BELDEN
SENDING ALL THE RIGHT SIGNALS

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TIME….

If you have spent plenty on cables you may well wonder WHY these cables are physically as they are. If care is taken to adhere to fundamentals, there are very good reasons for a physical design in audio cable, of both high (interconnect) and low (speaker) input impedance types. If we look at all the fundamental electricals through the audio band, is it any wonder every cable doesn't sound different? Let's see why that might be, and no magic need apply throughout this analysis.

What is happening in audio frequency ranges?
1.0 What exactly are we "moving" with zero distortion?
2.0 Current and Phase Relationships.
3.0 Electromagnetic wave propagation differences with respect to frequency.
4.0 Impedance and matching to a load at audio.
5.0 Capacitance and Inductance with respect to frequency.
6.0 Cable Capacitive and Inductive reactance properties rise and decay time distortions.
7.0 Current normalization / skin effect.
8.0 Dielectric effects.
9.0 AC resistance changes and frequency.
10.0 Cable symmetry issues.
11.0 Attenuation at audio.
12.0 Passive low pass filter effects.

If we look at pure tones; sinewaves, square waves, frequency and TIME are interchangeable. Math says that this is so, and there isn't anything new that explains that away. When we add TIME based distortion to the sound delivery system our ears are quick to "hear" the deterioration in fidelity based on frequency arrival time and phase coherence more than amplitude limitations (attenuation). How much is a cable responsible for this? The superposition of the 12 listed distortions (and there are more) are much more significant than any one taken on its own. There is truth to the concept that slew rates, or how fast a system responds (wider bandwidths), affect performance. A square wave is but a multiplicity of sine waves. Mathematically every frequency's characteristics, at every point in a cable can be predicted. Cable is far from perfect at moving electromagnetic wave through the audio band, however well we can calculate the accumulating TIME based distortion as the electromagnetic wave moves down the cable. Better designs minimize those distortions and place more or less emphasis on each one depending on the designer engineer's concept of audible influences. The fact remains, cable design is still driven by the DESIGN needed to reach the R, L and C values with minimal influences on tertiary elements. Can you hear a more fully optimized design? This is why we present these designs for audition.

1.0 ELECTOMAGNETIC WAVE PROPOGATION

The issue – What do we actually LISTEN to on a cable? What is the "root" reason to be for a cable?

Cables exist to move the "signal" from one place to another, but few really consider WHAT that signal is. The signal we "use" is the electromagnetic wave moving down the cable at the group velocity of propagation of the dielectric. OK, what did I just say? Imagine our wire surrounded by a donut with a hole in the middle! The electromagnetic wave is this donut. There is an ELECTRIC (E-field) around our wire too, but this field is attached to the donut radially, and ninety degrees orthogonally to the donut's circumference. To make the E-field, take a bunch of tooth picks and stick them all around the outside of the donut, that's the E-field.

Now we have two imaginary waves, one low frequency and one high, sitting there. To MOVE that field, electrons flow starts it happening. To keep it simple let's distort our wire to be a TUBE full of marbles (electrons) that has an inside diameter the same as the marble's diameter. To make the magnetic field move, and drag along the E-field with it, we apply an electromotive force (electrons / marbles) to the. When a marble is inserted into the end of the tube, the marble at the opposite end pops out as fast as the marble can be inserted into the send end of the tube. This "speed" is determined by the velocity of propagation of the dielectric, or the tube in our case. Something funny happens with the magnetic field though; it follows the PROGRESSION of the electron (marble) flow. When the marble is half way into the send end of the tube, our donut with all our toothpicks (the B and E fields) is halfway down the cable already! When the marble is inserted all the way in at the send end, the B and E fields are at the END of the cable. So the "signal" we use travels at the VP (velocity of propagation) of the cable, and NOT the speed of the electrons at all. Those move very slowly compared to the electromagnetic B and E fields. Now we have the donut at the end of the cable. But, we won't ever see a baker's dozen, or zillions more moving electrons appear at the same time at the opposite end of the cable if we carry more than one frequency concurrently since every frequency has a different VP through the audio band. All individual frequencies will have significant arrival time "distortion" between frequencies. In other words, every marble that represents a frequency in my example is inserted at a different speed (Velocity of Propagation) depending on the frequency the marble represents. Ideal cable should move a signal (now we know it is the B and E fields) down a wire at the same speed and shape at all frequencies. It doesn't.

2.0 Voltage and Current Phase

The issue – Current and voltage are locked into a phase shifted relationship, always.

The reactive properties of inductance and capacitance are responsible for a ninety degree time based shift in all electronics, not just cable. There is a common ditty about the current to voltage phase relationship that goes like this; "ELI the ICE man". It is a memory tool to remember that voltage (E) leads current (I) in an inductor (L) and that current (I) leads voltage (V) in a capacitor (C).

Why is this? A capacitor has to charge with applied current to reach a steady state voltage, so as the voltage potential increases the current drops. The current has to be there BEFORE the voltage potential hence current leads voltage in a capacitor.

An inductor resists current change when voltage is applied. Current reaches a steady state over TIME with applied voltage, so as the current potential increases the voltage drops. The voltage has to be there BEFORE the current potential hence voltage leads current in an inductor.

These two locked-in relationships lead to all sorts of other TIME based issues in cable and circuits. They are the variables that constitute PHASE in an impedance trace, for instance, and reactive TIME CONSTANTS that we'll cover later in the paper.

3.0 VELOCITY OF PROPAGATION ISSUES

The issue – VP varies the arrival time of signals moving down a cable. Signals should ideally leave and arrive at the same time and shape as they are sent at all frequencies.

Audio is in an electromagnetic transition band. This is the elephant in the room. It prevents cable from EVER being perfectly accurate when moving low frequency electromagnetic waves. The propagation constant, the speed at which the electromagnetic wave / signal moves down the wire's outer circumference, and not IN the wire, is determined by the dielectric material that the electromagnetic wave is predominantly traveling through. We can measure this effect directly and indirectly.

At RF, where life is way more consistent for cables, we can calculate the velocity from the DELAY equation. For Ethernet cables the following equation is used;

Delay EQUATION at RF

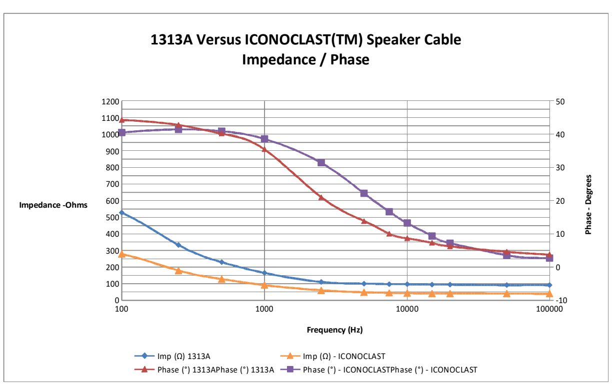
$$(534 + \frac{36}{\sqrt{f}})$$

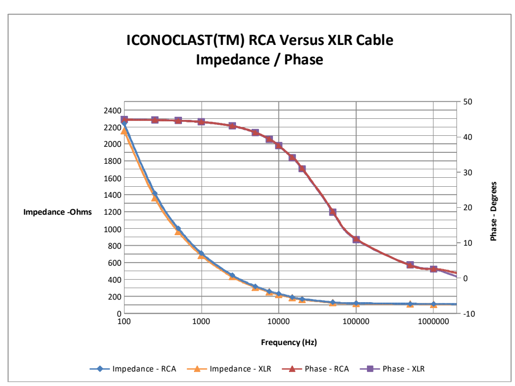
The delay equation uses FREQUENCY. This is a TIME based value so it tells us that we have an arrival time issues as the frequency changes, and less so at RF, and WAY more so at audio frequencies. The table illustrates the slow erosion of speed as we reduce the RF frequency. A little change is evident but audio frequencies see much more change.

Delay values measured at RF (MHz)

Freq	Actual	Upper	Lower	BLU, WHT/BLU	ORG, WHT/ORG	GRN, WHT/GRN	BRN, WHT/BRN
0.772	1.112	573.139	-Inf	547.946	521.155	539.652	516.752
1.000	1.112	573.139	-Inf	547.946	521.155	539.652	516.752
4.000	4.361	556.239	-Inf	555.146	521.872	544.439	517.755
8.000	7.609	552.061	-Inf	554.637	520.768	543.830	516.410
10.000	10.045	550.358	-Inf	553.237	520.291	542.621	515.835
20.000	19.791	547.092	-Inf	550.812	517.962	540.236	513.588
100.000	100.191	542.597	-Inf	547.016	514.345	536.444	510.034
200.000	200.083	541.545	-Inf	546.097	513.486	535.523	509.177
300.000	299.974	541.079	-Inf	545.691	513.125	535.143	508.818
400.000	399.866	540.800	-Inf	545.449	512.906	534.904	508.624
500.000	499.757	540.610	-Inf	545.304	512.774	534.754	508.500
600.000	599.648	540.470	-Inf	545.195	512.695	534.656	508.414
625.000	624.824	540.440	-Inf	545.176	512.688	534.633	508.416

Actual data shows what audio cables do; the impedance RISES as we go LOWER in frequency, by a lot. This is because the DELAY / VP factor drops, and adds TIMING issues to signal delivery.





Above are actual traces of how ICONOCLAST performs across the audio frequency band vs. typical zip cord speaker wire (1313A) and out to RF, to prove a point. The impedance increases considerably below the RF frequency reference values. Those 87% and 90% VP factors we love to "hear", high VP, are clearly not valid in the audio band.

How significant is the VP change? In the example above we drop from ~110,000,000 m/Sec @ 20 KHz to ~5,000,000 m/sec @ 20 Hz or a factor of 22 times slower through the audio band.

To make matters worse, it is a LOG function so it is not linear. This is what physics has thrown into the design process. Can we hear this change? Attenuation at audio is a passive linear variable and considered to be insignificant (keep your cables short) but every variable keeps adding up to the overall actual performance.

Notice that the cable's impedance, made for audio not RF, flattens out @ ~ 50 ohms above 100,000 Hz (see the table below for the actual values). Just because something has an "impedance" (real and reactive L and C component) does not mean it is a transmission line.

Look at the low-frequency range. Isn't cable supposed to be the same at all frequencies or the same TIME base? The velocity constant at a frequency is TIME, so the fact that we see a difference indicates a non- linearity across the usable audio band. *The problem is that thing called propagation velocity (VP) or the speed that information travels at differing frequencies in the cable.*

The equation at audio compared to RF is more complex (wouldn't you know it!);

Z = sqrt((R+j*2*pi*f*L)/(G+j*2*pi*f*C))

impedance (Z),
capacitance (C)
inductance (L)
resistance (R)
conductance (G)

Using the general simplified RF equation, where all the extra stuff in the complicated impedance equation at audio goes to a one or a zero and drops out, we are left with; 101670 / (Capacitance x Velocity) = Impedance. At RF for ICONOCLAST speaker cable;

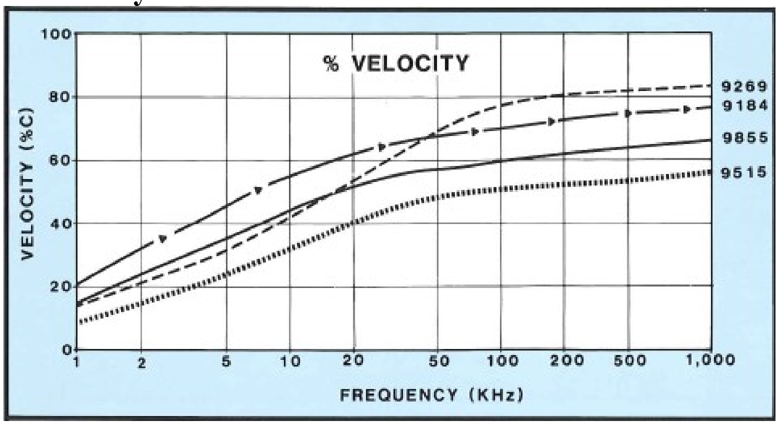
$$\frac{101670}{45\text{pf/foot} * (\text{velocity of propagation})} = 50 \text{ ohms @ RF}$$

Solving for velocity of propagation we see it is no higher than 45% at RF. This isn't RF cable, and the design changes necessary for audio are what ICONOCLAST is after. We need to ideally FLATTEN the VP curve for audio cables to better time align the signal in the frequency range where we use it.

The calculated graphs using a 75-ohm coaxial cable below show that VP change as we go lower and lower in frequency. Look at the IMPEDANCE at audio frequencies shoot way up, and the VP drop like a rock in a pond. Notice, too, that VP begins to flatten out at 100,000 Hz, just like the charts above on ICONOCLAST. This is real stuff, and it won't go away…you have to MANAGE it to a balance in each cable.

What does our measured data show that corresponds to the theoretical chart above? Below we see several BELDEN products measured VP drop considerably from RF to, and through, the audio band. And, the measured values are near the exact same values I will calculate from measurement on ICONOCLAST; ~ 5% VP to 50% VP between 20Hz to 20 KHz.

WHAT CABLE Velocity REALLY DOES THROUGH THE SWEPT FREQUENCY



The impedance goes up as we go lower in frequency because the velocity keeps going down, and the alternative variable, capacitance, just sits there (we'll get to that soon). We have a differential in signal velocity across the audio band. Also notice that typical 1313A ZIP cord behaves much worse than ICONOCLAST™, rising to double the ICONOCLAST reference impedance value. Be warned, audio cable does NOT respond to impedance matching like RF.

Speaker cables are theoretically designed to be much lower impedance, and terminate into reactive 2-16 ohm loads, and some point way north of 16 ohms. Interconnect cable is terminated into "high" impedance resistive loads of 47K to 120K or higher, and should be much higher theoretical impedance than speaker cable, and the graphs above show exactly that.

It is good to see impedance matching to a load, but other variables are in play, and impedance matching isn't meaningful or practical at these frequencies and impedances. Good designs usually address ALL parameters, however.

Interconnect and speaker cables, with VERY low audio range VP values show a much faster VP in the RF band. The values of 87% VP @ RF are NOT really correct for WHERE the cable is used, but "sounds" exciting.

What do we see at RF on an ICONOCLAST interconnect cable? We can calculate what we measured in the graphs above. We can use a grossly simplified equation to predict the VP based on capacitance measurements;

$$\frac{101670}{11.0 \text{ pf/foot} * (\text{velocity of propagation})} = 105 \text{ ohms @ RF}$$

Solving for VP we get a value of 88%, using the measured values of 1 KHz referenced capacitance. This VP factor will DROP considerably in the audio range to much LESS than that. Imaginary values (L and C) stay the same from 1KHz to RF frequencies so VP is changing;

101670

-------------------- = ~2000 ohms @ 100 Hz (audio)
11.0 pf/foot * (velocity of propagation)

INTERCONNECT
VP = 4.3% @ 100 Hz. (101670 / 2156 Ohms * 11pF)
VP = 57% @ 20 KHz (101670/163 Ohms * 11pF)

SPEAKER
VP = 2.17% @ 100 Hz 101670/ (278 Ohm * 45pF)
VP = 55% @ 20 KHz 101670/ (41 Ohm * 45pF)

If we take the VP reduction factor of a coaxial cable into the audio band @ 22 X lower, we see; 87% / 22 = 3.9% @ 100 Hz. Close to the same answer in our rough calculation.

The data shows a 13X to 20X or so DECREASE in cable speed as we drop in frequency. Signal arrival times are NOT staying in perfect symmetry relative to the input start point. The AMPLITUDE may be near the same, but the TIMING is certainly not. Arguments persist as to how long the cable needs to be to her the arrival time coherence.

4.0 IMPEDANCE AT AUDIO

The issue – All cables should terminate into their characteristic impedance (not really true at audio). At audio, the cable isn't a fixed impedance, or even really an "impedance". Interconnects see a resistive "infinite" load, but not speaker cables, which see a highly reactive low impedance load.

Impedance is a REACTIVE vector value. This is a dead giveaway that we'll have to deal with Dv/Dt stuff. All cables are a wire that is in series with an inductor and a capacitor to ground. All three R, L and C, keep getting bigger the longer the cable on a bulk value basis. The impedance is a VECTOR sum of the REAL part and the IMAGINARY part. The PHASE is created by the imaginary part of the impedance vector value. The impedance values aren't the same for all frequencies (see the 1 KHz and 1000 KHz chart below) since VP keeps changing, and this is a component of the impedance value. Since the impedance is a vector sum magnitude ratio, it stays constant for each frequency point no matter how long the cable is. R, L and C increase proportionally.

Reactive Change with Frequency

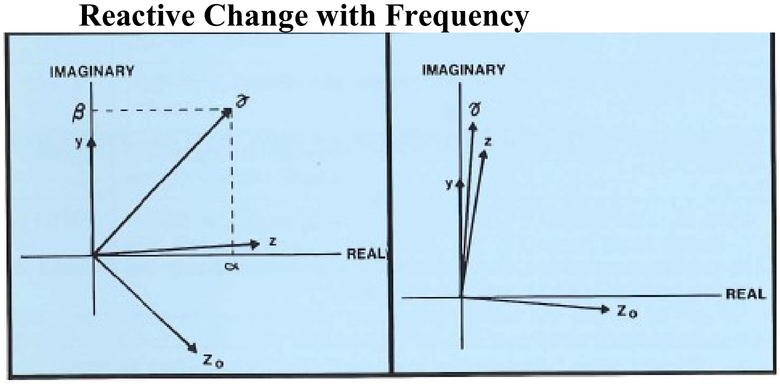


Figure 2. Angular Relation of Parameters at 1 KHz   **Figure 3.** Angular Relations of Parameters at 1000 KHz

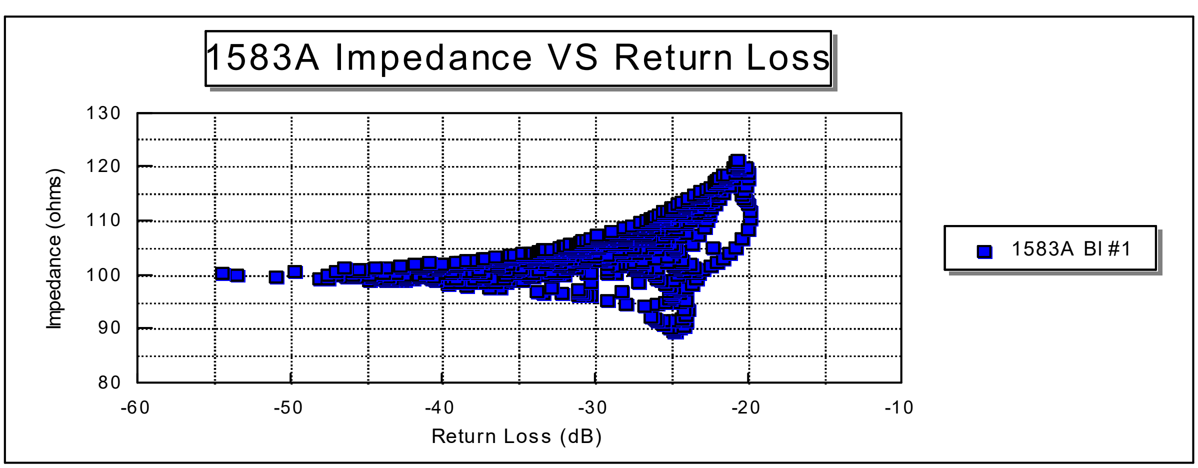
Most of us kind of know that we are supposed to match the impedance to the load for the best transfer of energy. We are actually only terminating the resistive component we call "impedance" to the load; a resistor in the case of interconnects, or a speaker load for low-impedance speaker cables. There is a reactive component that is also at issue for good signal transfer. That reactive (usually capacitive) part of the Impedance vector magnitude diminishes the transfer of energy in time. Audio is not RF, so this matched resistor to resistor ideal isn't exactly correct anymore, even for high impedance interconnects. The physics of the velocity of propagation make impedance matching impossible at audio as does the wavelength, which is far, far too long to react like a true "impedance" vector.

For transmission line effects to be a factor, the cable length also has to be at least 10X or more the quarter wave length of the frequency of interest. This relates to the fact that a voltage change has to happen BEFORE it gets to the end of the cable and audio speaker cables transit times are too fast, even @ 50% VP, for this to happen.

A cable can have impedance (real and imaginary values), but it is largely irrelevant to true load matching. There can be a signal reflection based on the CUT length of the cable relative to the speaker. This simple reflection can be absorbed with a ZOBEL network across the speaker terminals if it induces amplifier oscillations. But, low cap cables are benign to amplifiers, even with this simple length defined reflection. The cable will sound the same with or without the network as the parallel circuit is not in the signal path. The tertiary effect of better amplifier stability is what improves the sound with too high capacitance cable.

At RF, a signal is "used" efficiently only when two like resistive loads see each other. RF cables are designed so that the cable impedance matches the restive termination load. Audio cables don't work like this at such low frequencies since we can never transmission-line "impedance" match to a load with short passive cables. But, the "work" done across the load STILL has to be resistive. The imaginary components of a vector (Impedance is a vector sum of the real and imaginary components) store and release energy since they are composed of reactive variables; Capacitance and Inductance, both variables, are store and release variables of voltage and current respectively. Short cables still have reactance.

We can see what happens at RF. The graph below shows actual cable data of what is called Return Loss. The return loss, RL, represents the "reflected" signal that does not transfer to the load for an RF Ethernet cable. RL= the imaginary part that can't do work till it is "real" or resistive. Notice that we see several RL values "dead nuts" on 100-ohms from a low of -55 dB to a high of ~ -22dB. WHY are the RL variables not all the same? The impedance shows 100-ohms for all those RL values. The impedance at every frequency has a different reactance due to a lot of things too complicated to explain today. Simply put, at the frequencies with the lowest imaginary component, more energy is transferred to the load. In our example, if the impedance is above or below 100 ohm, and more or less reactive, the RL is decidedly worse. This is the cause of the FAN shaped graph that we see below.



Audio cables aren't used at RF, though, and suffer from simple reflections more than load matching ones. This isn't bad thing, as the critical attributes at RF aren't restricting what we need to do in the audio band for better signal quality. We don't need to worry about minute wire diameter fluctuations that cause the above graphed RL reflections. Audio wavelengths are too long to see the diameter variation issues so designers can work with geometries that may not be ideal at RF, but are far more useful for coherence adjustments in the audio band. Those adjustments still have to be real, of course, and measured or calculated with accepted standards.

Audio speaker cable with AC signals is terminated into a load that is resistive and reactive. Alternating current reacts to the imaginary circuit cable values and regulates how fast, and when, we can get work out of the cable. Some early cables were so reactive that amplifiers would shut off using them. Even though our cable is not a true impedance we do have reactive elements.

Interconnects see an "infinite" ideal resistive load; 47K-ohm on up, and speaker cables see a very low, and varying, reactive input impedance (the impedance of all loudspeakers changes with frequency).

Speaker cables are CURRENT signal devices that are designed to transfer power to an electromechanical motor. And, a motor that constantly "changes its spots" at every frequency as does the cable. The "argument" between the speaker EMF and cable is complex.

Interconnect cables are VOLTAGE signal devices terminating into a HIGH impedance resistor. We want to transfer the signal shape and amplitude to a load. To avoid distortion(s) we don't want the cable or the load to mess with the transmit circuit, but they do.

Audio cables are way too short to be transmission lines, needing at least 10X the wavelength inside the dielectric to be a true transmission line. Even 20 KHz is way too long a wave length to match that definition. We DO have simple reflections off the LOAD (speaker itself) that cable can't manage as the load varies with frequency. This is very different than RF where I can make a cable nearly look like the load, minimizing reflections. I said "nearly" as all cables exhibit reactance, a TIME based storage of energy. Audio cables have significant measured time based propagation error due to VP and now we add-in a rise time error from reactance. The reactance of cable can be used to calculate "time constants". At audio every frequency is associated with a different constant value. We'll look at time constants later.

Zobel networks have been used to good effect to dampen the cable to speaker load variation, but they are estimations of *where* the two are most aggressively reflective. A Zobel network is a passive means to connect two differing but fixed characteristic impedance lines with a resistive value. Neither the cable nor the speaker are linear loads making it an approximation as to where to tune the Zobel network.

For more on Zobel networks and speakers go to;
https://en.wikipedia.org/wiki/Zobel_network
Zobel networks and loudspeaker drivers

Compared to our "typical" Belden cable (blue trace), ICONOCLAST is flatter (orange trace) in velocity change as we go lower in the theoretical impedance. This is more the result of a higher, but still low, capacitance between the two designs. Lower inductance was preferred over capacitance.

The table data below is REAL and represent what even really good cables do through the audio band. The physics of the propagation delay match the measurements.

WHAT CABLE IMPEDANCE REALLY DOES

Unjacketed OF ICONOCLAST (10 ft)	Impedance			Phase		
Freq (Hz)	Open (Ω)	Short (Ω)	Imp (Ω)	Open (°)	Short (°)	Phase (°)
20	1.30E+07	5.31E-02	831.437	-71.4712	0.1092	-35.681
50	6.13E+06	2.34E-02	378.399	-78.0024	0.5847	-38.709
100	3.30E+06	2.35E-02	278.446	-82.1789	1.1697	-40.505
250	1.37E+06	2.34E-02	179.379	-85.7130	2.8502	-41.431
500	7.01E+05	2.36E-02	128.516	-87.4938	5.7346	-40.880
1000	3.54E+05	2.37E-02	91.512	-88.5236	11.3773	-38.573
2500	1.42E+05	2.60E-02	60.703	-89.1755	26.4832	-31.346
5000	7.13E+04	3.30E-02	48.525	-89.4053	45.1130	-22.146
7500	4.77E+04	4.20E-02	44.739	-89.4971	56.0905	-16.703
10000	3.58E+04	5.21E-02	43.188	-89.5401	63.0721	-13.234
15000	2.39E+04	7.33E-02	41.824	-89.6011	70.9411	-9.330
20000	1.79E+04	9.55E-02	41.337	-89.6160	75.1671	-7.224
50000	7.21E+03	2.32E-01	40.935	-89.6967	82.5690	-3.564
100000	3.60E+03	4.36E-01	39.607	-89.7270	84.3411	-2.693
500000	7.24E+02	2.10E+00	39.017	-89.8018	86.2472	-1.777
1000000	3.61E+02	4.12E+00	38.595	-89.8276	87.2161	-1.306
2000000	1.78E+02	8.22E+00	38.297	-89.8452	87.9051	-0.970

The interconnect tables follow and yes, they too show time based changes.

TPC RCA	Impedance - RCA			Phase - RCA		
Freq (Hz)	Open (Ω)	Short (Ω)	Imp (Ω)	Open (°)	Short (°)	Phase (°)
100	2.84E+05	1.77E+01	2239.533	-89.7951	0.1559	44.820
250	1.14E+05	1.76E+01	1416.868	-89.8583	0.3839	44.737
500	5.69E+04	1.76E+01	1002.241	-89.8940	0.7557	44.569
1000	2.85E+04	1.77E+01	708.941	-89.9185	1.5032	44.208
2500	1.14E+04	1.77E+01	449.059	-89.9263	3.7497	43.088
5000	5.70E+03	1.78E+01	318.582	-89.9081	7.4661	41.221
7500	3.80E+03	1.80E+01	261.538	-89.8837	11.1170	39.383
10000	2.85E+03	1.87E+01	230.807	-89.8583	14.8582	37.500
15000	1.90E+03	1.91E+01	190.161	-89.8020	21.3845	34.209
20000	1.42E+03	2.01E+01	168.887	-89.7443	27.5218	31.111
50000	5.62E+02	2.98E+01	129.434	-89.3716	51.6089	18.881
100000	2.70E+02	5.26E+01	119.122	-88.6282	66.4518	11.088
500000	5.01E+01	2.54E+02	112.734	67.2957	-74.4866	3.595
1000000	1.18E+02	1.04E+02	111.003	-72.9472	67.7165	2.615
2000000	3.23E+01	3.66E+02	108.703	-32.5630	29.7645	1.399

TPC XLR	Impedance - XLR			Phase - XLR		
Freq (Hz)	Open (Ω)	Short (Ω)	Imp (Ω)	Open (°)	Short (°)	Phase (°)
100	2.73E+05	1.71E+01	2156.372	-89.9058	0.1583	44.874
250	1.09E+05	1.71E+01	1364.011	-89.9219	0.3896	44.766
500	5.46E+04	1.71E+01	964.727	-89.9333	0.7669	44.583
1000	2.73E+04	1.71E+01	682.613	-89.9529	1.5243	44.214
2500	1.09E+04	1.71E+01	432.124	-89.9454	3.8062	43.070
5000	5.46E+03	1.72E+01	306.661	-89.9216	7.5737	41.174
7500	3.64E+03	1.74E+01	251.921	-89.8951	11.2643	39.315
10000	2.73E+03	1.77E+01	219.826	-89.8650	14.8582	37.503
15000	1.82E+03	1.85E+01	183.200	-89.8029	21.6463	34.078
20000	1.36E+03	1.94E+01	162.794	-89.7438	27.8432	30.950
50000	5.39E+02	2.90E+01	125.081	-89.3652	52.0070	18.679
100000	2.58E+02	5.16E+01	115.360	-88.6061	66.7865	10.910
500000	5.17E+01	2.36E+02	110.360	66.2911	-73.6695	3.689
1000000	1.09E+02	1.05E+02	106.807	-70.6409	65.5753	2.533
2000000	3.28E+01	3.42E+02	105.898	-24.4279	23.6929	0.368

5.0 CAPACITANCE AND INDUCTANCE

The issue – What do the reactive variables do with respect to frequency?

Capacitance and inductance are essentially FLAT with frequency. Yep, capacitance and inductance are, interestingly, the same from near DC to the “sky is near the limit” frequencies. Capacitance is set by the dielectric, assuming it is a linear dielectric material, and some aren’t (PVC). Measurements show that stable dielectrics offer frequency linear capacitance. Inductance is set by the distance between the wires and the loop area; it isn’t changed by the dielectric at all. These two values are always steady Eddies, but their time based effects on current and voltage change with frequency.

Here is ICONOCLAST speaker cable that shows L and C data, and it is FLAT with frequency using Teflon® as the dielectric.

	Ls	Cp
Units:	µH/ft.	pF/ft.
Freq. (Hz)		
100	0.084	44.84
1000	0.080	44.69
2500	0.079	44.65
5000	0.079	44.61
7500	0.079	44.60
10000	0.079	44.59
15000	0.079	44.57
20000	0.078	44.55
50000	0.078	44.50
100000	0.077	44.47
200000	0.074	44.59
500000	0.071	44.45
1000000	0.070	44.53

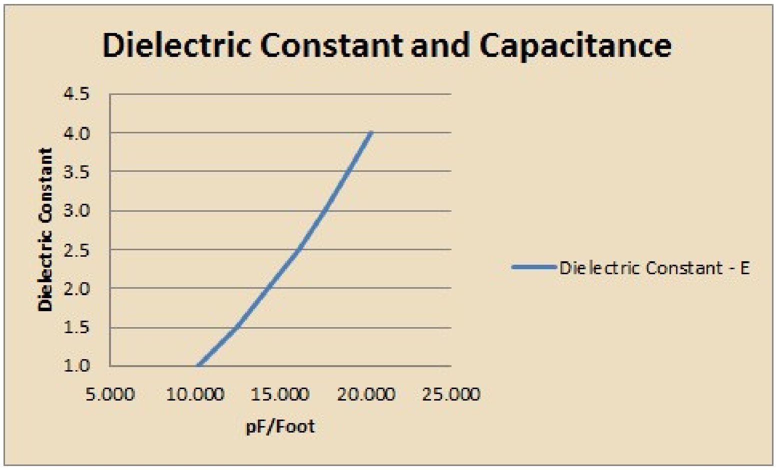
The choice of what plastic to use sets the dielectric constant. You want stability with respect to frequency. Teflon® has the lowest dielectric of any SOLID plastic and thus the lowest capacitance with the thinnest walls of any material and, it is durable. It costs a LOT to buy and process, too. Cost isn't why we use it, performance is.

Plastics aren't magic for capacitance, that is just the way it is. You want to pick the lowest dielectric constant value not just for low capacitance, but to help offset the change in the dielectric constant with respect to frequency. PVC dielectrics are far worse in linearity with respect to frequency, and the slope is not the same everywhere. The chart and graph below assumes a set wall thickness and changes to the dielectric material alone. We can alter the WALL thickness based on the dielectric constant to get a given capacitance between two wires. Double the dielectric constant means doubling the wall for the same capacitance. Use the cheap stuff then? Sure, but more wall thickness increases loop area (space between the wires) which increases inductance! Oops, we're not going to get zero cable reactance that way! A wire in a vacuum inside a braid ground would be the smallest size with lowest capacitance you can realistically see. This design would also have the lowest inductance since the loop area would be at a minimum with the vacuum acting as a low dielectric material.

We can calculate the effects of the dielectric and capacitance using a shorthand RF formula 101670 / C *V. We fixed the reactive impedance to a set value, so for a fixed wall of insulation, the capacitance rises as the dielectric constant is higher. Since we know that the capacitance value is flat with frequency, this applies to the audio band as well. Better dielectrics for a given wall mean lower capacitance. This has nothing to do with Inductance, which is related to the magnetic field lines. Inductance is related to the distance between conductive surfaces, the less the better and field cancellation…if any.

Impedance = 100 ohms
Velocity = 1 / SQRT (E)
Capacitance = 101670 / (impedance * VP)

VP	Impedance	Capacitance		Capacitance (pF)	Dielectric Constant - E
100.000	100.000	10.167		10.167	1.0
81.650	100.000	12.452		12.452	1.5
63.246	100.000	16.075		16.075	2.5
57.735	100.000	17.610		17.610	3.0
53.452	100.000	19.021		19.021	3.5
50.000	100.000	20.334		20.334	4.0



6.0 INDUCTIVE AND CAPACITIVE REACTANCE VARIABLES, X_L AND X_C.

The issue – all cables store and release energy (current or voltage) reactively to the frequency being electromagnetically moved through the wire, adding time based distortion.

Look at the Impedance / Phase trace shown above on Part 3, Velocity of Propagation Issues. Notice that the PHASE on BOTH cables changes. PHASE include reactive components that TIME shift the signal's ability of a signal to become resistive (If the phase trace hits "0" the circuit is resistive and has no reactive component).

A capacitor looks like an OPEN to DC or to very low frequency AC voltage changes. The cable is very "reactive" to voltage changes at lower frequencies. As you go up in frequency the cable's bulk capacitance looks more and more like a SHORT circuit. The cable becomes more "resistive" looking with less reactance to voltage change. The trace explains why we can use 75-ohms and 100-ohm loads for RF cables, they look "mostly" resistive at RF.

Using a high impedance probe to measure the cable's reactance produces the traces that you see. There is little current flow into the cable and, this is essentially how interconnects are used. The terminating load is VERY high impedance limiting current flow. When you put a voltage across a capacitor (our cable) it sends a momentary inrush of current to try to fill the capacitor. Output devices loading the circuit are ideally super low impedance to allow for this "inrush current". Cables with lower capacitance mitigate the inrush current issue. Current LEADS voltage in a capacitor so there is a TIME shift caused by the cable.

Speaker cables are differing in that we don't measure them like they are used; terminated into what is essentially a short circuit, the speaker. The large current flow in speaker cables responds to reductions in INDUCTANCE. Inductors resist current flow changes and that's what speaker cables are trying to "move". Voltage leads current in an inductive circuit and again, we see a TIME shift caused by cable but the opposite reactive variable, inductance verses capacitance, than the interconnect cable.

Also consider that in speaker cables, the most reactive region is exactly where speaker's impedance is also the most reactive, too. We want is a cable that is purely resistive but that's impossible since a cable is a vector of capacitance and inductance.

Can we look at this another way? Yes, we can. If we examine the capacitive reactance equations below, and stick in the values at DC (F=0) and infinity frequency (remove F) and see what the results are we get the same answer; reactance is high at low frequencies and lower as you go up in frequency.

$Xc= \frac{1}{2} * pi * F * C$

$X_L = 2 * pi * F * C$

The inductive reactance is the opposite, it looks much smaller at DC (F=0) than at higher frequencies (F= infinity). An inductor is a SHORT at low frequencies and an OPEN at higher frequencies. Fortunately speaker cables are relatively lower frequency making things less severe than at RF.

Cables, and all circuits, have capacitive and inductive reactance. Capacitive reactance resists voltage change and inductive reactance resists current change. They are both frequency dependent.

The TIME it takes to CHANGE the signal applied against a reactive load is measured in TIME CONSTANTS. It takes about 5 to 6 time constants to reach steady state amplitude. Our signal is also distorted the longer it takes to reach steady state amplitude so it may get nearly as big (we'll pretend attenuation isn't an issue), but it isn't the same SHAPE. Don't forget, every frequency is associated with a different time constant, and the decay or removal of the signal is the inverse. It takes TIME for the signal to bleed away to zero and this alters the decay signal.

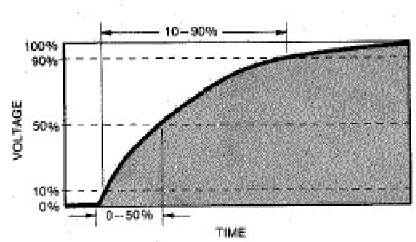
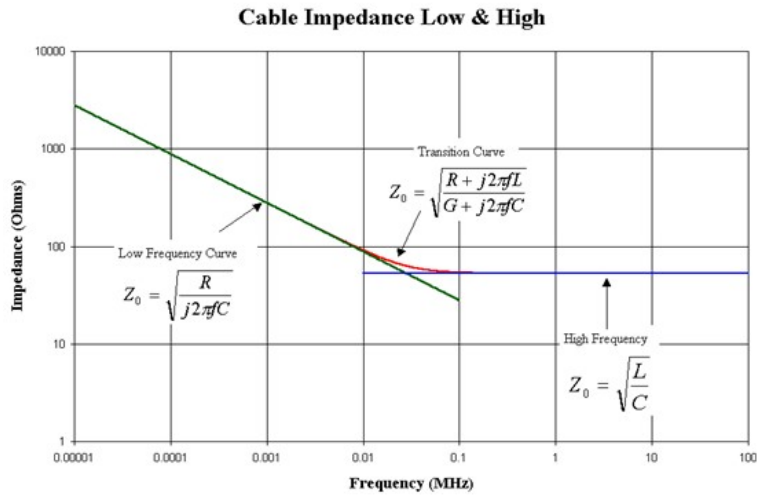


FIGURE 1. *Rise Time.*

As frequency changes, so do the reactive variables the determine a cabler's reactive performance.

At the very high end of the graph below, we see simply SQRT (L/C). At the low end the simple reactance (denominator) enter in.



7.0 SKIN EFFECT

The issue – Current magnitude normalization at audio frequencies. Is this real?

There are several ways to calculate skin depth, and they all will yield the same answer. Impedance / RL can be derived from several inter-related factors and so can skin depth. It is real, and it can be managed to control phase distortion.

We all know about skin effect, but WHAT exactly is it doing at audio frequencies and is it real? Yes, skin effect is real at audio and all industry accepted calculations show that it is. The definition of skin depth is the point inside a wire where the current decreases to 37% the surface current magnitude. Skin depth is always the same depth of penetration no matter the wire size. Skin depth will vary based on the material's electromagnetic properties and the frequency of the signal. For audio we calculate @ 20 KHz.

$$\delta_s = \sqrt{\frac{2}{\omega * \mu * \sigma}} = \sqrt{\frac{1}{\pi * f * \mu * \sigma}}$$

μ = permeability (4π* 10-7 H/m), note: H = henries = Ω*s
π = pi
δs = skin depth (m)
ρ = resistivity (Ω*m)
ω = radian frequency = 2π*f (Hz)
σ = conductivity (mho/m), note: mho [Electrical 'mho' symbol - RF Cafe] = Siemen [S]

At low frequencies it simplifies to;
δs = SQRT (2ρ/ ωu)

Looking at COPPER, we would calculate 461um (0.0181" depth).

If the skin depth at a given frequency is 10-mil on a 100-mil wire the 37% current point is well near the wire's surface, it's just 10-mil away in 50-mil radius. If we halve the wire size, the current magnitude is larger through more and more of the wire. Each time we decrease the wire size, the larger the current magnitude becomes across the wire relative to surface current. In our 18-mil skin depth wire example above, the current in the "center" of a 36-mil wire will see 37% the magnitude of the surface current. Making wire smaller will

INCREASE the current magnitude in the wire's center to be closer and closer to the surface current in the wire at higher frequencies.

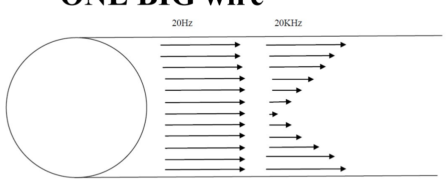
AC resistance involves FREQUENCY which is a TIME based variable.

R_{AC}= (R_{DC}) (k) SQRT (Freq)
K is a wire gauge factor that involves skin depth.
Freq is in MHz.

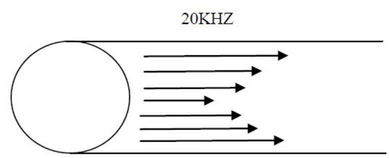
The internal wire impedance (AC resistance) is driven by the INTERNAL magnetic field's relationship to inductance. Inductors RESIST instantaneous current flow and have higher "resistance" as AC frequency goes up. Current flows in the least resistive part of the wire as frequency goes up, so it reaches the surface where the self-wire inductance is nearest to zero.

Once we flatten the velocity change as best we can with a good dielectric design, we need to ALSO time align the effects of the dielectric at ALL frequencies using SMALL wires. Small wire improves arrival times as it forces the effects of the composite dielectric speed to be more uniform, as best we can, at all frequencies. This counters the skin effect problem that moves the current density magnitude to the surface of the wire as frequency goes up. Smaller wire increases the current magnitude (arrow length) in the wire center region to make it more efficient at time alignment.

ONE BIG wire



More SMALL wires



Even if we have the SAME current magnitude throughout the wire at all frequencies (impossible unless our wire is one atom in size) the velocity of propagation of the electromagnetic wave energy is STILL different at every frequency! But the ears say if we MANAGE the problems, our cables can sound much better. I took the time to measure all of this and flattened the impedance trace as much as I could. The VP changes less with frequency the flatter the impedance curve. Capacitance stays the same at all frequencies, so this VP is therefore changing less the more consistent. Smaller wires are more consistent dielectrically at all frequencies.

Bigger wires will cause even more signal speed change relative to frequency because each electron's is far smaller inside the wire. Each magnetic field contribution changes velocity the closer or farther that electron is away from the dielectric material. When a current is applied (electrons start moving) an inner wire located high frequency current mode travels slower than the same frequency signal on the outer wire surface and all these current modes are superimposed one on top of the other. This is called group DELAY.

Not all signals at the same frequency arrive at the same time, it depends on WHERE they traveled (MODE path) through the wire and what the velocity of propagation is from the geometric perspective. The lower in frequency you go the less you can change the group delay since the current density through the wire is more and more consistent.

The overall magnetic field is a summation and superposition of ALL the moving electrons, the whole "group". This is also why air is often used in interconnecting cables to mitigate the dielectric's impact on the signal, and why you see more small wires in speaker cables. Electromagnetic field uniformity in the dielectric is important. The overall audible improvements are more debated. But, there is science involved in the optimization process.

8.0 DIELECTRIC EFFECTS

The issue – dielectrics can impact weak electromagnetic signals disproportionately. Electromagnetic fields are squared law fields, and are most influenced by dielectrics nearest the wire. Weaker electromagnetic fields are most susceptible to dielectric distortions and the group velocity is mostly set by the strongest signals dielectric medium.

Using too many small wires splits up the current and starts to allow the dielectric to influence the sound more and more, negating the "advantage" of dielectric uniformity. The electromagnetic field is strongest nearest the wire, decreasing with the square of the distance moving out away from the wire. The electromagnetic signal moves from being "in" the dielectrics to being around it. The signal propagation speed is an average of ALL the dielectrics, with the material the stronger fields reside in have the most influence on the average of the "group".

Four-fifths or more of the current magnitude at audio is below 3 KHz. Some call this the spectral power density, or roughly where the most energy is being placed. The electromagnetic energy does not STOP in the plastic or air. It emanates out in an inverse LOG power decay THROUGH all the materials it encounters along the way. The predominant material VP effect occurs CLOSEST to the wire. The smaller the signal (interconnect cables) the bigger the effect of the immediate dielectric nearest the wire.

Weaker signals will be impacted by the dielectric's effects more than stronger ones, as they decay to far weaker signals moving away from the wire. The speed is more and more determined by the dielectric near the wire as we go up in frequency. Interconnects see little of the plastic out away from the bare wires as the field decays so quickly, but, the smaller the electromagnetic signal, the MORE it is influenced by the material nearest the wire. That superposition of materials SLOWS the signal (air to plastic) or speeds it up (plastic to air) relative to just the initial material's properties.

We can see this in actual practice as the "group" velocity of all the materials on Ethernet cable shoes a value SLIGHTLY higher than the dielectric (66%) itself, and measures 71%. The signal is in the "air", a good dielectric" and this influences the overall signal speed.

ICONOCLAST interconnect design switches this around, and puts the AIR nearest the wire, where the signal strength is highest. This negates the outer plastic dielectric's contribution to the group velocity, so we see a higher 87% value at RF. This translates to lower capacitance number where we use the cable in audio applications.

The VP speed variation caused by the "composite" velocity is complicated by the fact that the LOWER in frequency you measure, Mother Nature's devious plan slows everything and this time shifts the audio band.

We can't change the fully diffusion coupled (same magnitude current through the wire) low frequencies, so we try to time align the faster upper frequencies. At RF the upper frequencies are "on" the wire surface so the dielectrics affect them nearly 100%. At RF this is fine because it is near the same VP at all RF frequencies. At audio, we want to move most of the high frequencies AWAY from the dielectric so the speed is closest to the lower frequencies.

We already know that the VP is faster the higher in frequency we go so this messes up the signal arrival times. The only good way to slow the upper frequency magnetic field is to make the wire smaller so less energy is JUST at the wire surface nearest the dielectric. More current is "in" the wire versus "on" the wire based on skin depth.

Can we overdo field current normalization? What if we could make a wire one atom wide? Now, the impact of the DIELECTRIC is as big as it will ever be and with a really, really small current in each wire. The total current will be the sum of all the wires we want to use in parallel. The more wire you use, the smaller the current in each wire. Current is the number of electrons past a point with respect to time. Well, we have ONE tiny electron moving in each "wire" and THAT is as small a current as you can have! Model a weak signal, and the electromagnetic wave is so weak it never really leaves the dielectric, whatever material the dielectric is. The dielectric better be really decent as it is hugely involved in capacitive rise time (calculated capacitive reactance rise times constants) signal arrival time (velocity of propagation).

At very high frequencies, and if the wire is infinitely big, we see ONLY the dielectric as the current is at the surface (skin effect). Likewise if the wire is infinitely small we AGAIN see JUST the dielectric (no skin effect can happen). Between the extremes of wire size, somewhere, we can alter the arrival time of the upper frequencies with wire diameter and dielectric choices.

Interconnects are much easier, but not real easy, as they terminate into a high resistance, nearly open looking circuit. The reflections off a CONSISTENT resistive load of 47K-120Kohm aren't as bad as the mismatch speaker cables experience as BOTH the cable AND the load are in constant flux. Worse, the speakers change by design! The seemingly high measured impedance slope of RCA or XLR interconnects in the initial graphs aren't as bad as they seem. Not only are the "impedances" not real at audio but you have far bigger issues with the non-linearity of cables loading the output devices in your preamplifier. Trying to match ideal infinite input impedance on RCA or XLR cable would mean *tiny* capacitance values. We go as LOW in capacitance as we can to allow the output devices to see an easy load. This is way we shoot for keeping capacitance reasonably low.

Massive signals in the speaker cable are less impacted by the "composite" dielectric speed. The electromagnetic field will travel at an "average" of all the stuff it is moving through, so the better the "average" material is that the electromagnetic field is in, the FASTER the signal travels, and the less TIME the signals have to become separated as they travel down the cable. This is the time and distance story problem.

PC's stopped using FLAT cables because the signal arrival TIME differential got to be too high. They went to SERIAL digital designs, and re-clock the data from memory. This at first seems counterintuitive, adding the re-clocking circuit, but unless the TIME can be managed, you're screwed. Faster is better but I'd take SLOWER and the SAME in an instant! This is the "keep cable shorter" thing, but to be LONGER we have to be FASTER, too, if time errors are to be kept low. Mother Nature says we get a raw deal in the audio band verses RF.

In speaker cable, the stronger low frequency electromagnetic waves emanate into the air through the plastic dielectric more than the higher frequency signals so they are theoretically aided by the air around the wire (superimposed dielectric value) more than the weaker high frequencies that see more of the slower plastic dielectric. But the VP erosion as we drop in frequency eats-up that advantage in the low-end. It's there, but small. The problem is that the low frequencies still drop in speed way more than the air's addition to the overall speed.

Seeing more air as we go lower in frequency speeds the signal up relative to the faster high frequencies and offsets some of the problem…but it never aligns it away to zero. The VP still marches slower and slower as we go lower and lower in infrequency. Arrival times are more important than SPEED down the wire.

The highest frequency carried in the speaker cable is most fragile, but compared to interconnect cable, it is relatively robust. The high impedance interconnect cables are yet another problem. ALL the signals are VERY, VERY low current electromagnetic field energy states. Here, I need the BEST material possible to time align the energy field "whipping" (slowly whipping) down the wire; air. The VP is the inverse of the dielectric constant so we want a fast dielectric and the lowest associated capacitance it can also provide. This is why I HAVE to use AIR core designs to properly time align the energy AND use SMALL wires to better distribute the dielectric's effects at ALL frequencies nearest to the same composite velocity. The third leg is to decrease output device capacitive loading. Air helps mitigates velocity variation across the frequency band that is the bane of audio signal transmission. It incidentally also pushes UP the "impedance" to better match the load, the opposite of a speaker cable. I'd be wary of that improvement as we need to be aware that audio isn't a transmission line.

It seems counterintuitive to use air, as it speeds up the higher frequencies relative to the lower frequencies (makes the difference worse) but the capacitive reactance influences rise time error if you let it get too high. The propagation time and the rise time need to be balanced, somehow. There is no perfect solution.

We call, it "sound quality" when we use the cable, but it really is the arrival time alignment of all the signals. The human brain hears superimposed time alignment and amplitude preservation first, everything else a distant second. The argument is: does this make a difference?

9.0 INTERCONNECT CABLE RCA to XLR MATCHING

The issue – Changes in electromagnetic properties between interconnect cables types can alter the ideal "tone" that was intended.

An often ignored issue is, what do you do with a really good sounding RCA cable? Why not make a really good sounding XLR that's the same reactive measured design? Most RCA to XLR cables never match. ICONOCLAST is no accident. I purposefully designed the RCA and XLR to be the exact same reactive match and thus the same "quality" of sound through the channel. The above impedance chart that we saw earlier shows both the RCA and XLR. Look closely, they are electromagnetic buddies.

Does that make a difference? If you have a very good RCA design, it sure can't hurt to start there on the XLR!

10.0 CABLE SYMMETRY

The issue – how to make complex cable's cross section look like one simple wire electrically, and every wire sound the same?

Matching multiple wires into a complex structure isn't easy to do well. The ideal cable is one wire that is exactly the same as the opposite polarity wire. To meet other objectives, we usually have several wires.

More small wires will make a nice big capacitor (wires with a dielectric between them) and trash reactive signal conversion to resistance products. Inductance will inversely follow capacitance, messing up the current delivery, and to get BOTH intrinsically LOW, you can't go "whole hog" on the opposite variable. The two variables are tied together inversely. Rats! A suitable compromise must be reached? Yes, audio is a compromise, as we are seeing. BOTH L and C need to be low in value and good design manages this. Trade-offs for better sound can, and should, be logically explainable.

The less understood variable is Inductance. This variable is a big contributor to more wires. We all think, "capacitance" for audio. Realize that if we had NO inductance, we could separate the wires as much as we wanted and eventually have no capacitance (outer space actually has capacitance, so that's impossible, too). The reduction of the magnetic fields by proper cable geometry reduces the inductance, allowing a larger wire center-to-center distance for low capacitance. The LOWER the electromagnetic field, the LARGER the loop area can be (lower capacitance) for a given inductance and vice versa. Too many cables ignore getting the electromagnetic field as low as possible. The higher the current (speaker cables) the more field energy you need to eliminate. Wires with low electromagnetic fields and small loop area have the lowest inductance. ICONOCLAST's speaker cable design balances out the wires' proximity to one another so as to not "rob Peter to pay Paul". The unique weave pattern increases the average wire C-C (Center to Center) distance creating a wire pattern that CANCELS the electromagnetic field while increasing the average spacing for low capacitance. Cancelling the field energy allows me to also lower inductance which would be impossible to do with JUST wire spacing for capacitance alone. No magic need apply.

EVERY wire in a cable has to be the same wire if you use superposition of the electromagnetic fields traveling down each wire. This is why symmetrical cable designs are used to efficiently remove reactive time alignment issues. I measured the reactive time based issues on other designs and they all came up short. Capacitance and Inductance have to be the same on EVERY wire to as tight a manufacturing standard as is possible. Multiple, and differing wire sizes are too complex to align things nearly as well. The signal's SPEED has to be best matched at all frequencies and not just the physical wire length. The wire's "signal length" is the problem. Use too many non-symmetrical, differing sized wires and this is all but near impossible to do with all the variables involved. I call this type of mixed wire cable, "cable in a cable". The effect is a kindergarten lunchroom in the dark; a mess.

In passive cable, you can't force the highs to go in the small wire and the lows in a bigger wire, and adjust the wire lengths to offset the VP changes. The ENTIRE spectrum goes into EVERY wire, so now we compound the time based issues. Only active electronics can separate the spectrum, and that's a problem too.

Does ICONOCLAST remove the "cables in a cable" problem? Only one way to find out and that is to MEASURE them. The data is showing each polarity with 12 two wire BONDED pairs, 24 wires in each polarity, and 48 total wires in each cable;

175.3815 pF (X) +175.3815 pF = 180.1803 pF
175.3815 pF (X) + 171.4507 pF = 171.4507 pF
X = +2.74 % and - 2.29% variation between wires, or, they are ~ 97.5% the same.

Niehoff 6 x 6 PPI 4.0				Avg. pF/ft.	STDEV	Min	Max
177.0955	177.4340	172.3321	179.0224	175.3815	2.4364	171.4507	180.1803
172.8369	171.4930	176.5402	176.5411				
174.2683	175.2594	174.7609	175.8963				
175.8969	178.0881	172.8248	179.1448				
176.2732	171.4507	171.9916	176.7639				
174.0600	177.8210	178.7609	173.1713				
172.3291	177.8486	172.0927	173.2086				
180.1803	171.7460	177.0839	175.2722				
177.3002	173.0879	175.0548	172.6448				
174.8771	176.2519	178.0202	176.1054				
173.6109	177.2030	172.5906	172.4072				
179.3871	176.1192	177.6033	176.5716				

I would say yes, I got it right.

For ICONOCLAST speaker cable I set my design goal at no more than 50 pF on capacitance and 0.1 uH/foot an inductance (45 pF and 0.08 uH typical). On the interconnect I set the goal at 12.5 pF and 0.16 uH (12.0 pF and 0.15 uH typical). This is WITH connectivity and tested to prove it.

The complex electromagnetic designs of the RCA, XLR and speaker cables allow ICONOCLAST to exist. The RCA is the most pure electromagnetic equation that I have to work with and defines the interconnect cable problem. How do we reach the greatness that a PROPERLY designed RCA does in the XLR design (matched impedance / phase)? How can I convert the small signal world of the RCA and XLR into the large current world in the speaker cable (low inductance with still low capacitance)?

11.0 ATTENUATION AT AUDIO

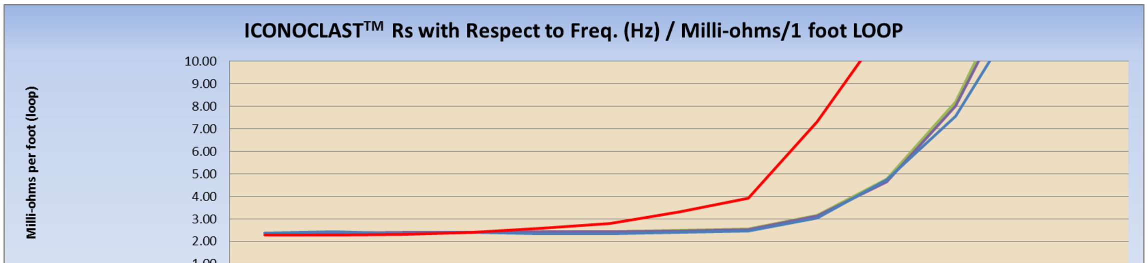
The issue – is it mostly LOG linear so we can't hear it?

If it is true that we can't hear LINEAR attenuation (measured Rs values say there is non-linearity) or TIME based issues in audio cables, WHAT are we hearing with optimized designs, i.e. those that try to get L and C to near ZERO as we can and with low time based issues? The design goal difference in ICONOCLAST is TIME based and I'm not so sure that the inaudibility of difference values of 5-10 micro seconds is correct. Linear attenuation, I agree, is MUCH harder for the ear to pick out in typical cable lengths. I said LINEAR LOG type decay.

Rest assured, if there is snake oil in these products it sure looks like physics to me. All the above data is measured and real. The question remains, WHY do the cables SOUND so much better if TIME based issues aren't audible? WHAT are we hearing, then? The reactive TIME altering L and C along with the VP change with respect to frequency seem to be the difference in cables, and audibly so. Linear attenuation can't account for the differences. Series resistance says that that factor isn't as linear as we'd like, either. There is a measurable difference in cables resistance across the audio band.

Is attenuation linear? I measured the Rs (series resistance), with respect to frequency, of ICONOCLAST and saw a significant CHANGE in attenuation with high quality R, L and C. Look at standard 1313A speaker, 10 AWG Zip cord style cable (red trace). ICONOCLAST flattens resistive non-linearity artifact, and the interconnects are both flat to 20 KHz human hearing test point. Still, look at the UNITS; it isn't a wall of lost energy above 20 KHz.

SPEAKER CABLE



FREQ. (Hz)	100	1000	2500	5000	7500	10000	15000	20000	50000	100000	200000	500000
ICONOCLAST SPTPC (0.020")	2.37	2.37	2.37	2.39	2.40	2.43	2.48	2.55	3.17	4.77	8.20	14.51	21.06
ICONOCLAST TPC (0.020")	2.37	2.37	2.39	2.41	2.42	2.43	2.47	2.53	3.12	4.65	8.01	14.04	20.26
ICONOCLAST TPC (0.022")	2.38	2.41	2.35	2.39	2.34	2.34	2.40	2.45	3.03	4.73	7.56	12.49	17.71
1313A	2.27	2.27	2.30	2.40	2.57	2.78	3.31	3.90	7.30	11.67	18.35	31.78	49.24

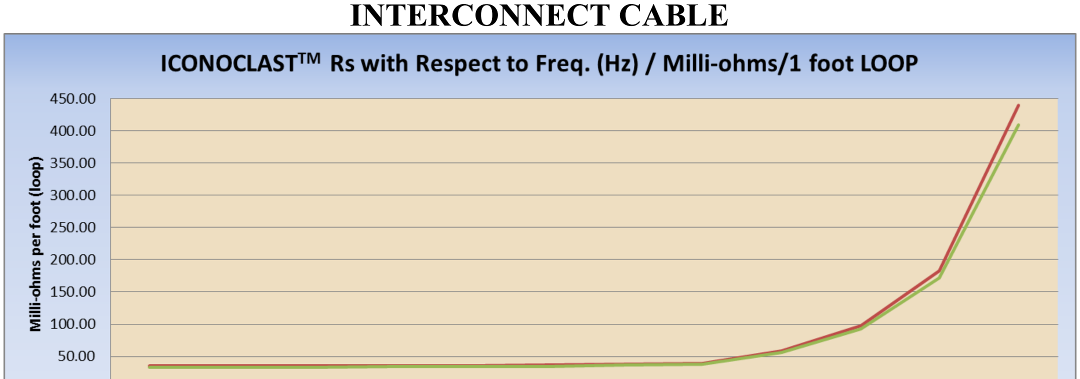
- There is a measured 6.75% change from 100Hz to 20kHz for Rs for ICONOCLAST™ speaker cable.

	Results				
				Impedance	
	Ls	Rs	Cp	Mag.	Phase
Units:	µH/ft.	mΩ/ft.	pF/ft.	ohms	degrees
Freq. (Hz)					
100	0.084	2.37	44.84	297.83	-43.81
1000	0.080	2.37	44.69	98.09	-39.50
2500	0.079	2.39	44.65	65.67	-32.43
5000	0.079	2.41	44.61	50.89	-23.07
7500	0.079	2.42	44.60	46.66	-17.17
10000	0.079	2.43	44.59	45.00	-13.59
15000	0.079	2.47	44.57	43.63	-9.80
20000	0.078	2.53	44.55	43.12	-7.59
50000	0.078	3.12	44.50	42.40	-3.70
100000	0.077	4.65	44.47	42.00	-2.80
200000	0.074	8.01	44.59	41.32	-2.42
500000	0.071	14.04	44.45	40.46	-1.78
1000000	0.070	20.26	44.53	40.04	-1.31
	Loop DCR (milliohms/ft.)		2.40		

- This is a 1313A equivalent CMA wire design, with fewer wires. There is a measured 71.8% change in Rs from 100Hz to 20 kHz.

	Results				
				Impedance	
	Ls	Rs	Cp	Mag.	Phase
Units:	µH/ft.	mΩ/ft.	pF/ft.	ohms	degrees
Freq. (Hz)					
100	0.125	2.27	17.13	460.63	-43.57
1000	0.155	2.27	16.94	152.64	-33.36
2500	0.154	2.30	16.87	112.22	-21.70
5000	0.154	2.40	16.80	100.93	-13.16
7500	0.153	2.57	16.77	98.06	-9.71
10000	0.152	2.78	16.74	96.85	-8.00
15000	0.150	3.31	16.69	95.49	-6.46
20000	0.147	3.90	16.66	94.49	-5.80
50000	0.136	7.30	16.57	90.61	-4.68
100000	0.127	11.67	16.53	87.81	-3.97
200000	0.121	18.35	16.58	85.43	-3.28
500000	0.114	31.78	16.43	83.95	-2.40
1000000	0.111	49.24	16.40	82.15	-1.96
	Loop DCR (milliohms/ft.)		2.27		

INTERCONNECT CABLE



FREQ. (Hz)	100	1000	2500	5000	7500	10000	15000	20000	50000	100000	200000
RCA	34.90	35.03	35.06	35.29	35.69	36.22	37.69	39.65	58.01	98.00	183.33	439.93
XLR	33.48	33.50	33.57	33.82	34.23	34.79	36.32	38.32	55.86	92.47	171.60	409.80

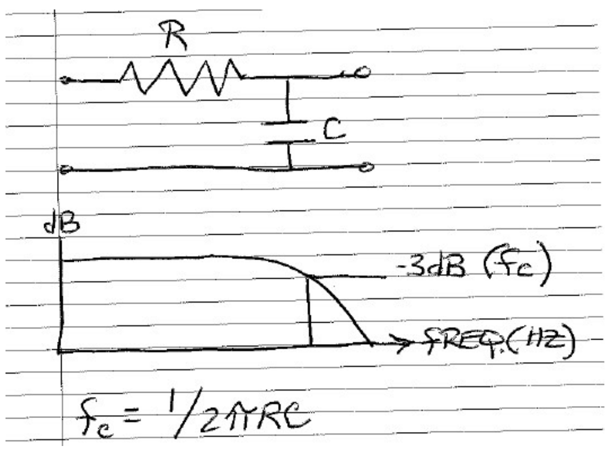
12.0 Low Pass Filter Effect

The issue – Cable is a low pass filter, and rolls off the frequency at the frequency of the filter's cut-off; F_c. How does this change what we hear?

I saved this one for dead last since it was even overlooked on my categorization of issues with audio cables. You'll see why in a moment.

Here is the basic circuit. There is actually a SMALL inductor in series with the resistor but notice that it doesn't appear in the equation that defines how the filter will behave, and is omitted. There are circuits that involve larger inductors, and unless we have a resistor to ground, they won't apply to "cable" filters. Well, decent cable anyway.

The capacitor is a reactive device, like I've mentioned before, so its properties change with frequency as does an inductor. A capacitor eventually looks like a short to ground (capacitive reactance value keeps changing) at higher frequencies so the signal energy takes the path of least resistance through the capacitor to ground. R is in Ohms when capacitance is in picofarads (pF).



The good thing about almost ALL audio cables is that the roll-off properties of the filter are WAY above the audio band. Yes, a first order filter will change the PHASE at the -3dB attenuation point by 45 degrees, and time based distortions are more audible than the roll-off attenuation. First order filter attenuation nor phase changes are going to be an issue, theoretically.

Typical ICONOCLAST™ R, L and C Variables

	RCA	**XLR**	**SPEAKER**
Capacitance	12.5 pF/foot	12.5 pF/foot	45 pf/foot
Inductance	0.15 uH/foot	0.15 pF/foot	0.08 uH/foot
Resistance	32 Ohm/M'	14 Ohm/M'	1.15Ohms/M'

The RCA shield "goes away" as it is such a low resistance in series with the center wire, leaving essentially the center wire DCR.

The XLR uses TWO 25 AWG wires in parallel for each polarity, so the resistance is HALF the two wires, or about the same as a ~22 AWG wire.

Calculating F_c we arrive at;
15.5 GHz for the 5 foot RCA.
36.4 GHz for the 5 foot XLR.
15 GHz for the 10 foot Speaker Cable.

The real problem with cable is that it can load down the output op-amps with too high capacitance and change the frequency response and possibly phase response. Some really high capacitance or high inductance speaker cables can bug the heck out of power amplifier output stages, too. But these problems aren't filter problems, but bulk capacitive or inductive loading problems on the output circuits.

All circuits “push back” below their operating region into the pass band but a rule of thumb is to keep the f_c pass band 10X or more above the circuit’s operating frequency. We surely are meeting that requirement with any decent cable, even zip cord.

SUMMARY

Many outside this sub-discipline of engineering will STILL insist that electromagnetic field time management and time alignment are not important, and that only the bulk R, L and C matter. The ear is a time domain instrument and readily time aligns the signal to the natural world we live in. EVERY effort was made to pay attention to TIME domain issues in audio cables and attenuation non-linear artifact. There are a myriad of ways to lose track of TIME, and an audio cable is not a good place to make mistakes.

Consider all the measured and factual information above on cable design and then ask yourself why cables sound different. Why wouldn’t they sound different given how complex it all is? True, poorly made cables all fall into a bunch of warm and soft sounding products. Elevate the engineering and they indeed measure different. The above is 100% true for ALL cables, if I may add. If I mischaracterized a topic then, of course, only my cables are affected! All the cable designs in the ICONOCLAST line are under US patents.

I hope my cables bring years of enjoyment to you, and NEVER a feeling of complacency in what was provided to enhance your hobby’s (mine too!) pleasure. The search is constant to try to align TIME based issues to arrive at the best sound possible. The bad layers of the onion can’t be removed, but the order and thicknesses can be altered. Signal coherence is both arrival time and amplitude time dependent. Passive cable won’t allow perfection, just a lot of hard work to manage the ill effects that Mother Nature threw our way.

“Sound Design Creates Sound Performance”, and this means driving down all measurable variables to the lowest possible balance we can achieve. Does this make better *sounding* cable?

Sincerely,
Galen Gareis
Principal Product Engineer.
ICONOCLAST Design Engineer