6.8 Loudspeaker cables and their effect on system performance

Few subjects in the world of audio systems excite so much controversy and heated debate as the subject of loudspeaker cables. A truly enormous amount of pseudo-science has been written about this subject, and, once again, so many cases have been reported which have tried to extrapolate from the specific to the general case, which is clearly nonsense.

In the world of high fidelity, there are many esoteric designs of amplifiers and loudspeakers which do not show the robustness of more typically professional equipment, and they tend to be used in domestic circumstances where electrical installations will not have been made with the type of attention to detail that would be found in a top professional recording studio. In some of these cases, a certain cable may clean up a sound, but the same cable in different circumstances, such as when used with professional equipment with clean electrical supplies, may not lead to any sonic improvement whatsoever.

Granted, an inadequate cable can certainly degrade a system, but there is no justification for using inadequate cables if serious listening is contemplated. So, perhaps we should look at what we mean by adequate.

6.8.1 The bare minimum

A loudspeaker cable, like an electrical power cable, needs to have a current carrying capacity such that it will not overheat, and a voltage insulation such that it will not arc, but the current carrying capacity of a loudspeaker cable cannot be calculated from the simple $W = I^2R$ formula that would...
apply to the wiring of an electric heater. What is more, loudspeaker cables may be carrying 11 octaves of frequency range and not just the single frequency of an electrical supply, so what happens over the whole range of operation is of interest, and all frequencies must be passed as uniformly as possible.

In the case of the vast majority of transistor amplifiers we are dealing with what amounts to a constant voltage source. This means that from the minimum rated load impedance up to infinity, the output voltage of the amplifier, for any given input voltage and at any frequency within its range, will be independent of the load to which it is connected. However, this is not the case with valve (tube) amplifiers, whose output loads must be critically matched to the output impedance of the valves, usually via a relatively complex output transformer, but for now we will restrict our discussion to the more typical transistor amplifiers.

In order to behave as a voltage source, and remain independent of load, the output impedance of the amplifier needs to be very low indeed - typically hundredths of an ohm. The ratio of the load impedance to the output impedance gives us the damping factor, which is an indication of the ability of the amplifier to suppress the natural resonances within a loudspeaker.

This electrical damping effect can be easily tested by lightly tapping the cone of a low frequency loudspeaker with the amplifier connected but turned off, then comparing the sound by tapping again with the amplifier switched on. A significantly deader sound should be heard in the latter case, when the near zero output impedance of the amplifier short circuits the voice coil. A similar effect can be demonstrated without an amplifier, simply by connecting a wire between the loudspeaker terminals, thus short-circuiting the coil.

When a loudspeaker diaphragm is struck, it behaves like a microphone. In fact, when a loudspeaker is connected to a microphone pre-amplifier input it makes quite a good microphone. The movement of the diaphragm in response to vibrations in the air moves the coil within the field of the magnet, which generates a voltage across the terminals. If the terminals are short-circuited, a current flows which tends to drive the voice coil in a direction which opposes the resonant movement of the diaphragm.

The shorted coil acts as a dynamic brake. The damping effect of an amplifier can greatly 'tighten up' the sound of the bass, because it allows the amplifier to better control the resonant movement of the low frequency drivers. In other words, the transient response is improved. The need for a very good short circuit is important, so if the resistance/impedance of a loudspeaker cable is not close to zero, the damping will not be as close to perfect as possible, and therefore the effect of the amplifier on the loudspeaker resonance will be reduced.

When dealing with such low impedances as are found in typical loudspeaker circuits, such as 4 ohms or less, we are dealing with impedances much lower than would normally be encountered in general electrical wiring. In order to achieve a moderately good damping factor of 40 on a 4 ohm load, the total of the series impedance exhibited by both the amplifier output impedance and the cable impedance could not exceed one tenth of an ohm.

The principal concern of an electrical engineer, when choosing a gauge of cable, is that it will pass
the required current without either overheating and producing a fire risk, or causing a voltage drop due to its predominantly resistive impedance (at 50 or 60 Hz) which would reduce the effectiveness of the device to which it is connected. So, if the motor is running at its correct speed and the cable is stone cold, then that is more or less the end of the story from an electrician’s point of view.

Conversely, far from dealing with a fixed voltage at a single frequency, a loudspeaker cable has an impedance which may be dominated by its resistance only at low frequencies. At high frequencies the *inductance* can be contributing more to the impedance than the resistance, and a loudspeaker working on the end of a 10 metre cable producing the same SPL as when connected to the output of the amplifier with 50 cm of cable is no indication that the cable is lossless.

If a cable has a *resistance* of 1 ohm and is connected to an 8 ohm loudspeaker, the voltage drop across the cable would be one part in 9 (i.e. across 1 ohm out of 9 ohms total). This represents about 11%, or about 1 dB, which would be barely audible.

For a voice announcement installation, such a cable may be entirely acceptable, but for a high quality music system it would impose a serious limit on the damping factor, and hence on the accuracy of the transient response at low frequencies. The subsequent resonance due to the loss of damping may even restore the 1 dB loss of perceived volume, but the nature of the sound would have changed.

From the point of view of the loudspeaker, the cable is a part of the output impedance of the amplifier, and the damping factor is defined by:

\[
\frac{Z_{\text{load}}}{Z_{\text{source}}}
\]

In other words, the load impedance divided by the output impedance. Therefore, if an 8 ohm load was connected directly to an amplifier having an output impedance (source impedance) of 0.1 ohm, the damping factor would be 8/0.1 or 80. If the two were now connected by a cable having a resistance of 1 ohm, the damping factor would be dependent on the combined resistance of the source and the cable: \(1 + 0.1\) ohms. The resulting damping factor would be:

\[
\frac{8}{11} = 0.72
\]

which in audio engineering terms is poor, and likely to lead to subjectively woolly bass.

At higher frequencies, the drive units which are used do not generally have the mass or compliance to freely resonate, and are additionally resistively damped by the air load. However, at these frequencies the cable *inductance* can behave like a frequency dependent resistor, and act as a filter. When used with loudspeakers which present variable impedance loads with relation to frequency, both the resistance and the reactive components of the impedance can act as potential dividers,
giving rise to a frequency response that varies according to the relative values of cable impedance and loudspeaker input impedance. The loudspeaker response will then vary in different ways as cable length is varied.

Cables also have capacitance between the conductors, but this is not usually problematical because the capacitive reactance is so low compared to the impedances of loudspeaker circuits that its effect would not normally become apparent until hundreds of kilohertz. However, it has been known to affect some marginally stable amplifiers, although it could be said that these problems should be solved at source. Some cables are intentionally capacitive, up to 0.2 microfarads, to maintain the high frequency response at the loudspeaker terminals, but they may unpredictably alter the performance and stability of amplifiers.

**The status quo**

### 6.8.2 The status quo

In terms of professional use, a marginally stable amplifier has little to justify its use. In fact, a marginally stable professional amplifier is almost an oxymoron - a contradiction in itself. However, in the world of hi-fi, some designs exist which are so esoteric that practicality and justifiable engineering are not high on the list of design priorities.

Some of these are more works of art than works of science, and they are designed to be pampered and appreciated rather than to be bolted into a rack and forgotten about. Nevertheless, without doubt, some of these specialised hi-fi amplifiers do perform extremely well under the limited circumstances of their intended use, but some are so minimalistic in their design, (even if not in their price) that they can sometimes be only marginally stable (although very few), and often their unbalanced input circuits and high sensitivity (100 mV as opposed to 1 volt) make them more prone to disturbance than the less sensitive and often more robust professional designs.

It is therefore not surprising that such amplifiers may show a higher degree of sensitivity to both the input *and* output cables with which they are connected than do the more robustly designed amplifiers for professional use, which must work even in relatively hostile environments. However, the term 'professional' does not ensure sonic transparency, and some supposedly professional amplifiers which are more robust than transparent would not be very sensitive to cable differences due to their own limited performance.

In all fairness, it must be stated that domestic high fidelity and professional recording are two different worlds. Despite the fact that they have a lot in common, they also have many differences. Whilst professionals tend to work with standardised, known, and objectively designed equipment, domestic equipment tends to be individualistic, and marked by diversity more than commonality.

Often, in the home of a hi-fi enthusiast, the equipment has pride of place, where aesthetic design can be almost as important as sonic design, and where minimalism and purity at domestic listening levels take precedence over the tolerance of hard-driving and abuse which may be needed by professional equipment. An idiosyncratic, 8 watts per channel valve amplifier has rarely found a home in a professional recording studio, and especially not if it cost 5000 euros or more.

It is therefore worth re-emphasising that the innumerable stories about either input or output cables
magically changing the sound of domestic equipment (whilst a giant and highly respected organisation such as the BBC has ‘no policy’ on esoteric cables) are more a testament to the sensitivity of much domestic equipment to minor changes in termination than to the general importance of esoteric cable design or materials of construction. However, that is not to say that cables are cables, and that any cable will suffice for connecting a loudspeaker as long as it manages not to catch fire at full volume.

So, perhaps we can now look at some of the more important aspects of professional loudspeaker cable design. [Although we should perhaps note, here, that professional recording engineers do tend to be rather more conscious of microphone cable design].

6.8.3 Cable designs for loudspeaker use
The first way to combat the resistance problem is to shorten the cable; halving the length of the cable will halve all the impedance components. Another way to halve the resistance would be to double the cross-section of the cable, but whilst this may be effective on the resistive part of the impedance, the increased spacing between the centres of the conductors will increase the inductance. The effect may therefore be beneficial at low frequencies but detrimental at high frequencies.

A way to overcome this problem is to use a co-axial cable, where the two conductors share the same axis. This can minimise the inductance by effectively cancelling the opposing magnetic fields in the two conductors, but as a result of this construction there is more opposing surface area between the conductors, so the capacitance can increase moderately, although this will usually not be a problem.

What is important is to always keep the pairs of loudspeaker wires as close and parallel as possible. This enables the magnetic fields around each core to cancel as much as possible of the inductance. Twisting the wires is another way to achieve this, but twisted wires are inevitably slightly longer than straight wires for any given overall length of cable. Well designed twisted cables have proved to be successful in high quality applications.

What should be avoided is the use of single wires, each following its own route to the loudspeaker. Such configurations can act as effective aerials, and can introduce RF interference into amplifier circuitry. Figure 6.5 sums up the general philosophy.

There is also a phenomenon known as skin effect. It is a controversial subject as to what effect it has at audio frequencies, but, as was shown in Figure 6.3, if high frequency roll-offs give rise to significant phase shifts below 20 kHz, then their effects may be audible. Skin effect is the tendency for high frequencies to travel through the outer skin of a conductor, and not through the centre of the core. The whole cross-section of the conductor is therefore not used, so the resistance rises as the conducting section of the cable reduces, introducing a high-frequency roll-off. Once again, the shorter the cable, the less the problem.

Some manufactures have opted to address the problem by plating the outside of the conductors with a lower resistance metal. Another approach is to use Litz-wire, where multiple, individually insulated, hair-like wires are twisted together. They thus have a much greater ratio of surface area to volume.
The evidence seems to suggest that on lengths of 10 metres or more, this type of cable can exhibit improved results when compared with ‘ordinary’ loudspeaker cables, but in professional situations, placing the amplifiers 10 metres from the loudspeakers would not normally be considered to be good engineering practice, for other reasons which will hopefully become apparent from the latter sections of this chapter. But first let us look at some detailed measurements which were made on loudspeaker cables.

**The amplifier/loudspeaker interface**

It must be clearly understood that when a loudspeaker is used with an amplifier employing negative feedback from the output stage, either globally or locally, (and at least 99.9% of amplifiers in professional use are so designed) the loudspeaker cable passes signal in both directions. The amplifier sends drive voltages to the loudspeaker, which cause currents to flow through the complex impedances which the loudspeakers present as a load.

Figure 6.5 Magnetic fields surrounding cables. Better cancellation lowers the inductance. a) parallel conductors. Partial cancellation as parallel conductors exhibit only weak external magnetic fields - the resulting inductance is low. b) Coaxial pair. Almost total cancellation of the magnetic field due to the concentric conductors - the resulting inductance is very low. c) Unrelated pair. Due to the relatively wide and random spacing of the conductors there is little cancellation of their magnetic fields, so the inductance tends to be higher than for the cables shown in (a) and (b).

The reactive components of the impedance, and in particular the moving mass component of the diaphragm/coil assembly, give rise to back-EMFs as the whole assembly resonates in the magnetic field. These EMFs (electro motive forces, or voltages) produced by the resonating loudspeaker acting as an electrical generator rather than as a motor, arrive at the amplifier output terminals via
the loudspeaker cables. The circuit of the system is shown in Figure 6.6.

The low output impedance of the amplifier cannot effectively damp the back EMFs (reverse voltages) generated by the natural movements of the loudspeaker if an excessive impedance, in the form of a cable, is separating the coil from the output terminals of the amplifier. Cable impedance (or lack of it) is therefore critical in terms of optimising the performance of the amplifier/loudspeaker combinations.

It can thus be seen how the cable can control what passes from the amplifier to the loudspeaker, by virtue of the frequency dependent nature of its impedance,

![Circuit diagram of the amplifier, cable and the loudspeaker impedances. a) Basic circuit. b) Effect on damping. c) Effect on back-emf](image)

**Figure 6.6** Circuit diagram of the amplifier, cable and the loudspeaker impedances. a) Basic circuit. b) Effect on damping. c) Effect on back-emf
and it can also control what passes to the amplifier from the loudspeaker, and hence affect the damping of the transducer system. The effect of any loudspeaker cable therefore must be considered in both directions.

One great problem about generalising about many, or most, of the effects of the performance of loudspeaker cables (once the basic properties of resistance and inductance have been adequately specified) is that their effects can be so system-specific. In other words, what occurs with one combination of amplifier, loudspeaker and location may have very little in common with what occurs with a different combination.

The only universal solution for minimising the effect of loudspeaker cables is to minimise their length, by mounting the power amplifiers as close as practically possible to the loudspeakers. A total length of about 2 metres from the amplifier terminals to the motor/driver terminals is a reasonable maximum to aim for. And of course, suitable cable must be used.

In the experience of the authors, the differences between cables of appropriate resistance and inductance at lengths below 2 metres are too small to be of any real significance, but exactly what section should be used for what power rating of loudspeaker is something that needs to be worked out case by case. For example, as previously mentioned, an excessively large format cable may be detrimental to the response of a tweeter because the increased cable inductance, due to the cable spacing, may be more of a problem than the increased resistance of a thinner cable.

There exist some large, high powered, passively crossed over, professional monitor systems that are very difficult to drive. When the drive voltages going forward meet the back-EMFs coming in the other direction, all in the highly reactive circuitry of a low impedance, passive, high order crossover, peak currents of up to 100 amps have been measured during some complex musical passages at high studio monitoring levels.

It would seem obvious that a cable specified for such a system, using amplifiers capable of driving continuously 3000 watts into half an ohm, would need a higher specification than the cables used in a system of similar power rating and acoustic output but using an active crossover, multiple amplifiers, and where the low frequency drivers presented an almost uniform impedance to the amplifier, (at least in the frequency range over which they were being driven).

When calculating the cross-section of loudspeaker cables, we cannot simply take the approach:

\[ W = I^2R \]

\[ W = \frac{I^2}{R} \]
\[
1000 = \frac{I^2}{R}
\]

\[I^2 = 250\]

\[I = \sqrt{250}\]

\[I = 16 \text{ amps}\]

As 1 mm\(^2\) of cable will safely carry 5 amps, we will therefore use 4 mm\(^2\) cable to give a little margin of security.

In terms of electrical engineering, the above concept is a perfectly safe and viable approach, there is no possibility of the cable overheating, but it in no way takes into account the effect on the sonic perception of musical signals when amplifiers are driving difficult loads. In the case of loudspeaker cables, the emphasis is on the cable impedance rather than thermal/current capacity.

Coming up in **Part 5**: Some provable characteristics of cable performance.

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