

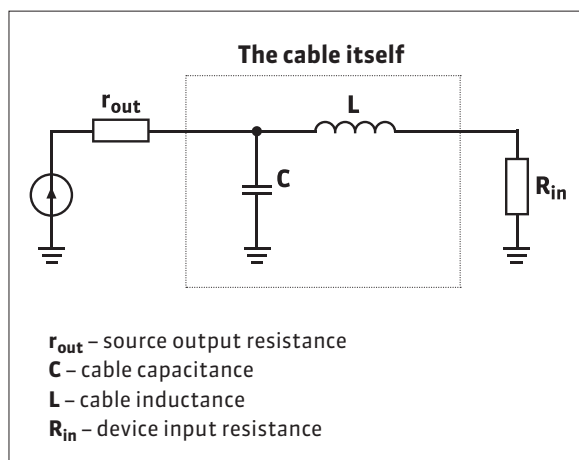
Audio Interconnect Cables

It's really quite simple, just not that easy to explain

IT IS THE GOAL OF THIS PAPER TO SHOW THAT THE Tunnelbridge™ design addresses and obliterates the most fundamental sound quality loss sources within audio interconnects, and to show how this is achieved.

Let us first try and understand what exactly, in electrical terms, a simple, traditional audio interconnect is. It is often held that an audio interconnect has only a negligible capacitance C and inductance L , because the output resistance of the audio signal transmitter is relatively low, and the input resistance of the signal input receiver is relatively high.

If we model an interconnect as a set of lumped parameters [1] (in other words, a low pass filter), the equivalent schematic of such a cable connected to the audio gear looks like this:



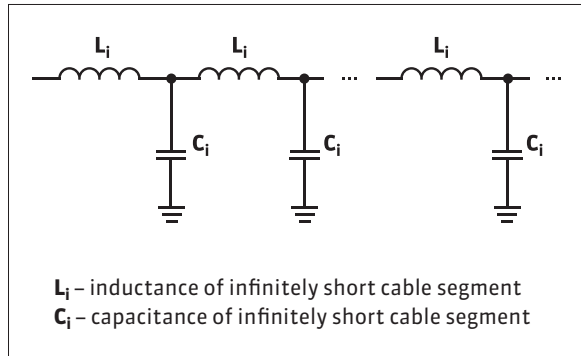
Because the resistance of the cable itself is so much smaller than the output and input resistances of the gear, we choose to discount this resistance of active loss, and we simply add it to the gear's resistance (i.e. the electrical resistance of a cable is many orders of magnitude smaller than the normal dispersion of 100k Ohm resistors incurred during manufacturing, which, in the best of cases, are manufactured to only a +/- 1% tolerance of accuracy, and nobody hears or can hear this amount of deviation).

“ then f , the bandwidth passed by the cable, is about 15 MHz

The bandwidth of such a schematic, influenced by its capacitance C , is equal to $f=1/2\pi r_{out}C$. And, influenced by its inductance L , is equal to $f=R_{in}/2\pi L$. Supposing a typical cable capacitance value of $C=100\text{pF}$ and $r_{out}=100\text{ Ohm}$, then f , the bandwidth passed by the cable, is about 15 MHz. Therefore, any typical cable, according to this model, should pass an audio signal from component to component without any noticeable frequency distortion. →

[1] **Lumped parameters** are a simplification in a mathematical model of a physical system where variables that are spatially distributed fields are represented as single scalars instead.
 For more see http://en.wikipedia.org/wiki/Lumped_parameters

However, if we consider a cable as a distributed series of small inductances and capacitances, which is what it in fact is because it has a length, the more accurate equivalent schematic now looks like this:



Here, L_i and C_i correspond to infinitely many inductance and capacitance values at infinitely small lengths of the cable [2].

The characteristic impedance of such a cable is defined as

$$z_0 = \sqrt{L_i / C_i}$$

If we connect such a cable into a system whose source and receiver were both also of this equal impedance, we would have a *matched* [3] line, in which we would not perceive distortion of frequency response nor of impulse response. However, there is no official standard of implementing matched lines in home audio applications. As a rule, the output impedance is made to be low, and the lower the better. The input impedance is made to be high, and often times, the higher the better. The aim of this is to create the best conditions for the first model we mentioned above, as a set

of lumped elements. That model is insufficient to explain the design merits of true high performance audio interconnects. In other words, you can still hear the difference between cables.

In a transmission line model, the source signal is introduced into the input end of the cable, and the other end is said to be “open.” This represents, in effect, a quarter wave resonator ($\lambda/4$) or *stub* [4]. It is often overlooked that this creates a very profound resonance at the frequency whose wavelength is about four times as long as the length of the cable. For example, if the cable is 1m in length, this large resonance will be around 75 MHz.

“ that model can't explain the design merits of high end audio interconnects

One other aspect which is often overlooked when describing the effect of an interconnect cable on sound quality is the spontaneous electric polarization or “memory effect” of the dielectric material situated in the electric field within the cable [5]. This effect is often taken into consideration when investigating the influence of capacitors on sound quality. We can notice and measure this effect by carrying out the following simple experiment.

First, charge an electrolytic capacitor, then fully discharge it by shorting its two leads for a few seconds. Unshort the capacitor and then quickly measure the voltage across the capacitor. What you'll see is that the voltage is at first zero, and then quickly begins to rise. The capacitor seems to “remember” that it was recently charged. Of course, a good capacitor should not exhibit such behavior. →

[2] The **Telegraph Equations** are from the 1880s.
 For more see http://en.wikipedia.org/wiki/Telegrapher's_equations

[3] For more see http://en.wikipedia.org/wiki/Transmission_line

[4] In microwave and radio-frequency engineering, a stub is a length of transmission line or waveguide that is connected at one end only. The free end of the stub is either left open-circuit or (especially in the case of waveguides) short-circuited. For more see [http://en.wikipedia.org/wiki/Stub_\(electronics\)](http://en.wikipedia.org/wiki/Stub_(electronics))

[5] Ferroelectricity is a spontaneous electric polarization of a material that can be reversed by the application of an external electric field. For more see: <http://en.wikipedia.org/wiki/Ferroelectric>

Detailed studies have shown that this effect is not limited specifically to electrolytic capacitors. Any capacitor whose dielectric material's dielectric constant ϵ is substantially larger than 1 portrays this effect, and, as it turns out, the larger the dielectric constant ϵ and, therefore, the larger the electric field inside the capacitor, the greater this *memory effect* [6]. Because a cable is in this regard a capacitor (simply unrolled), the same holds for loss of signal quality in cables. When the signal is no longer present at the cable source, it can “show up” somewhere in the cable at a later time. It is no wonder, then, that manufacturers of high quality cables emphasize the importance of the quality of the chosen dielectric material.

The Tunnelbridge secret is that there is no secret.

The architecture is that of a coaxial cable with two concentric shields. The signal is fed into the center conductor and the outer shield is the “ground”. The middle shield receives the same signal as the center conductor through a voltage unity gain buffer amplifier. The buffer's function is to protect the signal in the center conductor from loss and distortion arising from capacitance between itself and the outer shield. Because there is never any potential between the center conductor and the middle shield, there is also no electric field there. If there is no field, there is no capacitance; nor is there any spontaneous dielectric polarization. Thus, we have tackled the “memory effect.” The signal, without having been exposed to the electric field, now makes its way through the cable into the input socket of your destination gear.

We experimented with this concept and heard clearly that it works very well. Then we took it one step further. Where we first obliterated the capacitance of the center conductor to the ground by compensating the electric field there, we now managed to

compensate the center conductor's magnetic field as well. This aspect of our final design was the most difficult to achieve. As a result, the center conductor now has no magnetic field, which means that it also has no inductance.

“The signal never experiences capacitance or inductance in this design”

After many experiments with electromagnetic field simulation software, real cable models, and much audiophile gear, the results achieved surpassed our wildest expectations. It turned out that our theoretical model proves itself in practice. There was an obvious difference in sound quality when comparing the **Tunnelbridge™** with traditional interconnect cables made with identical materials. When a cable's dielectric is not influenced by both the electric and magnetic fields, its behavior is electromagnetic *neutrality*, meaning *non-influential* to the signal in the center conductor, which never experiences capacitance or inductance in this design.

Ooo. Electronics. Scaary.

Isn't a cable supposed to be completely passive? How about the dangers to pristine sound quality brought forth by the inclusion of active schematics in the **Tunnelbridge**?

There is no direct influence, because the signal which reaches the input of your gear never encounters the circuitry in the **Tunnelbridge™**. And the signal in the **Tunnelbridge™** which does encounter this circuitry never makes its way into your gear. The only function of the circuitry is to obliterate both the cable's capacitance and inductance which would normally affect the signal. →

[6] It can be noted here that the trend towards the miniaturization of electronics during the past half century has been made possible largely by extensive R&D into new materials with ever higher ϵ values.

Let's put some numbers on it. If, for example, the **Tunnelbridge™** electronics would cause a 0.01% distortion of the powered **Tunnelbridge™** signal, then it would not cause a 0.01% distortion of the system; it would only cause a 0.01% rise in capacitance and inductance in the cable when compared to no cable at all.

We want to emphasize that we respect your audio signal's integrity the way the designer of your gear envisaged it. We assume from the outset that the signal which is introduced by your gear into the **Tunnelbridge™** is ideal. Even though the **Tunnelbridge™** is a powered audio interconnect, it does not amplify, correct, influence, nor in any way "beautify" the signal it passes. The function of the electronics associated with the **Tunnelbridge™** is merely to create ideal conditions for the signal to pass, completely unchanged, into the next piece of gear. Without the associated electronics, the cable functions as any other high quality interconnect.

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