The Speaker Cable

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Abstract

How hard can it be to make a good speaker cable? Reasonably low resistance and any simple cable would do the job as good as any expensive high end cable - or maybe not?

Cardas, Kimber and Nordost just to mention a few cable manufacturers that have great knowledge have invested huge amounts of time over many years to make really good speaker cables. And they do. But still - there are more to be learned. Standard cables are very easy to make, but when we try to make really great cables the complexity increases more or less exponentially as we approach limits of what is physically possible. At this level we need to innovate to be able to push the limits. But to do this we need to understand the physics of electromagnetism. As it is hard to understand all the technologies and complexity behind really great cables this opens the door for snake oil and too much marketing BS. The purpose of this article is to share some knowledge on what is required for speaker cables to achieve a minimum of degradation of the sound.

Do not forget that cables can never improve the sound. It is about minimizing the degradation of the audio signal as much as is physically possible. And it is really hard to achieve nothing, as nothing in the real world is ideal.

Introduction

What are the most important characteristics of a speaker cable with respect to degradation of the signal?

Let us first assume that the amplifier can drive any cable, that the purity of copper in the conductors is at least 99%, that pure and only silver conductors are too expensive and that the cable is at least 2m long. The three most important parameters, without mutual order are:

Low inductance & **Low signal losses** & **Low resistance**

Inductance is getting more and more important the higher the requirements are on a neutral and natural sound. Low inductance is the most important key to minimize both phase shift and reactive power.

Low signal losses are always important. It is simply not possible to have a transparent sound with a cable with high losses. High losses come with insulation material like PVC so always look for cables with low loss materials like PTFE, FEP, PFA, PE or cotton closest to the conductor. To add air close to the conductor but still avoiding surface oxidation is a good enhancement to solid low loss material. To go all the way to zero losses requires in practice the patent pending Regal Zero technology or similar.

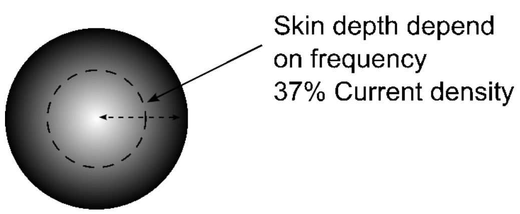
Too high DC resistance in the cable and the amplifier will not be able to control the speaker bass driver as accurately as intended. At least 2.5-3mm^2 should reduce these issues to a reasonably low level even if the requirement depends on the speaker impedance, cable length and amplifier output impedance/damping factor. But lower resistance is generally better, but in real life we have to find a good balance between resistance, inductance and skin effects.

The metallurgy is important but more so when the top three are managed well. As long as reasonably good quality connectors are used, this is also a fine tuning parameter. The skin effect could have taken a top three position if the cable designer was completely unaware of this effect. Then radial symmetry is more like fine tuning. Reducing the sensitivity to the environment is also valuable as the cable owner does not have to care so much about what is close to the speaker cable. Everything counts, but there is no point to start with fine tuning if the basics are not in place.

Radial Geometric Symmetry

The reason behind this section is that both current density and electromagnetic field symmetries affect the sound performance of a speaker cable. If the current density in the conductors of the cable varies with the frequency we get a nonlinear behavior and that results in distortion. If there are differences in the exposed electromagnetic fields between different parallel wires in the cable these wires will have different inductance and this will degrade the sound quality.

The skin depth for copper at 20kHz is about 0.5mm. But note that the definition of skin depth is that it stands for the depth in a conductor where the current density is 37% of its value at the surface of the conductor. The skin effect depends on the magnetic flux that induces a current in the conductor. This induced current is called eddy current. The skin effect increases the effective resistance of a conductor by reducing the cross-sectional area available for conducting current. The most common solution to reduce the skin effect is to use Litz wires. Litz wires have several thin and typically individually isolated conductors instead of one thick solid conductor. It is quite common that a speaker cable consists of multiple Litz wires.



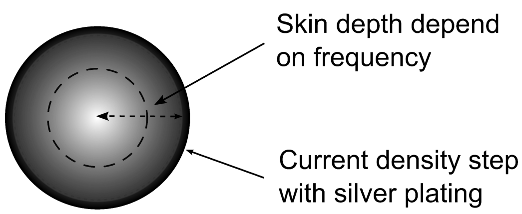
Skin effect with pure copper or silver

Next level of symmetry is the electromagnetic field symmetry. All wires in a cable create their own fields due to alternating current and voltages. If these fields interact differently between different wires in the cable this will end up with an inductance asymmetry. To address this, it limits the scope of cable geometries to circular ones. But this does not solve the whole problem. To have really good field symmetry and at the same time take care of the skin effect we have two options. Either we have to compensate for the differences in the field by the type of constant Q (L/R) relation or we have to make the conductor like a tube. A pretty good alternative to a tube is a hollow Litz construction. The picture on the last page of this article is a reference that shows some examples of different Litz constructions.

Cable Metallurgy

Speaker cable metallurgy has got an unproportional big attention on the market. Metal properties do affect the sound, but as long as the copper is reasonably pure the biggest sonic difference within metallurgy is between copper and silver. There are several alloys including other metals on the market, but so far, these do not contribute to the minimizing degradation of the audio signal in speaker cables. More the opposite. But even if there are clear differences in sound between copper and silver conductors, metallurgy is not within the top three of important aspects for speaker cables.

Silver with a high purity is optimum from a conductance point of view, but in most cases not feasible from a cost perspective. Silver plated copper will have an effect on the sound due to an increased skin effect. The sound in cables using silver plated copper can be a bit bright or thin. If plating is needed due to risk for surface oxidation, tin or gold plating are interesting alternatives that actually will compensate for some of the skin effect due to higher resistance than copper. It shall be noted that the skin effect is a gradual effect where the skin depth decreases with frequency.



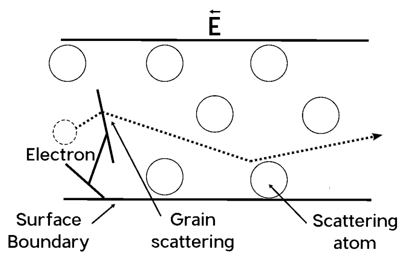
Skin effect with silver plated copper

An alternative to pure copper or pure silver is to have some wires in the cable made of solid copper with others of solid silver. This could work fine under some circumstances. As copper and silver have slightly different skin depth this should be compensated for if the wires have a diameter where the skin effect is relevant.

It seems like there is a slightly different behavior between copper and silver when an applied electric field starts to move free electrons. Does not affect amplitude or frequency response. The full answer within this area is not yet revealed and further research is needed.

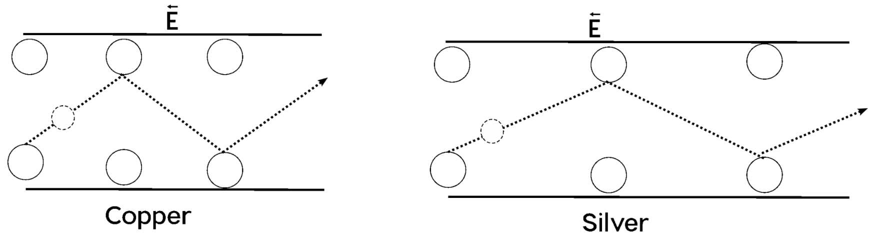
Much has been written about the importance of high purity copper - and silver. From a pure theoretical point of view there are clear electrical benefits using a conducting material with fewer grain boundaries and less oxygen. On the macro perspective the result of such material is a bit less resistance. But this level of macro perspective cannot explain sonic differences between different purities of the same metal. If there are sonic differences due to different amounts of grain boundaries per length unit or differences that depend on the purity of the material we have to look deeper. Impurities like oxygen atoms cause electron scattering. This is a bit simplified explanation of the increased resistance with an increased level of oxygen in copper, but the same reasoning applies also to grain boundaries. Less grain boundaries will slightly increase the conductance of the metal. But if we really hear a difference it should be more differences than just conductance.

If we compare copper and silver on a microscopic level there is something called mean free path. This is the average free path for electrons that moves in the opposite direction of an applied electrical field before it hits an atom within the structure and in most cases bounce in some direction. It is the relative amount of free electrons and this mean free path that make up the majority of the resistance in the metal.



Electron scattering

High purity of copper reduces the electron scattering in the material. This is good, but copper will never reach silver due to its significantly longer free electron mean free path.



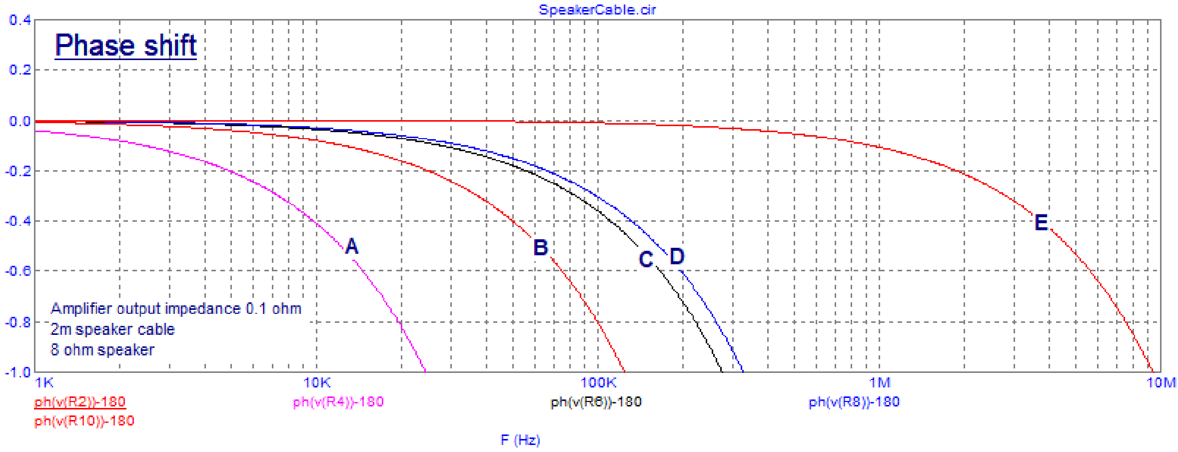
Electron mean free path in lattice structures

We have not yet been able to find the right measurements that correctly explains why we hear between silver and copper. This part of the story will continue..

Cable Constructions and Inductance

There is a term called reactance that can be either inductive (X_L) or capacitive (X_C). The unit for reactance is ohms. It is the reactance together with the resistance (R) of a cable that gives its impedance (Z). We calculate the impedance as $|Z| = (R^2 + X^2)^{1/2}$. As long as we have any reactance in the cable there will be reactive power when driving a speaker. And reactive power does not contribute to the work needed to move the speaker cones.
The inductive reactance ($X_L = 2 * PI * F * L$) also contributes much more to the phase shift than the capacitance of the cable. The picture below compares different speaker cables with a pure capacitive load represented by a high capacitance cable (without inductance). This shows the effect of reducing the inductance vs capacitance when minimizing the impact of

the sound. The picture below shows the phase shift of the signal at the speaker due to speaker cable inductance/capacitance. It is assumed that the output impedance of the amplifier is resistive. An ideal cable would result in a straight line at 0 degrees.

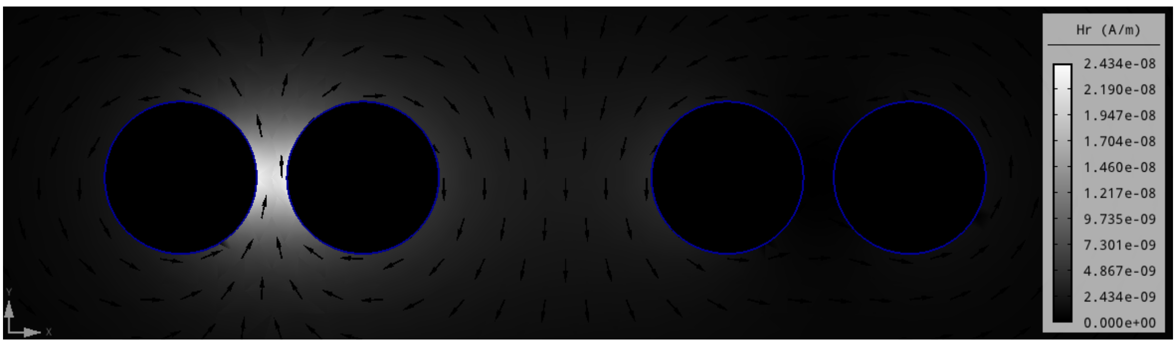


Inductance vs capacitance in speaker cables

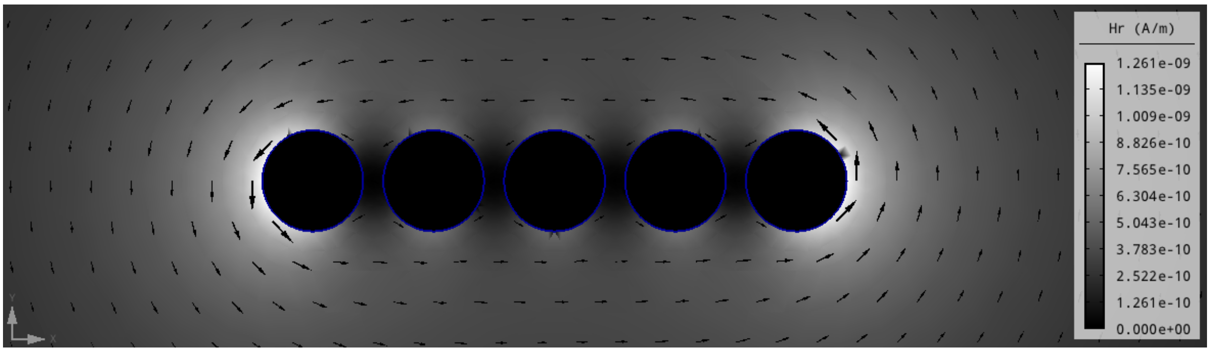
A - Low capacitance parallel wires (0,46 uH/m and 32pF/m)
B - Low inductance using braiding (0,09 uH/m and 435 pF/m)
C - Regal - Zero^2 Reference (0,04 uH/m and 664 pF/m)
D - Lowest inductance and high capacitance (0,033 uH/m and 1463 pF/m)
E - Ideal cable with no inductance but high capacitance (0uH/m and 1500pF/m)

High inductance causes time related distortion and reactive power with audible effects like poor definition of details and unnatural transients. The effect of the reactance is reactive power as the voltage and current are not exactly in phase with each other. Reactive power does not contribute to the work of moving the speaker cone. It is also known that if the inductance between different wires in a cable varies, the sound performance will degrade to some extent.

There are different methods to reduce the inductance in a cable. Parallel wires in a flat cable (like Nordost) or in the form of round Litz-type of cables are common. Braiding used in Kimber and Iconoclast cables use field cancellation to address the same problem. The challenge is to avoid secondary effects that affect the sound when reducing the inductance. Field cancellation is far more efficient than parallel wires, but this will always increase the capacitance. In more advanced cables it is common to combine different methods.

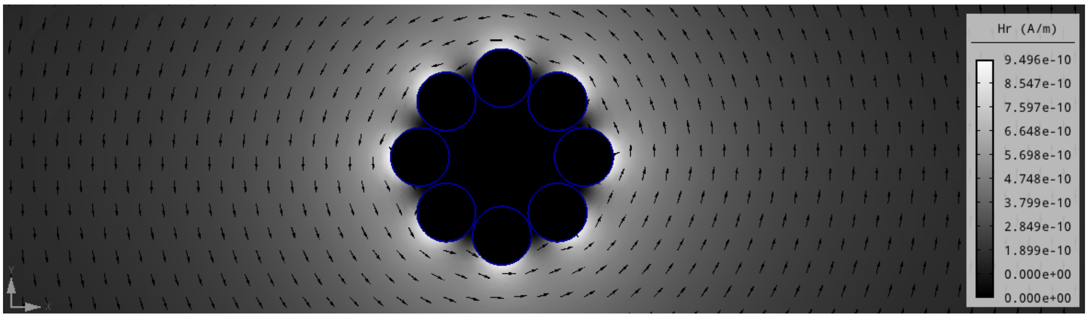


Left are two wires with opposite direction of current. The right wires show the configuration typically used for flat cables where opposite current wires are separated by different cables.
In the case of parallel wires laid out as a flat cable the outer wires create a non-symmetry in the magnetic field. The outer wires in the cable will have a different inductance compared to the others. The relative problem with this asymmetry is reduced with an increasing number of parallel wires.



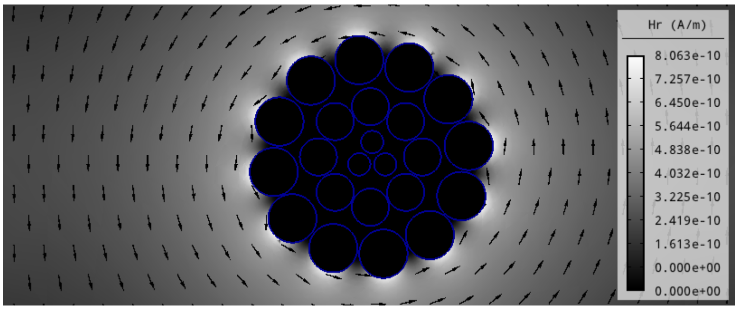
Asymmetry in the magnetic field with parallel wires

Litz type 1-4 (see page of this article) have a similar problem where the fields from wires in close proximity affect each other differently. This is a common problem with flat wires, that they are not symmetrical. Litz type 5-6 reduces this problem by having a circular geometry, isolated bundles together with a non-conducting core. The effect of good symmetry is that all wires in the cable have nearly the same inductance.



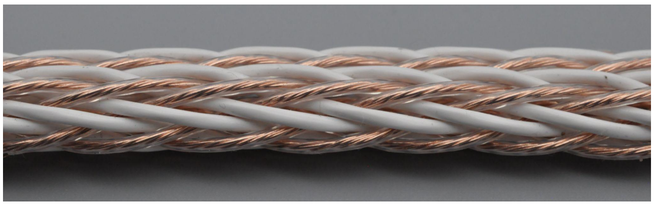
Litz type 5-6 creates a magnetic field that is the same for all wires.
Note: The fields in the center cancel each other.

One solution for symmetry is the constant Q concept (by George Cardas) with several layers of conductors where the diameter of the wires increase with each added layer. The aim is to get the same Q-value (L/R) for each wire on each layer. On the positive side with this construction is that the cable has a large conductive area per area cable. A minor drawback with constant Q geometry (also called golden section) is the different skin effects for each layer of wires, but as long as the diameter of the wires on the outer layer is not too large, this should not be a problem. According to the simulation below, the diameters of all inner conductors should be the same for constant Q as the magnetic field is canceled.



Magnetic field using Constant Q design concept by Cardas

Another strategy to minimize the inductance is to use braiding to cancel out some of the self inductance of the wires in the cable. This strategy is used by Ray Kimber. A very efficient method to reduce inductance that is also used by Galen Gareis for the Iconoclast speaker cables. Good field symmetry should be possible with this kind of construction.



Kimber 12TC

A recent development in the area of canceling self inductance is the Zero^2 (REGAL) technology. This is a development from Litz type 5 but with significantly lower inductance. A consequence of an efficient reduction of cable inductance by self inductance cancellation is an increase of the capacitance. This applies to all types of solutions.

Another direction in the development of Litz-based solutions is the in-akustik Reference AIR. This is a Litz type 6 cable with insulated bundles of Litz type 4 wires that are connected in parallel using separation disks. These discs maintain a well defined distance and a significant amount of air between each Litz wire. The result is low capacitance and low losses but the inductance is relatively high.

Cable Capacitance

Does the speaker capacitance affect the sound?

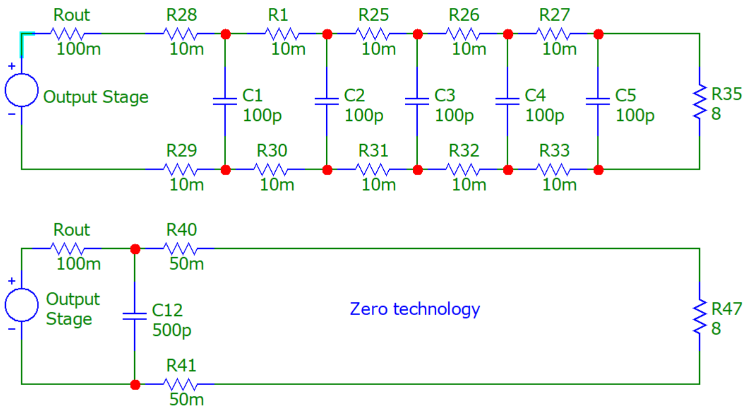
We have to include the amplifier output stage to find out if speaker cable capacitance in itself has an impact on the sound. But before doing this we need to understand that with capacitance comes signal losses that depend on the dielectric characteristics of the insulation material in the cable. This means that a cable with relatively low capacitance can have high signal losses and vice versa. And signal losses directly affect the sound quality. Two good examples of different cable constructions but both with low capacitance and relatively low signal losses are the in-akustik Reference Air and the Nordost Valhalla 2 speaker cables.

Most output stages of solid state power amplifiers have an output impedance within the range of 0.001 - 0.3 Ohms. While on the other end a SET output stage may have in the area of 3 ohms output impedance. If we have a 2m long very high capacitance cable like the Cardas Clear Beyond, the table below shows that even though the cable capacitance is as high as 3nF, the attenuation and phase shift is still negligible. With a combination of long speaker cables and a very high output impedance of the amplifier there can be a good idea to look for cables that have a bit lower capacitance.

Output impedance	Attenuation at 20kHz	Phase shift at 20kHz
0.3 ohm	-0.000000056 dB	0.0065 °
3 ohm	-0.0000056 dB	0.065 °

High capacitance may however affect the gain and phase margin of amplifiers with a feedback loop (it is very common that amplifiers use more or less negative feedback). If the designer of the amplifier's feedback loop does not take into account the capacitive load of a speaker cable this can affect the phase or gain margin so that the feedback in the amplifier becomes an oscillator. This can potentially cause damage to the amplifier/speaker. It is well known that at least some amplifiers from Naim suffer from this problem meaning that recommendations from the amplifier manufacturer regarding maximum load capacitance must be kept. It shall be noted that it is not hard to make an amplifier stable enough to be able to drive any type of speaker cable.

The measured capacitance of a speaker cable is the capacitance that can be called the load capacitance. It is a capacitive load as seen from the amplifier output stage. In almost all cables this capacitance is distributed along the signal conductor of the cable according to the picture below. However, this is not the case with cables using Zero technology, where this capacitance shall be seen as a pure load capacitance that is not distributed along the signal conductor. See picture below.



Standard cable vs Zero technology cable (Patent protected design)

The conclusion regarding speaker cable capacitance is that as long as the amplifier is stable there is normally no impact on the sound by the capacitance. However, the dielectric constant in the insulation material tells how hard it is to polarize the material via an electrostatic field. This polarization is not ideal and generates friction on an atomic level. The amount of friction depends on the molecular structure of the material. As an example the fluoropolymer PTFE has a very rigid molecular structure and this minimizes friction losses due polarization. The dielectric loss tangent is the measure of this kind of losses in the insulation material, but more on this in the Signal Losses chapter.

Cable Resistance

Is lower resistance always better?

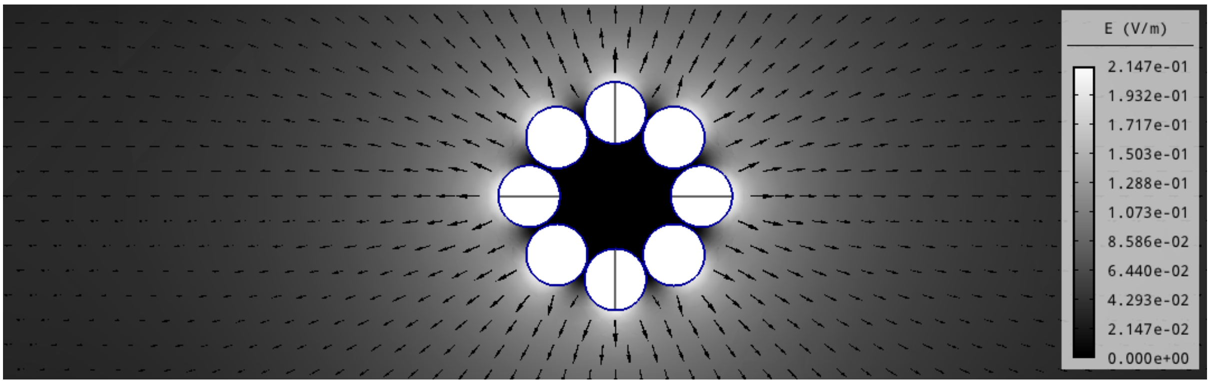
Yes, but there is nothing for free. With increased total conductive area of the cable comes other problems that may degrade the sound quality. Increasing skin effect due to larger diameter wires and increased inductance will in many cases at a certain point overtake the advantage of reduced DC resistance. But, as long as the inductance and the skin effect is kept at low enough, there is generally speaking no disadvantage in lowering the resistance. Of course there are other aspects like costs, weight and flexibility that are limiting factors.

What resistance is required as a general minimum for a good cable depends on the length of the cable, the speaker minimum impedance and the amplifier output impedance. At least $3mm^2$ should be recommended for a high-end system. A relevant comment should be that the resistance does not degrade the signal in itself, but high resistance will degrade the sonic performance in the base region due to relatively high currents.

Signal Losses

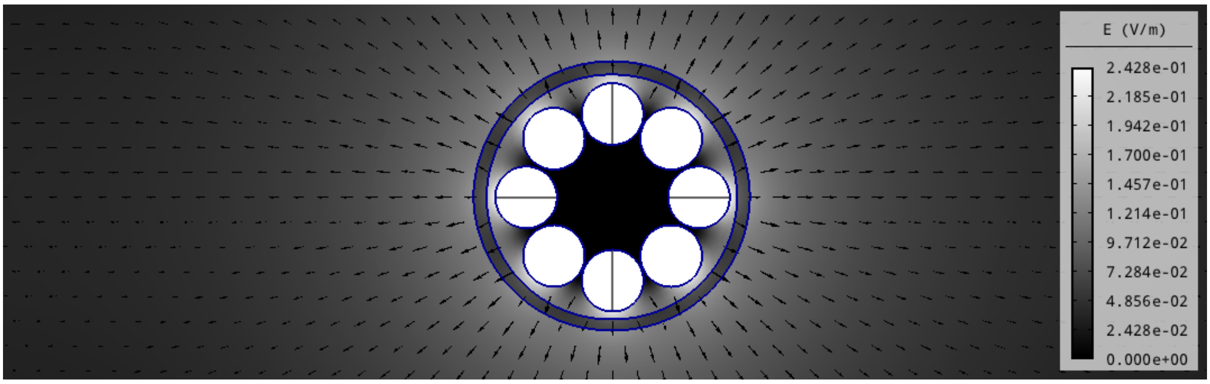
It should be obvious that all kinds of signal losses should be minimized in a good speaker cable. It is really important to understand that signal loss is one of the top three aspects within a speaker cable. There are many cable manufacturers that provide really good cables that have signal losses as top priority in the design. One example is Nordost, but there are many more. The reason is that it is impossible to achieve low degradation of the signal with high losses.

There are several types of signal losses in a speaker cable. Some are “losses” that occur due to reactive power and resistive losses, but also losses that occur in the electrostatic field around the cable. Alternating voltages generate electrostatic fields where any kind of insulation material close to the conductor will cause more or less losses. An electrostatic field in air is practically free from losses and this is the reason why many cable manufacturers add as much air as possible close to the conductors.



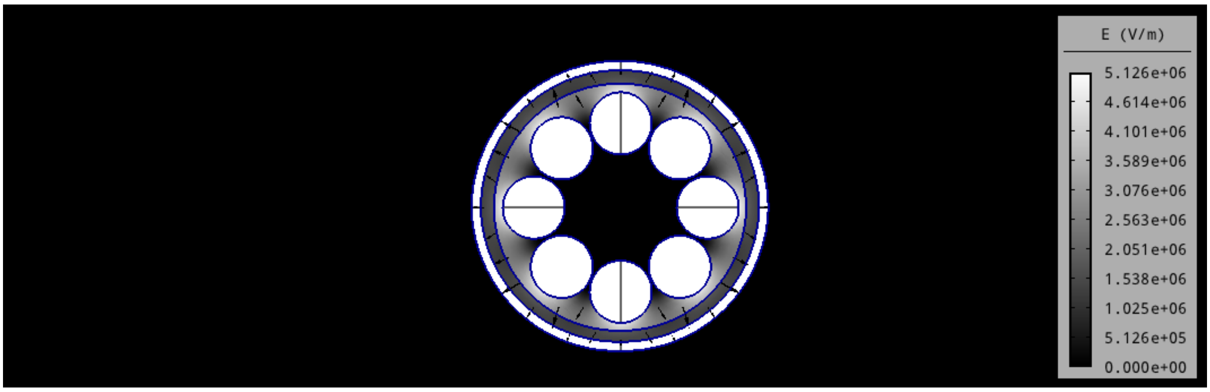
The electrical field from a Litz type 5-6 wire in open air.
Note: The electrical field in the center core is zero due to cancellation.

The most important thing to know about losses that occur in the insulation material is that they more or less affect the whole audible frequency range. The level of loss in different materials is described as the dielectric loss tangent in material specifications. Among common materials for insulation PTFE (Teflon) is the best from a signal loss point of view. Followed by various fluoropolymers like PE, PFA, FEP and others. Polypropylene is one one few polymers without flour that have a really low dielectric loss tangent. One of the worst insulation materials with respect to losses is PVC. PVC close to the conductor should be avoided in any high quality cable for analog audio. We have measured significant losses due to PVC even at a few millimeters distance from the conductor. The consequence is that PVC should not be used in high quality speaker cables unless there is a shield between the signal carrying conductor and the PVC material. To get a perspective of the importance of low loss insulation I made a listening test on a OCC-copper speaker cable that turned out to sound very far from transparent. I was very surprised how poor this cable sounded compared to, for example, Kimber cables. It turned out that there was PVC in the insulation. Then I tried with a lamp cord of the same length (similar area). It was about the same level of performance. This does not say that copper purity is not important. It just says that the insulation material is much more important.



The electrical field is passing through the insulation material, here PTFE with a dielectric constant set to 2.1.

The dielectric constant is the more known electrical property of insulation materials. This gives an indication of the dielectric losses but is typically used when calculating the expected cable capacitance. Cable capacitance is discussed in a separate section of the article, but the capacitance in itself is only relevant to the sonic performance together with the output impedance of the amplifier. The capacitance does not in itself cause any signal losses, but the polarization within the insulation material does. Adding a shield prevents the cable from EMI but it also makes the cable insensitive to the floor or other non-conductive materials.



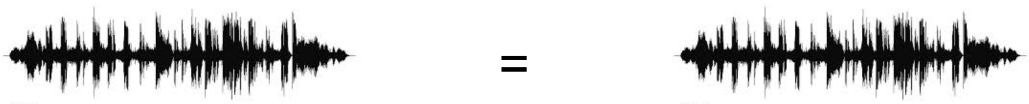
A shield around the Litz type 5-6 cable prevents leakage with respect to electrical fields but also protects the wires from external RF electromagnetic radiation.

The whole high quality audio cable industry searches for the best material or combination of materials with the same goal. To minimize losses. Even if manufacturers do not know in detail why insulation materials matter, they often use good materials like PTFE. At leased closest to the conductor. Many cable manufacturers want to go a step further by adding air close to the conductor. This has two advantages. The capacitance is reduced and the losses are reduced as air has very close to zero losses. Nordost twists a thin PTFE wire around the conductor to get as much air around the conductors as possible. Several manufacturers like for example Cardas use tubes inside the cable to add air. Cutton is also a popular material for the same reason. Foamed PE has been a standard in RF cables for many years, but works well in audio cables as well.

The root cause of the problem with signal losses in insulation materials is the electrostatic field that causes polarization and more or less losses depending on the material loss tangent and the amount of air close to the conductor. This is solved by REGAL in the Zero technology that cancels the electrostatic field. The consequence is that there will be no polarization and therefore no losses with this patent pending technology.

Phase Coherence

Phase coherence is an underestimated property that needs to be addressed in all areas where it is relevant in order to minimize degradation of the audio signal. Phase coherence within a cable means that regardless of the frequency the phase relations of all frequencies within the signal stays the same. But why is phase coherence important? Our hearing apparatus is very sensitive to time related distortion as this will alter the character of the sound itself. And we as humans have developed a highly sensitive ability to hear the smallest change in the character of a sound from an acoustic instrument or a voice.



Relevant properties to achieve good phase coherence are inductance, capacitance, electrostatic fields, electromagnetic fields, metallurgy and the geometries of the conductors. The complexity of making a very good speaker cable starts about here. We need to understand all these parameters, its dependencies and criticalities to find solutions where phase coherence is at an optimum within the design constraints we have.

The next level of optimization is to minimize asymmetries regarding these properties between all wires in the cable. And as we need to lower the inductance the only way forward with good symmetry is circular constructions.

All geometries within a cable will affect the electromagnetic fields around the conductors. The design goal should thus be to optimize the geometries to meet the design goal with respect to inductance and capacitance while maintaining symmetries as well as possible.

Even if the cable itself has good field symmetry the environment around the cable may disturb this balance. A good example is when a cable is laying on the floor, close to conductive materials or other cables. In some sense - if the cable is close to any material except air either of or both the electrostatic and electromagnetic fields will be affected.

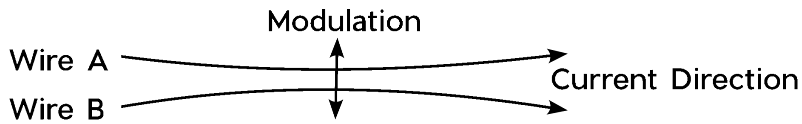
What many have heard by critical listening is that a certain cable seems to be affected by the proximity of other materials like the floor. Metal/iron can affect the magnetic fields so that the phase coherence is disturbed. Other materials like a wooden floor may result in significant changes in the loss characteristics of the cable. These dependencies have been verified both by measurements and field simulations.

Shielding can prevent impact on the electrical field but reduction of inductive coupling sensitivity can only be achieved via the cable construction itself.

Electromechanical Modulation

The current in wires creates a mechanical force that according to some creates movements between wires in a cable and that therefore affect the sound. But can this be a problem?

Two parallel wires carrying current will create a force that attracts them. Let us say that there is 1A in two wires in a cable consisting of several parallel wires. Assuming they are very close to each other (0.1mm), the mechanical force between these wires will be 0.002 Newton. This equals to a weight of just 0.2 grams. A movement between wires in a cable will affect the fields and thus the inductance.



Electromechanical modulation

But if this tiny force can cause a current dependent modulation is highly unlikely in a speaker cable. Regardless of its construction. So there is no practical relevance in that this kind of modulation can occur in real life.

This is one of too many examples where a theory is used as a “proof” for something that is not relevant in reality. These kinds of “proofs” can of course cause psychoacoustical effects, but I would consider this an example of snake oil. It is like if we were running on everything we see and not knowing what we are looking for. A bit more knowledge and we can go for the things that matter and enjoy music much more.

Cable connectors

If we assume that reasonably good quality copper is used as the base material in the connector, the very most critical part is the electrical interconnection between the metal surface of the speaker terminal and the connector of the speaker cable. The most important is that both connection surfaces consist of a metal that first does not oxidize and secondly has a good conductance. The best metals for connecting surfaces are gold and rhodium. Copper, silver and nickel are not recommended as surfaces. Especially copper but also silver will oxidize at the surface. Gold has the best conductivity but rhodium has a much harder surface. The choice between gold and rhodium is not significant from a sonic perspective.

To make a good electrical connection there are three parameters that are important. The contact materials, the contact surface area and the contact pressure. This is why spades are normally the preferred choice. But as long as there are good quality connectors with good materials, banana connectors work well too.

Break-in

How can a cable change its characteristics after some time of usage? First it is not about any type of molecular or structural change in the conductor or insulator materials. The reason for this effect is that there is an electrostatic charge on the surface between the conductor and the insulation that will gradually decay as alternating current flows through the cable - as it does when we use it in the system.

The break in time depends on the insulation material and the air gap between the conductor and the insulation. In general, it is often true that a better cable takes longer time to break in. But of course it is not as simple as that. The heart of the problem is the electric charge on the surface of the insulator material that is close to the conductor. Teflon, which is in many aspects the best insulation material, also has the largest electronegativity together with being a good insulator. It is this surface charge of the insulator that gradually reaches an equilibrium with the metal surface when applying an alternating voltage on the conductor. The rate of change depends on the insulation material characteristics, if there is an air gap and the voltage and mix of frequencies applied. Air gaps decrease the signal losses but increase the break-in time.

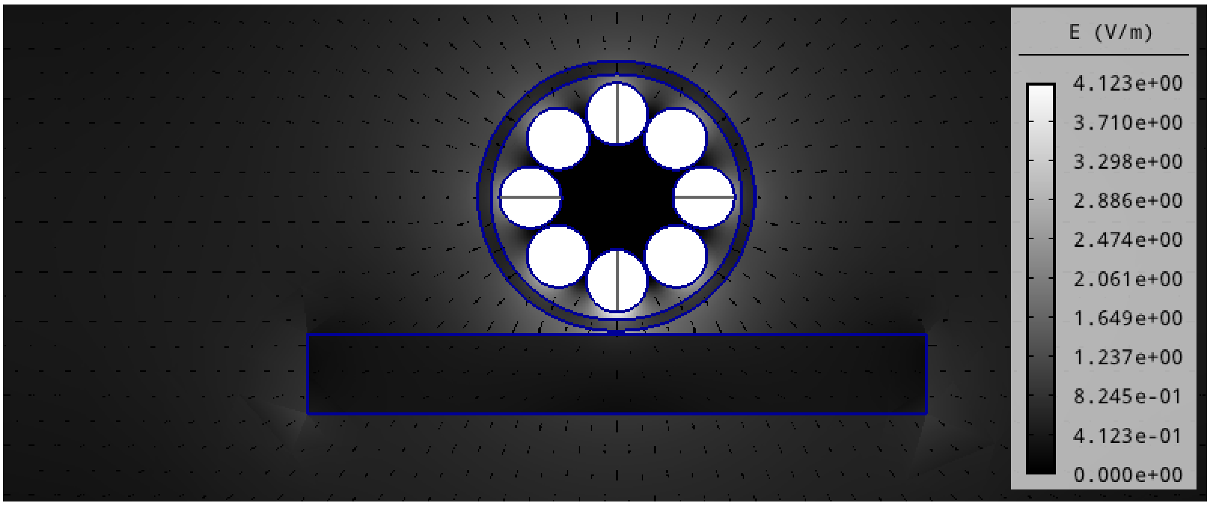
How to break-in a cable? Listening tests have shown that music or music like noise stabilize the sonic performance best. Listening tests with wide band noise do break in cables, but after a break in period with broadband white noise there seems to be a period of music or music like noise needed for the sound to stabilize.

Some argue that there is a time for cables to settle. Currently there are no scientific proofs for this, but as the same applies for electronics there might be something hidden in the dark. But we should not assume there is a time to settle just because musical instruments like guitars are said to have this. This is due to natural physical changes in strings and wood over time.

Cable lifters

For many people cable lifters seem just nothing but snake oil. For others cable lifters are said and believed to improve the sound quality.

Depending on the cable construction cables may be sensitive to the proximity to other materials. This is not limited to other cables or iron for example. Both measurements and simulations show that the electrostatic field around a cable can be significantly affected if the cable is laying on a floor. For low loss unshielded cable designs where some conductors come very close to the surface of the floor, an increase of dielectric losses of up to 600% have been measured using precision instruments. This level of impact requires that there is just a relatively thin insulation layer (in the tested cable PTFE) between the conductor and the floor. A cable construction that uses more or thicker insulation layer, this effect will be much less. Another way to avoid the risk of increasing the dielectric losses is to add shielding around the conductors.

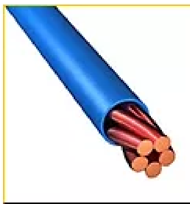
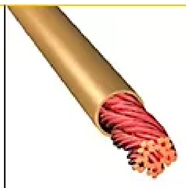
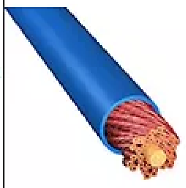
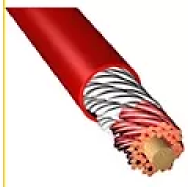
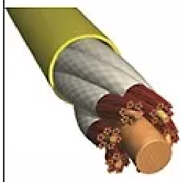
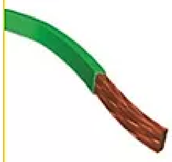
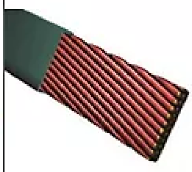


An unshielded cable on the floor will affect the electrical field and therefore the losses through this field. The dielectric constant of the wooden floor is set to 4.

The magnetic field can in a similar way be affected by other cables or iron that are close to the cable. However, the sensitivity to other materials depends directly on the cable construction. A shielded cable is much less sensitive to radiated high frequency electromagnetic fields but maybe even more relevant, less sensitive to the proximity to other materials (losses in electrical fields). However typically a shielded cable is still sensitive to induction or currents. This kind of sensitivity heavily depends on the twisting/braiding and similar techniques. The REGAL Zero^2 design has a HF shielding layer but also a construction that significantly reduces the emitted electromagnetic field strength. A cable that presents a low electromagnetic radiation is automatically less sensitive to EMI.

The conclusion is that in many cases cable lifters may be worth trying to get the very last piece of performance from the audio system. But the effect varies much between different cable constructions. The Zero^2 design uses shielding so its loss characteristic is therefore not sensitive to the environment close to the cable. The most sensitive type of designs seem to be low loss open braided cables like Kimber 12TC.

Standard types of Litz wiring

	Type 1 Litz Wire Single film-insulated wire strand, twisted with optional outer insulation of textile yarn, tape or extruded compounds.		Type 2 Litz Wire Bundles of Type 1 Litz wire twisted together with optional outer insulation of textile yarn, tape or extruded compounds.
	Type 3 Litz Wire Bundles of Type 2 insulated Litz wire twisted together with optional outer insulation of textile yarn, tape or extruded compounds.		Type 4 Litz Wire Bundles of Type 2 Litz wire twisted around a central fiber core with optional outer insulation of textile yarn, tape or extruded compounds.
	Type 5 Litz Wire Insulated bundles of Type 2 Litz wire twisted around a fiber core with optional outer insulation of textile yarn, tape or extruded compounds.		Type 6 Litz Wire Insulated bundles of Type 4 Litz wire twisted around a fiber core with optional outer insulation of textile yarn, tape or extruded compounds.
	Type 7 Litz Wire Film-insulated wire braided and formed into a rectangular profile with optional outer insulation of textile yarn, tape or extruded compounds.		**Type 8 Litz Wire** Compacted film-insulated wires or groups of compacted film-insulated wires twisted and compressed into a rectangular profile with outer insulation of textile yarn, tape or extruded compounds