

Skin effect

Nick Wheeler outlines skin effect and describes why it is irrelevant at audio frequencies.

Table 1. Effect of frequency on rf resistance in two wires with different diameters.

Frequency (Hz)	Wire diameter	
	2mm	0.2mm
10	1	1
100	1	1
1k	1	1
10k	1.095	1
100k	2.626	1
1M	7.7	1.095
10M	23.8	2.626
100M	74.7	7.7

Everyone involved with electronics will have heard of skin effect. And most will know that it has the effect of increasing the effective resistance of a conductor as signal frequency increases. This is due to the current flow being increasingly concentrated on the outer surface of the conductor.

The effect can be so pronounced that in some cases a thin-walled tube is as effective as a solid conductor. Silver plating and the use of oxygen-free copper are commonly used to reduce the effects of skin effect.

Silver plating reduces resistance of the conductor skin while oxygen-free wire has a fractionally lower resistance than the standard-quality option. Oxygen-free cable can be simulated by simply increasing conductor cross section. The diameter increase necessary to do this is so small as to be negligible.

Note that effective resistance, as referred to above, is also known as 'rf resistance'. It is an ohmic effect, and nothing to do with reactance. It's operation can be detected thermally.

What causes skin effect?

Consider a conductor made up of many strands of thin uninsulated wire, and carrying an alternating current. Current flowing through any single strand produces a field which cuts through the bulk of the surrounding conduc-

tors. In effect, these conductors form shorted turns as they are in intimate contact.

Currents flowing in the shorted turns oppose that flowing in the specimen strand, but those currents have to go somewhere. It is easy to show that they concentrate on the outer surface of the conductor bundle, or in the case of a single large conductor, on the surface.

Fields associated with the outside surface intersect less conductor material. As a result, the opposition to current flow is less on the surface, which is where it then flows. This effect depends strongly on increasing frequency and – because of the larger cross-sections involved – with increasing sizes of solid or uninsulated stranded conductors.

Stranded versus solid conductors

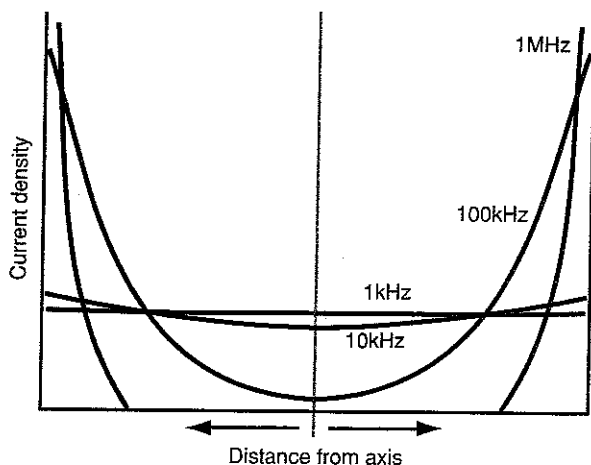
Imagine a conductor comprising 55 uninsulated strands of 0.1mm diameter copper, such as RS356-167. This has a copper cross-section of 0.43mm² and an equivalent solid diameter of 0.74mm.

At high kilohertz and megahertz frequencies, this cable performs very much the same as 22SWG solid, with a diameter of 0.71mm which has, as predictable from theory, fractionally less rf resistance. A conductor made up of 15 strands of enamelled 36SWG, amounting to a cross-sectional area of 0.425mm², as opposed to the 0.43mm² of the 55 uninsulated-strand wire, has about half the rf resistance at frequencies in the 1 to 2MHz region. This is, I think, as high as you need to consider if you are interested in audio.

Note that these principles are not new. They have been known and applied since the earliest days of radio, in the form of Litz wire.

The facts

It is a matter of simple scientific fact that – to three decimal places – a conductor of 0.2mm outside diameter has negligibly more rf resistance at 100kHz than its dc resistance. What this means is that, up to this frequency, the current distribution is uniform across the conductor cross-section, thereby making oxygen-free copper and silver plating irrelevant for



Current distribution across a 2mm conductor at various frequencies demonstrates skin effect.

audio work.

At 1MHz the rf resistance is up by 9.5%, where silver plating and so on really do start to be useful. On the other hand a conductor of 2mm outside diameter has 2.625 times the rf resistance, compared with dc resistance, at the significantly low frequency of 10kHz.

Figure 1 from reference 2, illustrates this, and Table 1, from the same source, summarises some experimentally determined data. Of course, if a conductor of very large cross-section is used, the dc resistance, and consequently the rf resistance, will be low in comparison with the highly variable impedance of the loudspeaker load.

Domestic twin-and-earth cable of adequate cross-section may well be the most cost-effective route¹. In terms of power loss, rf resistance is irrelevant in audio applications. What matters is that the low output impedance of a good amplifier may not be seen as effectively damping hf loudspeaker transients.

In summary

What this boils down to is that cables made up of many strands of thin uninsulated wire offer no advantages over the same cross-section of solid wire, except mechanical flexibility. Separately insulated multistrand cable can offer genuinely superior performance.

It would be prohibitively expensive to make up a coaxial cable of which the outer braid was composed of insulated wires, commoned at each end, and with an insulated multi-strand inner, but this must be the ultimate cable. ■

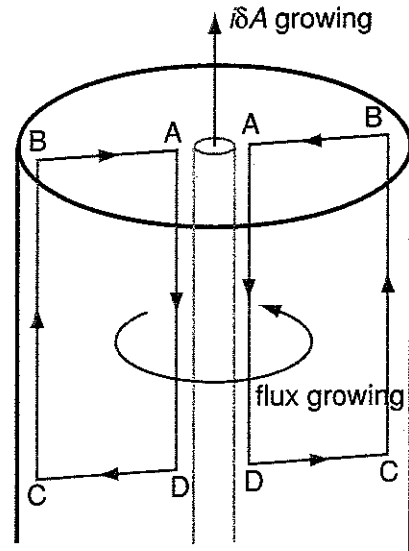
Reference

1. Speaker Cables, C. Bateman, EW Feb 1997
2. Services Textbook of Radio Volume 1 HMSO 1956.

Skin deeper

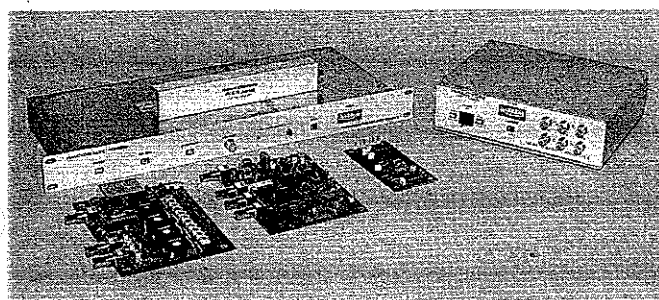
The following is an extract from reference 2.

Current density in this wire is iA/cm^2 . Current $i\delta A$ flows through an area δA on the axis of the wire and grows, creating magnetic field H . Through any radial section of the wire, such as ABCD, flux due to H is growing, resulting in an emf between A and D along the axis, and from C to B on the outer side. This emf tends to reduce current flowing along the axis and increase that flowing along the outside of the wire.



Skin effect. Any change in current along the axis causes induced voltages which oppose this change along the axis and promote it in the outer regions.

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