. 5). Comparing two-wire cables with the flat ribbon cable gave a subtle difference in the high treble. The subtlety of the difference correlates well with the measured performance of the same amplifier, cable, and speaker (Figs. 14 and 15). At no time did I ever hear (or measure) anything that approached the quantum leaps touted in some arenas.

Before you jump to premature conclusions, I urge you to try a double-blind (or even single-blind) listening test using great care to ensure that *only* cable-induced effects are being auditioned. You don't even need a switchbox; have an honest friend (a poker face helps) switch cables for you, and do not peek. The results may surprise you.

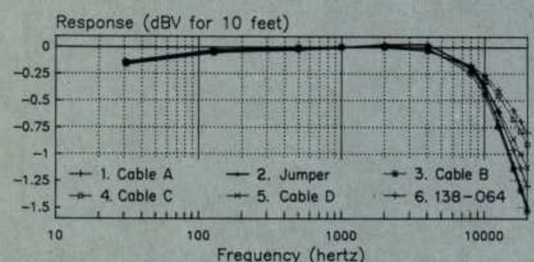


Fig. 12— System frequency response for amp A with speaker A, samples 1 through 6.

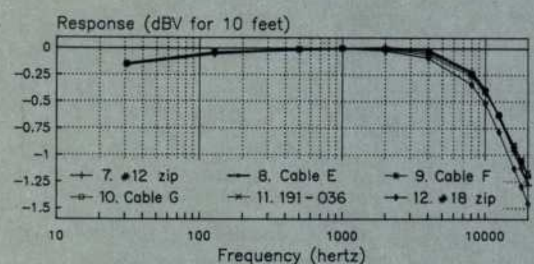


Fig. 13— System frequency response for amp A with speaker A, samples 7 through 12.

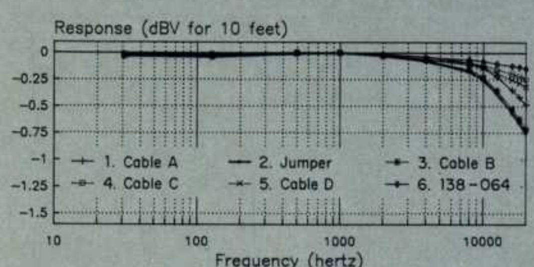


Fig. 14— System frequency response for amp B with speaker A, samples 1 through 6.

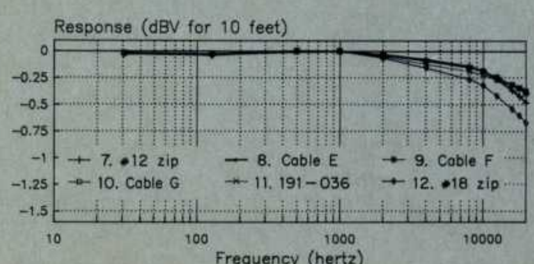


Fig. 15— System frequency response for amp B with speaker A, samples 7 through 12.

Conclusions

There are very real, measurable differences among speaker cables. However, for average systems and short cables, these differences are at the threshold of audibility. Most systems should not require more than 12 AWG, and all speaker cables should be kept as short as is practical and have clean, tight connections. For those rare systems that may require heavier gauges, be aware of the rapid increase in cable inductance with large cables and the attendant roll-off of high frequencies. Only unusual speaker loads should require special cables. More significant contributors to system sound will be speaker type and placement and, in some cases, amplifier differences. For those who consider very subtle differences to be important, the following conclusions should be noted.

If speakers were only simple resistances, then large, low-resistance cables would not be a bad idea. However, speaker systems often exhibit a frequency-dependent, complex impedance that can interact with the reactive components of amplifier and cable. In my tests, the best response was obtained with low-inductance cables and a well-designed amplifier, one whose output is of low inductance and whose damping factor is high and frequency-independent. This corresponds with standard engineering theory.

The best way to achieve adequately low resistance and inductance in a cable is by using many independently insulated wires per conductor rather than large, single conductors. Efforts to reduce the skin effect (such as litz construction, a multiplicity of individually insulated strands) will help, but improvements are due more to the reduction of inductance than the reduction of skin effect. Inductive reactance is more significant in large cables than skin effect. If it doesn't cause instabilities in the amplifier, larger capacitance in a cable is not significant since this component is comparatively small and reduces the effects of amplifier and cable inductive reactance. The use of exotic materials as conductor, plating, and insulation will have minimal (if any) audible effect but maximal effect on your wallet.

The best performance was measured with the low-inductance, multiconductor cables: 138-064, cable C, and cable D. Smaller multiconductor cables—such as 191-036, cable F, and cable G—also performed well.

Of the simple two-wire cables, 12 AWG provided the best performance with reactive loads, while both smaller and larger gauges (5 to 7 AWG and 18 AWG) showed greater high-frequency drop and interaction with the speaker's capacitive reactance. Only speakers with very low impedances would need a heavier cable. (For example, see D. B. Keele, Jr.'s review of the PSB Stratus Gold in *Audio*, November 1991.)

No one can deny the allure of the technology that brings us high-quality audio; the hardware is great fun and provides a pleasure all its own. But for me, it is the involvement with the music that is more important, and all the hardware is a means to that end. If you (and your bank account) feel that exotic wires the size of your wrist bring you closer to the music, enjoy! I prefer my speaker cables to have the least effect on system response, letting tone controls or a graphic equalizer perform tonal balancing only when required but otherwise leaving them switched out. By the way, keep the auto jumper cables in the garage!

Better cables have flatter impedance curves across the audio spectrum.

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