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ICONOCLAST Vp and Impedance Calculations and Measurements

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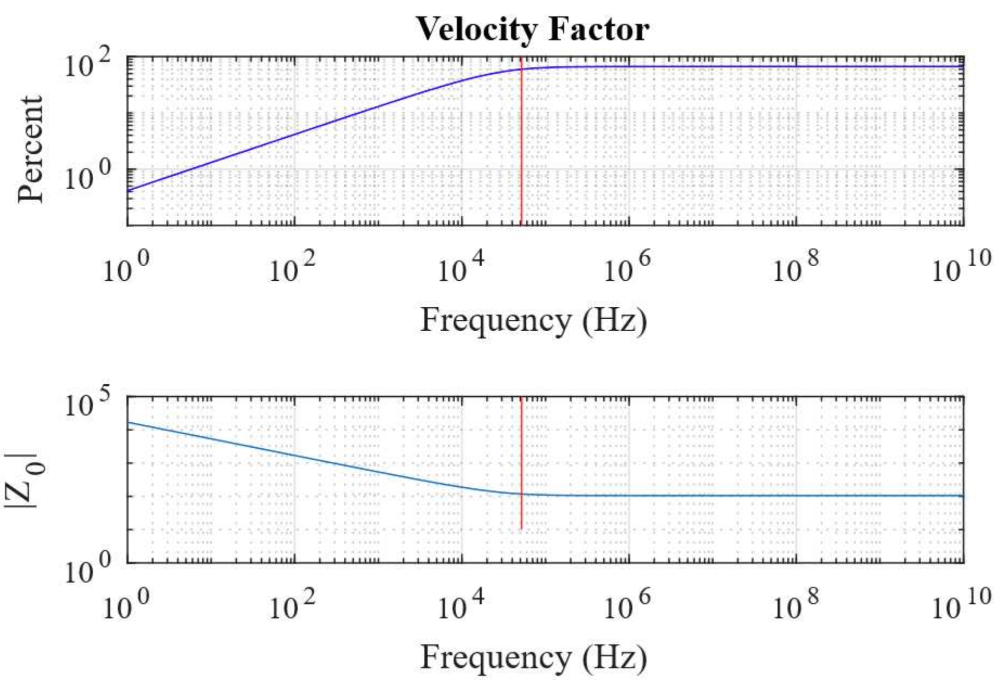
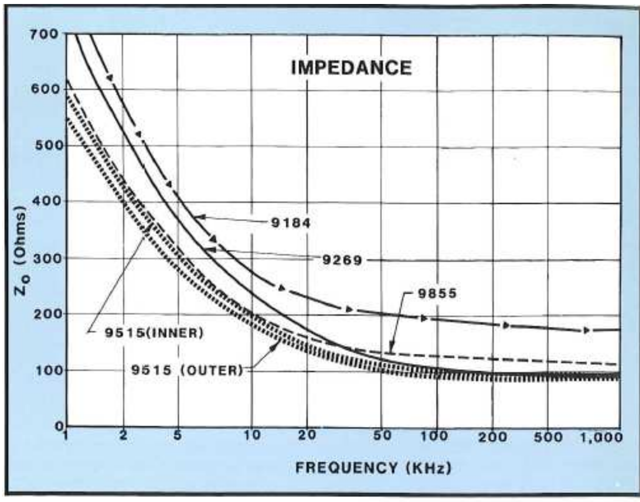
BACKGROUND: Speaker and Interconnect cables for the audio range have an Achilles' heel that must be directly addressed, or is often completely ignored. Audio cables are more about the TIME dependency of the signal through the audio band than simple attenuation, resistance, or the concept that we just need low resistance, capacitance and inductance.

We can't allow capacitance or inductance to actually go "as low as we can" while balancing the cable's velocity of propagation's non-linearity through the audio range. What changes are happening when we consider the Vp differential and what can we do to INCLUDE this in our DESIGN? Do we even realize what the speeds of various frequencies are through the audio band?

BODY: The math behind Vp non-linearity isn't new. Belden Innovators® 1974 and 1984 SPRING magazine articles cover what we need to know and have measured, but seldom is it utilized to fully optimize an audio cable's performance. Many like sources derive the same Vp and impedance plots.
http://web.mst.edu/~kosbar/ee3430/ff/transmissionlines/z0/index.html



BELDEN INNOVATORS – Spring 1984



Notice that the 15 pair cable, 9515, exhibits slightly different values for Z_0 depending on whether an inner or an outer pair is measured.

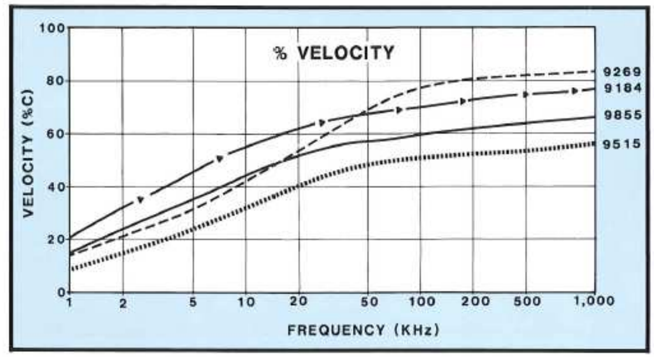


Figure 5.

The above two separate sources show the exact same cable properties for impedance at low frequencies. It goes UP, considerably, as Vp goes DOWN.

You can't escape Vp non-linearity through the audio band and the rise in impedance it causes. Physics isn't on our side.

What we do know, is that audio cable isn't a transmission line as it can use the wave property of the signal inside the cable dielectric. They just won't fit. The wavelengths are too long, even if we want to use one full wave period. Ideally we need at least ten wavelengths to reach a stable TEM (transverse electromagnetic wave) situation. I will never adhere that we have true TEM function type reflections in audio cable where impedance is matched to a load like an RF cable. It isn't and can't be in the audio frequency range and we'll see why in this article. We'll also see why RF cables aren't ideally matched, either, even at the exact same value as a load resistor.

What needs to be understood is that RF has some decided advantage to audio when it comes to system matching. The Velocity, or speed, of the TEM wave trapped inside the wire either between two wires (twisted pair) or between a wire and shield (coaxial cable) is a constant at RF. It does not fundamentally change with frequency. I say fundamentally because some will say if it changes *any* amount at all it "matters". OK, I'll give the perfectionists +/- a few percent.

There are several methods to calculate or measure RF impedance. Don't try any of this at audio or below 1 MHz. Even 1 MHz isn't truly reaching the impedance asymptotic stability level.

Ratio method. Here we can look at a known cable's impedance we feel is reported under test correctly. We can take the ratio of the diameter; center wire size to inner shield size and use that to make a cable bigger or larger or even see what its impedance is compared to known ratios. This works for twisted pairs, too, as we look at each insulated wire as a coaxial cable, but we place two in parallel. Two 50-ohm coaxial lines in parallel double the center to center distance so we have less capacitance and higher impedance, for instance.

We need to make sure that the dielectric Vp is the same, however, or this won't work. The speed of the EM wave is also changing the impedance of the cable in calculation and ratio measure.

If I double the wire size and double the insulation (same material) I will have the same impedance as the reference ratio. Pretty easy if the reference is made right and to the value you want.

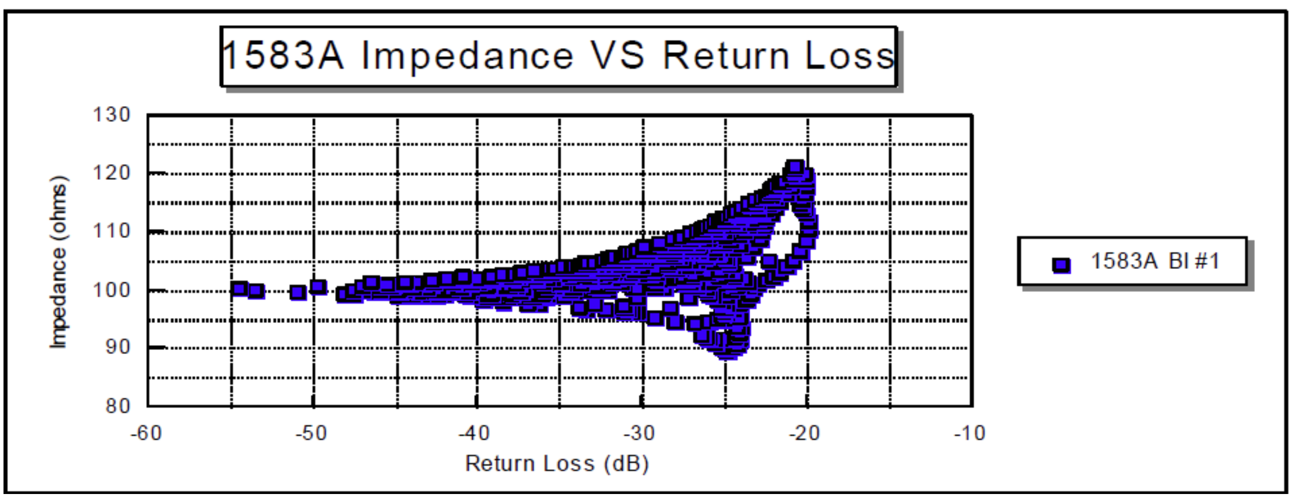
1.0) We can calculate the impedance with several equations; the easiest uses the RESONANCE method. This measure capacitance at 1 KHz, and then using two RF frequencies uses a resonance property to calculate the velocity of the signal in the cable at RF. Now we have nothing but C and Vp. That's all we need;

$$101670 / (C*V) = \text{impedance at RF.}$$

2.0) A measurement, not calculation, can use a variable bridge to measure a load that is resistive and can be varied, to determine the impedance. This relies on the cable STRUCTURAL RETURN LOSS. What impedance is the "structure". The load is varied until we test a minimum reflection of the test load swept across and RF band. The minimum fitted line is the cable's natural impedance but only at RF where a true transmission line property exists. Cable is MOSTLY resistive at RF, so we can use a resistive load. The cable, however is NOT a pure resistor even at RF. What does this do?

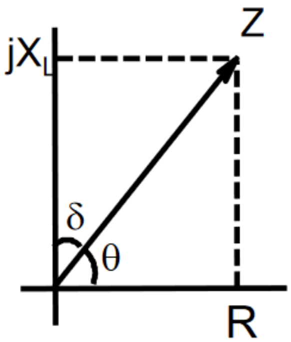
Here is what it does in a twisted pair, which has enough deviation to see relative to a coaxial cable. That is so good since it is hard to show the effect in an equation. On the left side of the graph is IMPEDANCE. This cable is supposed to be 100-ohms swept 1-100 MHz.

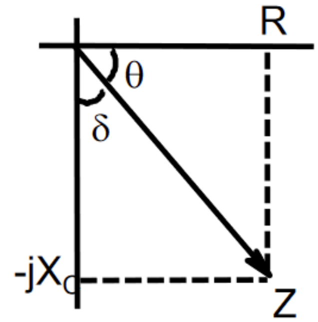
If we sweep the RL, RL differs from SRL as the LOAD is FIXED at 100-ohms so we can't cheat and adjust the load to minimize reflections, we get a bunch of RL points in dB, I plotted in the X-axis with the impedance of that point in the Y-axis. What's weird about this graph?



Let's just look at the 100-ohm center value. We see RL values from –55 dB (smaller is better) to –25 dB. How is this happening at EXACTLY 100-ohms impedance? The impedance is a VECTOR sum of the cable's real (resistive) and imaginary (capacitance or inductance, but usually capacitance) vector magnitudes.

The VECTOR is 100-ohms but it isn't resistive anymore so we get reflections. The SIZE or length of the resistive vector missed true 100-ohm values.





This tends to escape people's interpretation of impedance. What about the points above and below the 100-ohm reference? Here is where people seem to go, we have values higher and lower than a 100-ohm cable. But, some impedance that miss the 100-ohm center frequency have lower RL than those on the 100-ohm line!

Impedance at RF is still not an easy matter to define as it relates to signal transfer with all this going on.

3.0) An open-short-load and open-short impedance test can also be used. This method is most common for very low frequency tests. The impedance is calculated from the open and short measurements (see the chart). This method de-imbeds the "load" and concentrates on just the cable itself. It also is better the longer the cable at lower frequencies. The data provides the magnitude and phase.

$$Z_O = \sqrt{Z_{OC}\ Z_{SC}}$$

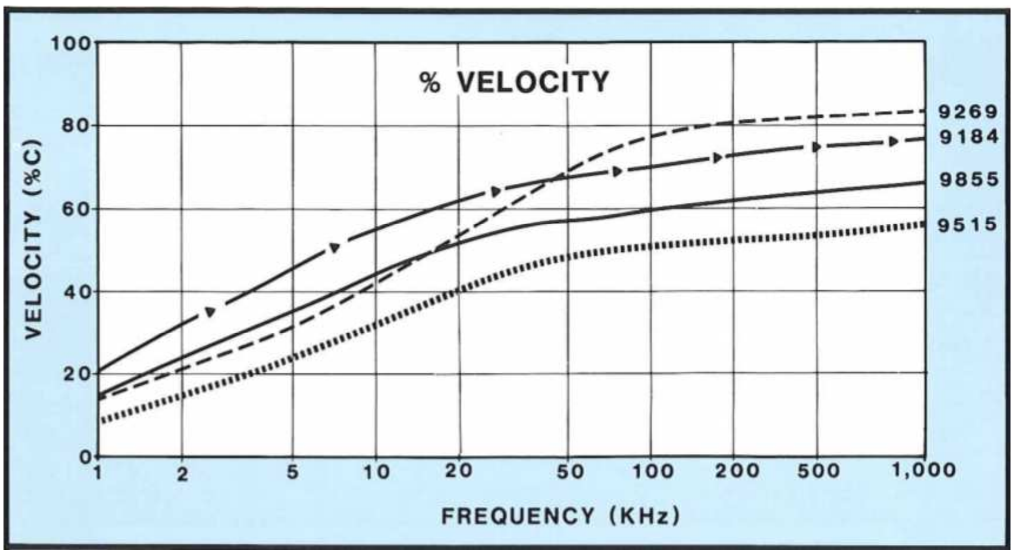
Z_O is the Characteristic Impedance
Z_{OC} is the Open Circuit Impedance
Z_{SC} is the Short Circuit Impedance

	#1					
	Imp - Mag (ohms)			Imp - Phase (deg)		
(Hz)	Open	Short	Imp	Open	Short	Phase
100	7.60E+06	4.43E-02	580.2413	-90	179.4	44.7
200	3.80E+06	4.54E-02	415.3553	-90.1	178.7	44.3
500	1.52E+06	4.57E-02	263.5602	-90	176.9	43.45
1000	7.59E+05	4.52E-02	185.2087	-90	173.8	41.9
2000	3.80E+05	4.35E-02	128.5183	-90	167	38.5
5000	1.52E+05	4.96E-02	86.71138	-90	150.4	30.2
10000	7.59E+04	6.51E-02	70.29289	-90	131.7	20.85
15000	5.06E+04	8.49E-02	65.54342	-90	120.4	15.2
20000	3.80E+04	1.07E-01	63.76519	-90	114	12
50000	1.51E+04	2.46E-01	60.99705	-90	99.1	4.55
100000	7.57E+03	4.80E-01	60.25423	-90	93.1	1.55
200000	3.79E+03	9.32E-01	59.44255	-90	90	0
500000	1.52E+03	2.26E+00	58.5141	-90	88.8	-0.6
1000000	756.6	4.47	58.15498	-90	88.8	-0.6
2000000	376.2	8.89	57.83094	-90	89	-0.5

From the chart shown above, we see impedance DROPS as we increase the frequency until it begins to flatten to ~60-ohms at about 1 MHz. Why, we wonder?

Let’s look at why. But importantly, the math fits the physics, not the other way around. A non-linear curve typically is correct in a few specific spots. A tonearm track is correct just twice in the sweep across a record. The exact right answer is not really “exactly” along the curve. It is curve FITTED data as best possible to actual measurements. If I change the length of the tonearm, the fitted equation has to change too. The curve has changed. The longer tonearm improves how close we are to right, so we can alter the design to reach different compromises.

This is why we measure the data if possible. Then a proper equation is accurate enough, verified to real measurements, to provide insight into additional design performance improvements. We can look at a few examples and see the actual Vp responses of KNOWN cable against measurement that the equation(s) are modeled from.



The above graphs show the Vp response of several audio cables. The equation derived from the curves is;

An approximation for the velocity can be given which is good at low frequencies

$$V_p = \sqrt{\frac{2\omega}{RC}} .$$

At sufficiently high frequency, a valid approximation for velocity is:

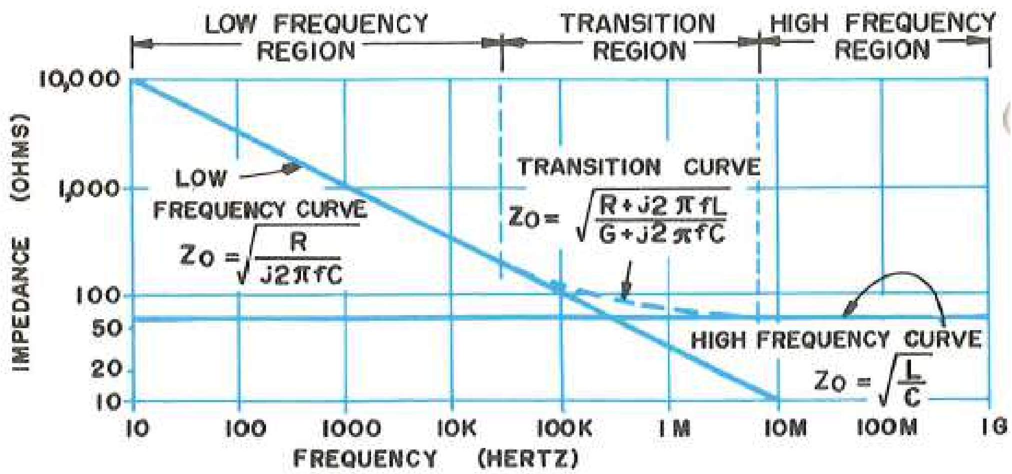
$$V_p = \frac{1}{\sqrt{LC}} .$$

If we grab a cable, 9515, and apply the approximation equation, we see the data table below. The Vp values across frequency closely match the plotted swept data from measurements. Get “R” or C too high and we need to redefine the equation and, fundamentally, we will see the same impedance rise as frequency drops.

Freq (Hz)	Vp 9515	OMEGA	R(loop/mtr)	C (pF/mtr)
1000	0.09	6280	0.15744	9.84E-11
2000	0.13	12560	0.15744	9.84E-11
5000	0.21	31400	0.15744	9.84E-11
10000	0.30	62800	0.15744	9.84E-11
20000	0.42	125600	0.15744	9.84E-11

We can see that in the low frequencies, we need a different equation to account for specific variables going to "zero" or "one" as we increase the frequency into the RF band. RF can use a SINGLE Vp value above 1 MHz. This has to be abandoned at audio frequencies. Have we seen this issue before? Yes, in the measure of IMPEDANCE -- and since Vp is part of the impedance equation, since it determines capacitance, this isn't a surprise after all.

We have three impedance approximations for cable and which one is used is frequency dependent since Vp is non-linear to frequency. Notice that the curve RISES as we drop in frequency, and orders of magnitude higher than at RF. This is why we can't make a "flat" or low impedance cable through the audio band. At RF impedance is essentially resistive and why NIC cards can use resistors as a load.



We also have simpler approximations at low and high frequencies starting at 100 Hz and at 1 kHz and 100 kHz. G, conductance, is the reciprocal of resistance in siemens (S) or mhos units. L and C are in farads and Henry. Yes, you need all the zeros; 12 pF is 0.000000000012 farads.

$$Zo = \sqrt{\frac{R}{G}} \qquad Zo = \sqrt{\frac{R}{\omega C}} \qquad Zo = \sqrt{\frac{L}{C}}$$

These simple equations don't have frequency in the equation at the low and high frequency range so the results are segment line graphs. At RF that's all we need, though. The mid-range equation does have frequency, OMEGA (ϖ), which is (2*pi*f). R and C is length dependent.

The "easy" definition of low frequency impedance ignores capacitive or phase effects at the very low-end and sees impedance as just DCR. Reactive effects are worse as we drop in frequency.

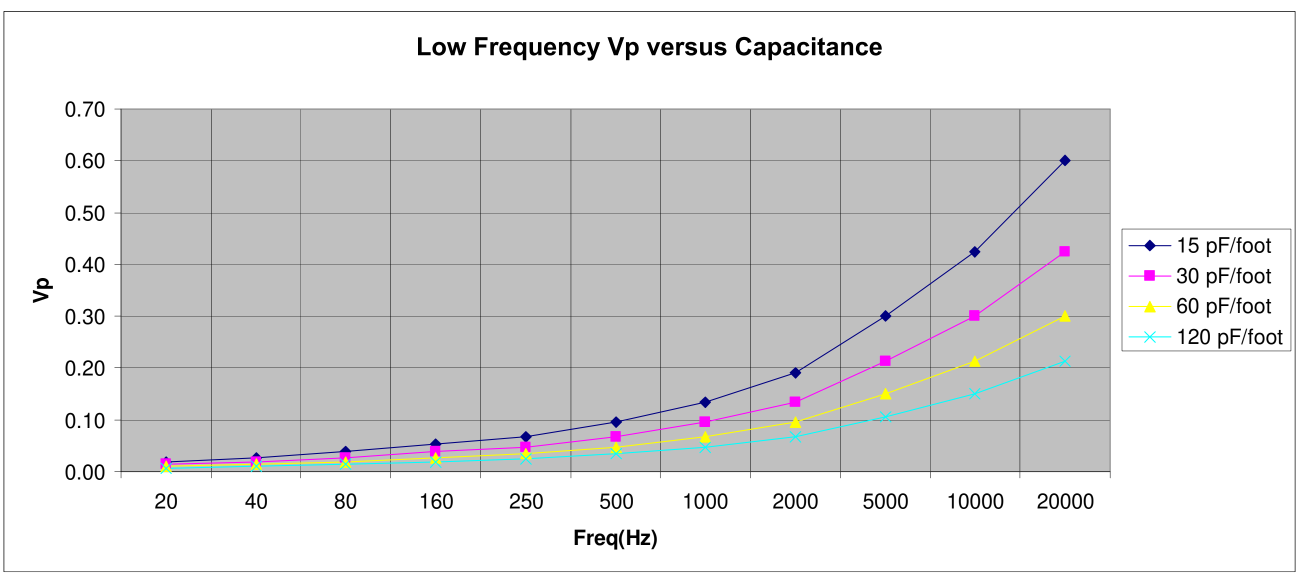
The input impedance of a transmission line, open at the far end (de-imbedded from the load), looks like a capacitor (high resistance to current flow). Impedance starts high and drops very low. Capacitors pass AC signal better and better the higher we go in frequency (lower Xc).

We see this high to low impedance effect caused by Vp and capacitive reactance change. The reactive effects slowly diminish at higher frequency (don't impede AC current flow). The Vp reaches a steady state based on the dielectric. Vp is purely based on the material property of the dielectric.

What can we do with this insight into the fundamental ability to CHANGE the Vp with frequency? Can we do something to improve the linearity?

Here is an example of what might happen in a cable that is designed to have varying levels of Vp differential based on managing the CAPACITANCE. We can do this with variable insulation size, or even the insulation material. For simplicity, we'll hold DCR the same to isolate the capacitance effects on Vp.

CAPACITANCE (pF/foot)		15 pF/foot	30 pF/foot	60 pF/foot	120 pF/foot
FREQ (Hz)					
	20	0.02	0.01	0.01	0.01
	40	0.03	0.02	0.01	0.01
	80	0.04	0.03	0.02	0.01
	160	0.05	0.04	0.03	0.02
	250	0.07	0.05	0.03	0.02
	500	0.09	0.07	0.05	0.03
	1000	0.13	0.09	0.07	0.05
	2000	0.19	0.13	0.09	0.07
	5000	0.30	0.21	0.15	0.11
	10000	0.42	0.30	0.21	0.15
	20000	0.60	0.42	0.30	0.21
R = Loop/MTR		0.15744	0.15744	0.15744	0.15744
C = Farads/MTR		4.92E-11	9.84E-11	1.97E-10	3.94E-10
Vp = SQRT ((2*OMEGA)/(R*C))					
OMEGA = 2*Pie*Freq.(Hz)					

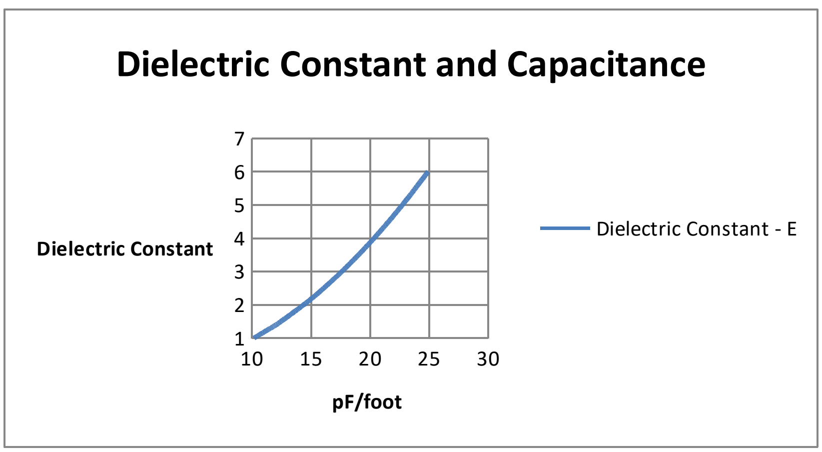


Notice the change is well within the audio range, and the Vp change is pretty extreme on an absolute basis. Short cable lengths can explain IGNORING Vp non-linearity. What if we DO NOT want to ignore this issue, yet better balance it with other cable parameters?

In the example above we look at ONLY capacitance. But, Inductance is LOOP AREA determined. I can arrive at the levels of capacitance several ways, and combinations of ways. If we want to retain LOW inductance for PHASE reasons across the frequency range, we need to hold loop area SMALL. Thicker insulation does not lower inductance, it increases loop area (space between the wires).

To keep loop area as small as we can for low inductance we need to use the absolute most efficient dielectric(s) we can, AIR is best and TEFLON as a solid plastic is the best choice. Low "e" allow two wires to be as close as they can be and reach a lowest possible capacitance with a given spacing. This helps keep loop area smaller to manage inductance. When E is high, cap is higher *at set RF impedance*.

VP	Impedance	Capacitance	Dielectric Constant - E
100.000	100.000	10.167	1.0
87.039	100.000	11.681	1.3
81.650	100.000	12.452	1.5
70.711	100.000	14.378	2.0
63.246	100.000	16.075	2.5
57.735	100.000	17.610	3.0
53.452	100.000	19.021	3.5
50.000	100.000	20.334	4.0
47.140	100.000	21.567	4.5
44.721	100.000	22.734	5.0
42.640	100.000	23.844	5.5
40.825	100.000	24.904	6.0



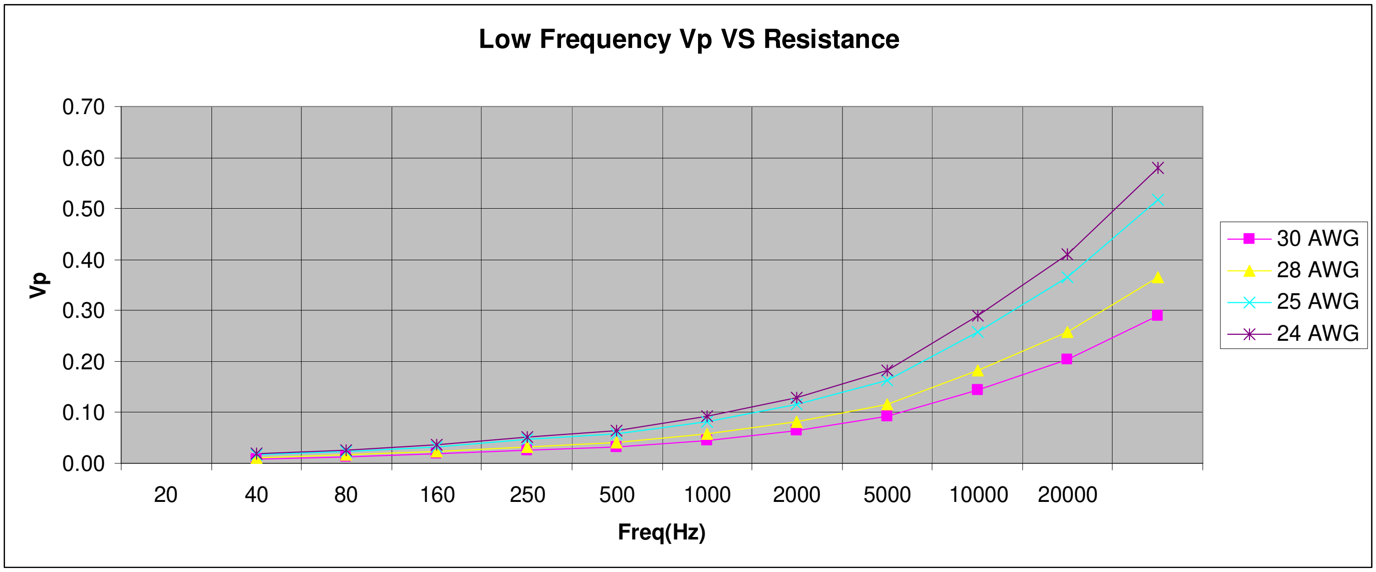
The graph above shows how capacitance is directly related to the dielectric constant for a 100-ohm RF cable type. "One" is air and higher values represents poorer and poorer dielectrics' velocity factor.

At RF;
Vp = (1/SQRT (dielectric constant)) or Vp = (1/SQRT (L*C))
L and C are "constant" from low frequencies through RF with a set dielectric material.

We certainly want to start with the lowest "e" value possible, and not just for capacitance alone. But does capacitance have to be as low as possible and we're done? Not exactly, no.

The above equation for low frequency Vp also has the variable "R". Resistance is almost always considered a "passive" element. It is thought to be responsible for ATTENUATION only, like turning up and down the volume knob. No, not really. It influences Vp non-linearity, too. Higher DCR flattens the Vp linearity through the audio band but ONLY if the DCR seen in each "circuit" is sufficiently isolated from other electrical paths. The data below shows what happens with RESISTANCE varied, and we HOLD the capacitance to 15 pF/foot (do we want ZERO R or C);

Vp ACROSS LOW FREQUENCY BY AW AWG

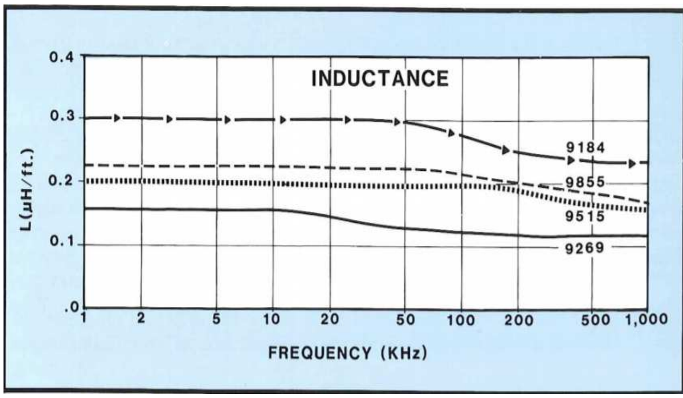


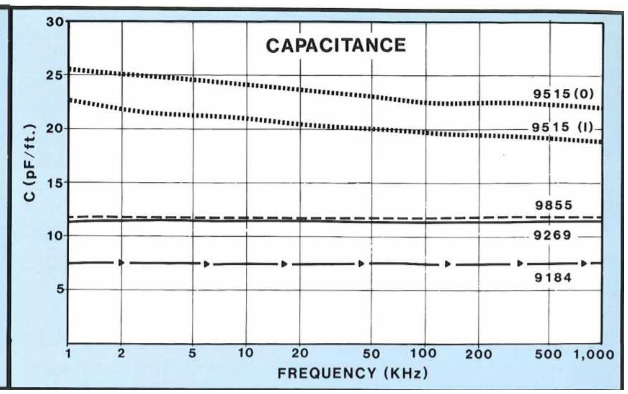
AWG (Loop/MTR/foot)		30 AWG	28 AWG	25 AWG	24 AWG
FREQ (Hz)					
	20	0.01	0.01	0.02	0.02
	40	0.01	0.02	0.02	0.03
	80	0.02	0.02	0.03	0.04
	160	0.03	0.03	0.05	0.05
	250	0.03	0.04	0.06	0.06
	500	0.05	0.06	0.08	0.09
	1000	0.06	0.08	0.12	0.13
	2000	0.09	0.12	0.16	0.18
	5000	0.14	0.18	0.26	0.29
	10000	0.20	0.26	0.37	0.41
	20000	0.29	0.37	0.52	0.58
R = Loop/MTR		0.676992	0.425744	0.212362944	0.1683952
C = Farads/MTR		4.92E-11	4.92E-11	4.92E-11	4.92E-11
Vp = SQRT ((2*OMEGA)/(R*C))					
OMEGA = 2*Pie*Freq.(Hz)					

The chart and table above shows that if we DECREASE the wire size which INCREASES resistance, we can also manage the Vp differential across the audio band. This allows us to use LOWER capacitance IF, IF, IF we can utilize higher DCR wire. Physics says we can't speed up the low frequencies, only slow down the higher frequencies. The curve flattens below 250 Hz. To avoid too high capacitance, we can also change just the wire DCR so capacitance can be held lower.

OBSERVATIONS – Let's look at a few things to better understand what we have to manipulate, and where they are working. We tend to understand "R", resistance, isn't stable with frequency as skin effect as proximity effect alters current efficiency.

In the ICONOCLAST prototype electrical table below we can see that the skin effect is predominant at higher frequencies in these designs. What most don't realize, is that L, inductance, and C, capacitance, are essentially the same across frequency. Yes, that GHz coaxial cable has C calculated and measured at 1 kHz.





Does our ICONOCLAST cable really show flat L and C, too? Yes, it does. The table below is an earlier design prototype that shows the R, L and C with frequency to 1 MHz. Notice R*swept* increases as we go up in frequency. Why? Some is skin effect and some is closely spaced wires. The proximity effect concentrates like current directions near the wire surface nearest one another, or pushes the current away from the two closely spaced wires in the reverse current directions. Both issues superimpose to decrease wire efficiency (less current uniformity across the wire cross section). This is why RF cables need conductive surface area not copper volume for low attenuation.

ICONOCLAST SPKR CABLE PROTOTYPE LUMP/ADJUSTED ELECTRICALS

Frequency (Hz)	L_s (uH)	R_s (mΩ)	C_p (pF)	L_s (uH/ft.)	R_s (mΩ/ft.)	C_p (pF/ft.)
20	0.9899	29.5020	211.1492	0.118	3.505	25.086
50	0.9039	30.3563	213.0893	0.107	3.607	25.317
100	0.8885	32.3966	213.8211	0.106	3.849	25.403
250	0.8500	23.8757	214.1101	0.101	2.837	25.438
500	0.8459	25.4571	214.5063	0.100	3.024	25.485
1000	0.8471	28.6772	215.7187	0.101	3.407	25.629
2500	0.8470	32.7426	215.7997	0.101	3.890	25.639
5000	0.8441	33.2218	215.8285	0.100	3.947	25.642
7500	0.8422	33.3735	215.8443	0.100	3.965	25.644
10000	0.8403	33.2784	215.7866	0.100	3.954	25.637
15000	0.8380	33.1024	215.7978	0.100	3.933	25.638
20000	0.8364	34.5638	215.8485	0.099	4.106	25.644
50000	0.8278	38.3403	215.8019	0.098	4.555	25.639
100000	0.8130	45.6621	215.8161	0.097	5.425	25.641
500000	0.7618	86.2206	215.8460	0.091	10.244	25.644
1000000	0.7494	115.6935	216.8898	0.089	13.745	25.768

Velocity of propagation and impedance are frequency dependent in the equations. BOTH have more complex structures as you drop in frequency. All three curves show increase impedance below about 1 MHz, and a steeper slope below 100KHz. The transition region is yet again another fitted equation.

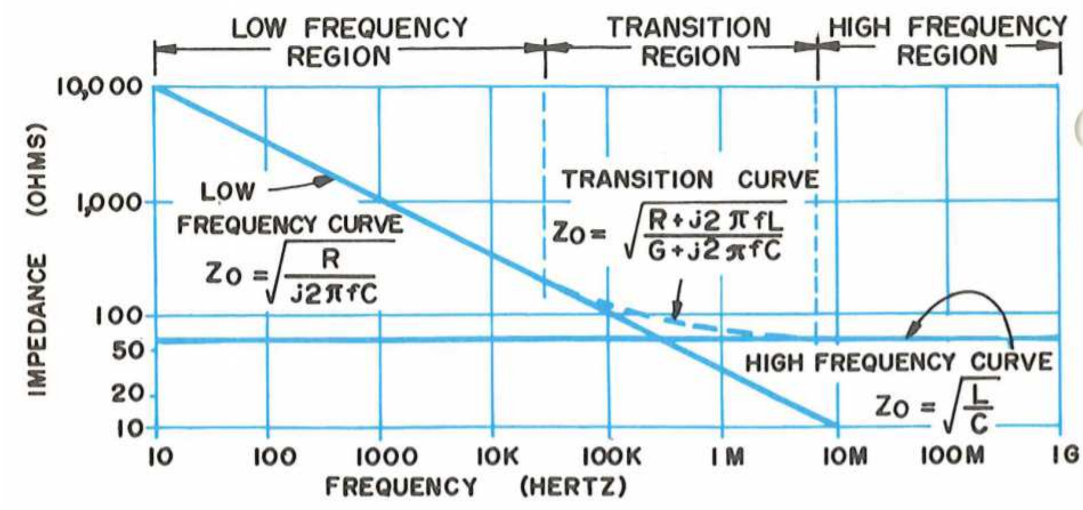
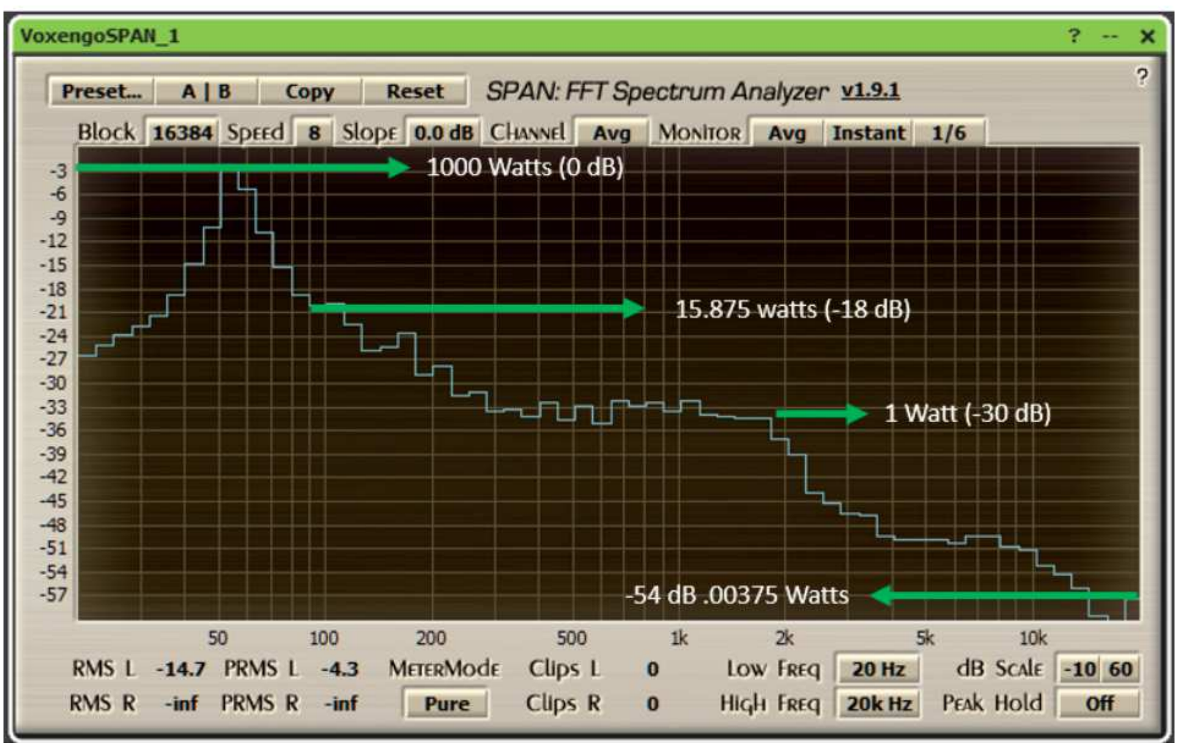


Figure 6. *Impedence vs frequency. (Dotted line joining low frequency curve and high frequency curve represents the transition region. Frequency range at which it occurs depends on the position of the low frequency curve.)*

The chart from Belden INNOVATORS®, SPRING 1972 clearly shows the fact that the impedance curve is non-linear and needs three separate "approximation" equations to characterize three different regions of test performance. The low frequency curve contains the imaginary component "j" times OMEGA or ϖ. OMEGA is equal to 2*pi*f. We saw this set of variables in the Vp equation at low frequencies too; Vp = SQRT (2ϖ/R*C). Capacitance is directly related: Vp = 1/ SQRT(E).

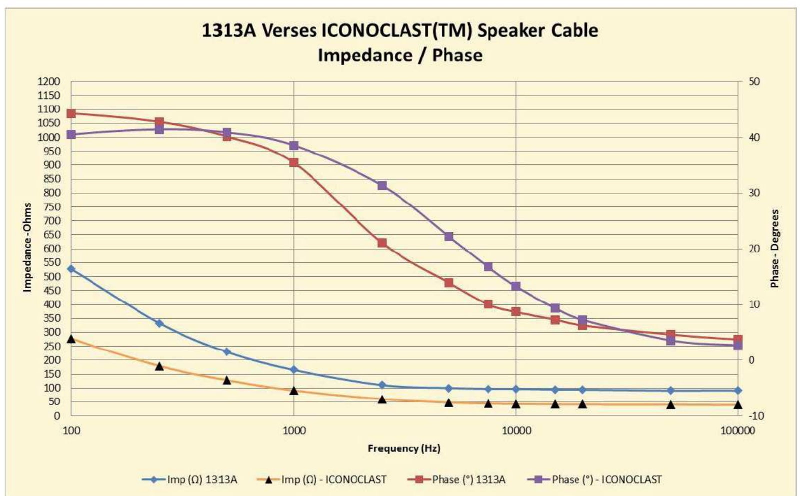
Why is increasing impedance a problem? Below we see a CHART from Paul's Daily Post that shows the energy spectrum of typical music. If we want to match power transfer, we need to do it at the highest average power spectrum we can with a non-linear distribution. Where is this actually? It is below 500 Hz, and smack dab in the region where the impedance curve is going up to much higher values than at RF's asymptotic minimum. This makes a true cable to low impedance load match technically impossible to do.



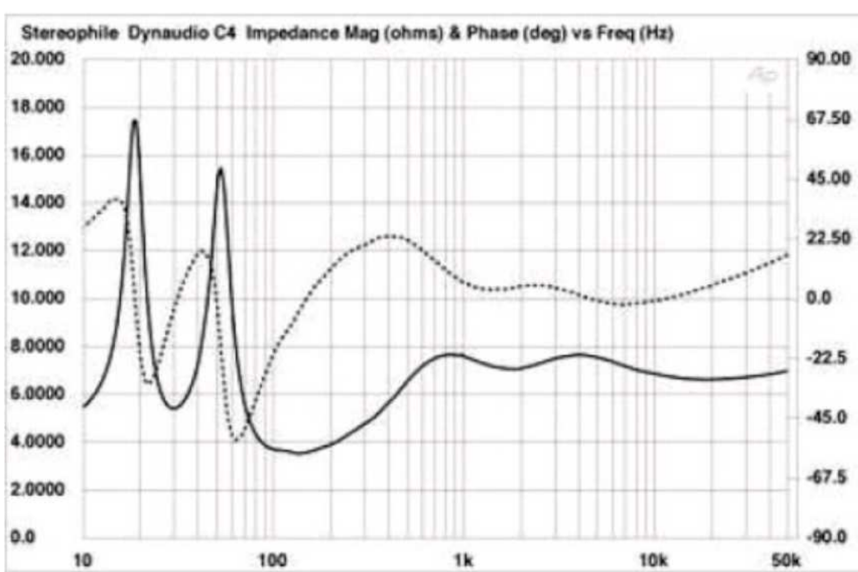
There is a near 1000 watt peak at 60 Hz. The impedance of a cable can not be close to 4 to 16 ohm in this region due to Vp non-linearity. True, and honest, impedance graphs of a speaker cable shows this to be the case. Better cable can indeed decrease the low-end impedance rise but not eliminate the physics we are working against that cause that impedance rise. The impedance and phase curves below exhibit proper open-short impedance measurements.

ICONOCLAST is a 0.08uH/foot and 45pF/foot 11.5 AWG aggregate design, all very good values for a complex design with 24 wires in each polarity to flatten Vp and thus lower the impedance rise at low frequencies. ICONOCLAST values fundamentally match a 10 AWG "zip" core 1313A (two 10 AWG wires parallel) response pattern.

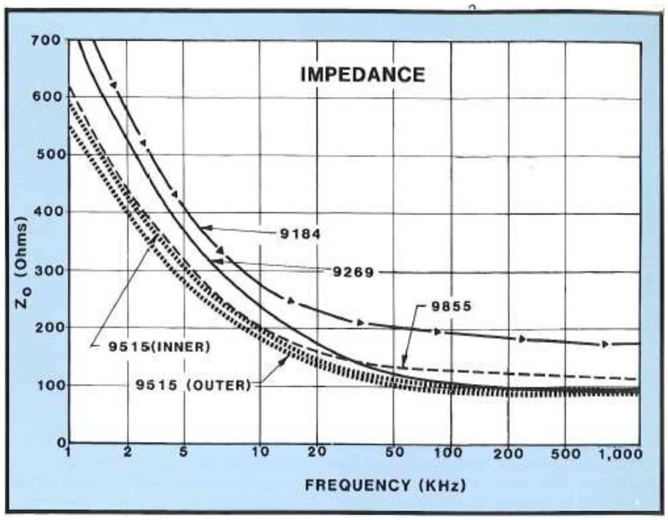
- ICONOCLAST LOWERS and FLATTENS THE IMPEDANCE



Here is what a typical ported speaker impedance trace actually looks like. Compare the impedances to what cable really does. We can't match "8-ohm" cable. SOLID – Impedance DASHED - phase



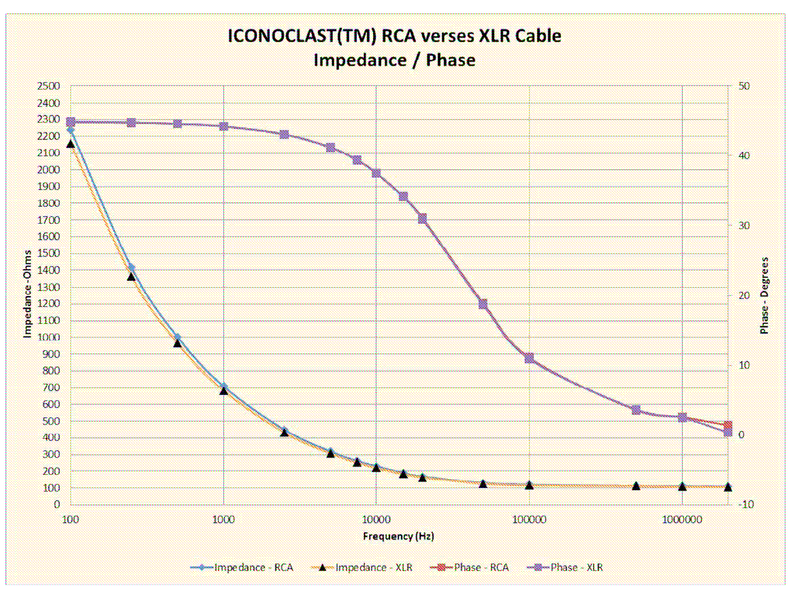
What do other cables do at low frequencies? The chart below graphs several measured cables. If we remember good old POTS type cable, we see that we can have 600-ohm cables at 1 KHZ! Yes, the dropping Vp differential low frequency properties increase impedance to about 600-ohms. We've decreased that effect to just 88-ohms in ICONOCLAST but 8 ohms is impossibly low reality in an open-short test. Capacitive reactance, Xc=1/(2*PI*F*C), keeps going up as the Vp keeps going down.



WHAT ABOUT RESISTANCE? The value of R in BOTH impedance AND Vp equations matters at low frequency. We generally think of resistance as insignificant and it isn't. As we drop in frequency we see R becomes more and more significant. The same is true in Vp across the low frequencies. R is important to the cable's performance if managed well. Capacitance can be increased to improve the denominator's factor, but we need to regard amplifier stability with too high capacitance.

We can't always rely on ignoring what we think is "passive." After all, R is REAL, or purely resistive so it is a good guy right? If you want to manage Vp across frequency the value of R is critical. What you do to the cable to raise the value of R will also impact L and C.

Let's see if the Interconnect XLR and RCA exhibit the same rise in impedance with frequency.



The above traces of the RCA and XLR are designed to have the exact same impedance and phase, thus the sound quality will track one to the other. I didn't want to make two different *sounding* cables, just two different physical *designs*.

Wow, look at the 100 Hz impedance, 2200-ohms and boy oh boy it does rise in impedance as frequency drops. That's certainly still a physical reality caused by the change in Vp. Is this a problem, though? What's happening?

Both cables are Generation one, and are 12.5 pF/foot and 0.15 uH/foot inductance. Extremely low values for IC cable. The DCR loop is the same as the coaxial's center wire, 25 AWG in size as the braid is so low resistance it is invisible. A there and back loop pretty much sees just the center wire DCR. The low braid DCR mitigates ground loop noise issues. It can't stop them, as this is really the ground point reference value.

IC cables terminate into a theoretical infinity load. We decided infinity is 47-k Ohm as a standard, higher is better. If we look at the load value to the cable, the load is so large the cable becomes near not there. Essentially no current flow and voltage signals are transfer across the end of the cable as though it was terminated into "nothing". The very low R and C in the Vp equation numerator cause the impedance rise. Since the load is so extremely high, the cable's open-short impedance isn't an issue as the signal essentially drops across the load and not the cable.

The series II RCA and XLR address the Vp linearity by increasing the AWG resistance to 30 AWG wire, and raise the capacitance to 17.5 pF/foot. This will flatten the Vp non-linearity. We can't go too high as voltage transfer function like to see low capacitance. PHASE through the audio band likes to see low inductance and the QUAD wire design lowers inductance to 0.11 uH/foot. We have limits to how and where we move the cable's non-linearity.

APPLICATION OF KNOWLEDGE - *The fundamental truth is shown. We need to INCREASE capacitance and/or INCREASE resistance to flatten Vp through the higher frequency audio band. Low impedance matching is hindered by rising capacitive reactance as frequency drops. Improving Vp linearity with just higher capacitance increases impedance at the low end by changing the capacitive reactance.*

Capacitance has to be mitigated to improve low frequency impedance and use resistance to manage higher frequency Vp linearity if possible.

There is a limit we can reach before other variables are compromised like inductance, total loop DCR, dielectric efficiency (air tube volume) and DCR voltage divider properties. The other parameters have to be carefully solved separately and then overlaid onto the Vp differential results to see how the overall cable works. How we reach the best R, L and C can result in some unique designs when we really try to reach best in class analog performance.

Most don't really understand HOW using many and/or small wires really work. Not only do we have Vp differential issues to solve but wire efficiency and smaller wire improves conductor current efficiency. The current through wire cross section is closer and closer to the same across frequency as wires get smaller. This improves conductor efficiency at the higher frequencies where the skin effect pushes the current towards the wire surface and proximity effect pushes and pulls current to one side of the wire.

The wire's self inductance makes the center of a larger and larger wire look more and more like a high impedance path to current flow. No current wants to flow in the wire's center as frequency goes up. One skin depth, per convention, is when the current in the subsurface of a wire is 37% what it is on the wire surface at specific frequencies. If a wire is small enough, it may never see current drop to 37%. Conversely a really large wire may see near ZERO current in the wire center at specific frequencies with the 37% value somewhere between the wire center and the wire surface.

We can improve wire efficiency through the audio band by either making wire smaller or, REMOVING the center of the wire where the copper isn't used. At RF, the later is really used where we replace the copper with cheaper materials like steel, CCS, or aluminum. This plating method works because we are at RF only and the SURFACE AREA determines attenuation where our signal really is flowing. And, we need all the surface area we can get at RF as that is our wire "size". RG11 versus RG6 versus RG59 coaxial cables share the same 40 micro-inch copper plating, but the 59, 6 and 11 are successively larger wire diameter (more surface area), thus lower attenuation at RF.

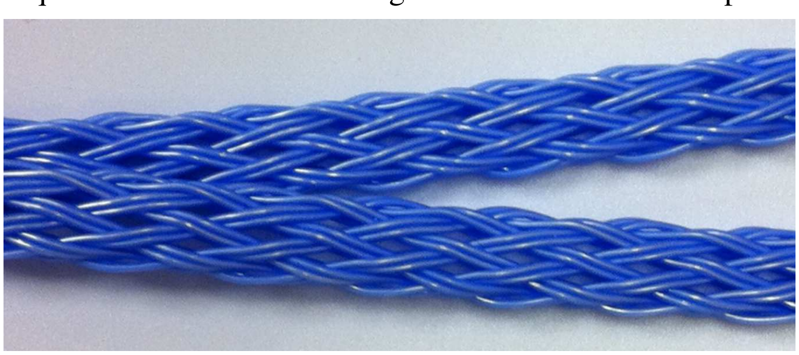
Some designs use hollow wire, but these are larger diameter structures with lower DCR which negates Vp flattening with lower, versus the needed higher, DCR. Small wires, and more than one, are needed in analog cable for the best performance; 4 in the RCA and 16 in the XLR and 24 per polarity in the speaker cable. The total number depends on the voltage divider rule, the current in each wire drops voltage at that "section". We don't want the voltage on the cable, we want it to be at the load. We can "trick" the voltage drop issue by dividing up the current. Current will split equally into each identical parallel resistance wire, and thus have a lower individual current value. E= I*R, so the voltage drop on each small wire is LOW as we dropped the current, I, even if we increased the resistance, R. How you make the wires "parallel" isn't straight forward to not mess up L and C.

Most IC cables are OK with one small wire, as they use 25 AWG or so signal wires, but the math says we can do far better if we try. More insulated wires increases capacitance, which seems initially good for Vp flattening but that changes L in the opposite direction significantly, too, which is bad for phase. The pesky third inter-related variable is always there no matter the other two you pick. To manage inductance as capacitance rises with more wires we employ phase cancellation technology to limit inductance in both speaker and series II interconnect cables.

In the audio range we use the ENTIRE wire cross section, so what we use has to be efficient at all frequencies. This means SOLID wire is best. We need to use one or more wire depending on the DESIGN to reach the proper DCR and Vp differential without excessive capacitance and inductance.

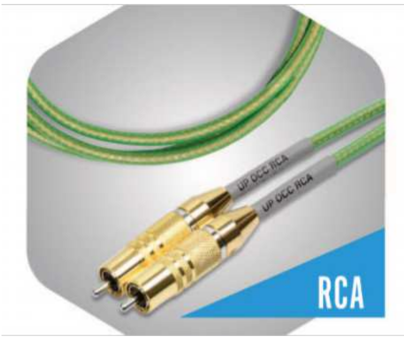
SPEAKER CABLE

The ICONOCLAST speaker cable uses a design that leverages many small 24 AWG wires with relatively low cap at 45 pF/foot. I chose to use a higher cap to further lower the Vp differential across frequency with twenty-four higher DCR 24 AWG wires per polarity (shown). BOTH improve Vp differential as we saw in the Vp analysis math. Balancing the capacitance and DCR both while being aware of where the Vp differential is going to be key. The unique design of the speaker cable allows lower capacitance with such a large number of small wires and to meet the voltage divider properties of the cable AND to use field cancellation technology to lower inductance to 0.08 uH/foot. Teflon® is used to allow tighter wire spacing and hold capacitance down and decrease loop area. The unique cross weave cancels magnetic fields to further drop inductance.

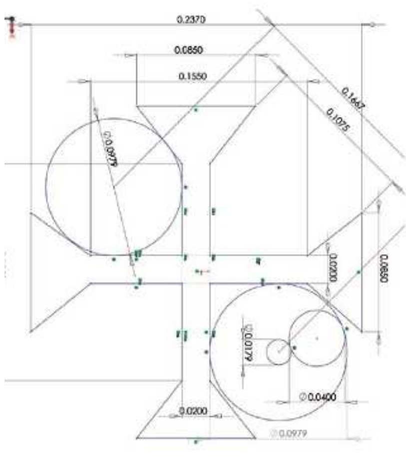


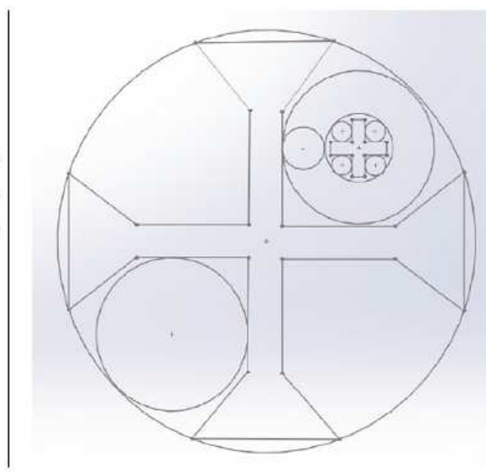
INTERCONNECTS

Generation ONE XLR and RCA use a small 25 AWG wire AND low 12.5 pF/foot capacitance. The SMALL center wire improves Vp differential, while the AIR dielectric allows tighter spacing at a given cap to allow a LOWER inductance to 0.15 uH/foot, or a small loop area.



Generation TWO XLR and RCA use a four wire 30 AWG "conductor" to INCREASE the separate wire path DCR to lower Vp differential even more. The capacitance DOES go up to 17.5 pF/foot. The smaller 30 AWG wire with higher DCR offsets combined with increased capacitance LOWERS the Vp differentials even further as both factors, R and C show up in the equation numerator.





SERIES ONE **SERIES TWO**

A series II star quad "conductor" lowers inductance to 0.11uH/foot to keep PHASE through the audio band LOWER than the generation one design. The changes allow a technically better analog cable to be made that meets known design properties.

Interconnect, by design, share the same LOOP DCR for the RCA and XLR of each generation.

RCA's loop DCR is essentially the center signal wire as the BRAID is almost "zero" DCR. This is why the center wire DCR is SO, SO important, it is "R" in the Vp differential equation.

The star quad 4x1 XLR (above left) is a full LOOP that use TWO wires in parallel such that the DCR is the same as ONE wire's measured value. We cut the DCR in HALF each way so a full loop is now the same as ONE wire's.

The 4x4 XLR (above right) uses FOUR separate wires per leg of higher DCR to lower Vp differential. Since we use FOUR wires in parallel, the LOOP DCR is LOWER than the 4x1 XLR even though we INCREASED the apparent signal wire DCR with four insulated current paths. The XLR wire size is critical to performance in the audio band.

SUMMARY: The ideal cable is always a balance of competing electrical properties. Resistance isn't as benign as we would like to think but utilizing its property results in some complex designs. Leveraging reactive variables, L and C are problematic, as it is a push-pull relationship. One goes UP when the other goes DOWN. We need to configure designs that are LOW L and C from the start. In my studies, allowing CAPACITANCE to rise some is necessary to meet Vp differential flattening but to not to allow capacitance to reach unacceptable values that would affect amplifier stability on either I/O line amps or power amplifiers.

All the mentioned variables are real. The net result of R, L and C in a cable is important. The ideal cable can't really be made entirely because we are making a reactive component. If we consider the tertiary effects of each variable, we can indeed improve what we design. ICONOCLAST is made with strict adherence to true calculation and measure to make the best possible cables current-manufacturing processes can meet.

That the cable sound different isn't a mystery to me, as the variables that would relate to TIME are improved and are directly associated with less distortion. *Sound Designs Create Sound Performances™.*