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2200 US HWY 27 South
Richmond, IN 47374

Phone: 765.983.5200
Fax: 765.983.5825

www.Belden.com

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RCA and XLR DESIGN BRIEF

In a previous paper I covered several issues that create signal distortion in audio cables. The most demanding variables involve the TIME related distortions that the ear is most sensitive to. Consideration must be made during cable design to mitigate the TIME based issues through the audio band. The following paper is the journey through the design process to arrive at a satisfactory RCA and XLR cable design. I must stress ALL quality cable designers have to work with the exact same known variables to solve problems at audio. Every cable is a compromise of some sort as distortions can't be eliminated. ICONOCLAST has made the outlined design decisions to arrive at, what we think, is an industry leading design based on real measurements.

SOUND DESIGNS CREATE SOUND PERFORMANCE™

RCA DESIGN BRIEF

1.0 Conductors.
 1.1 Copper Size.
2.0 Dielectric material(s).
3.0 Dielectric geometry.
4.0 Shield material and design considerations.
5.0 Jacket design and material considerations.

The design process will start with the RCA cable as this provides the most pristine electromagnetic properties possible due to the seemingly simplistic design. Once all is said and done it is "simple" looking. The more complex XLR will have to, somehow, match the RCA's electromagnetic properties if it is to be an "equal" on measured attributes. If the RCA isn't any good, I may as well start over again!

1.0 Conductors / RCA

There is a lot of mystery around copper. The grains, the molecular arrangement of the crystals themselves were recently found to NOT be what we thought; https://phys.org/news/2017-07-fundamental-breakthrough-future-materials.html).

"…granular building blocks in copper can never fit together perfectly, but are rotated causing an unexpected level of misalignment and surface roughness. This behavior (sic), which was previously undetected, applies to many materials beyond copper and will have important implications for how materials are used and designed in the future..."

The battle for material supremacy continues. However, what we tend to discount is that while the overall design of the tire we put on the car is important, the rest of the car has more to do with what that tire does than just the tire. We tend to over spec the tire and vastly under spec the car. I'm intent on building the car, not the tire.

The decision to use copper is based on several factors, none of which were price. Copper offers the best material for affordable cables with a significant level of performance in more ideal electromagnetic designs. Far more expensive materials in lesser designs won't work, and far more expensive materials in superior designs won't work…for most of us anyway.

Copper is available in several process treatments and after process treatments;
ETPC (as good as what used to be OF grade).
OFHC (differing process, but *far* from *vastly* lower impurities content).
OFE is another step in the purity of copper above OFHC (what ICONOCLAST™ uses).
UP OCC (what is often called long grain type, and again a differing process to further improve purity and less grains per unit lenght).
Cryo treatments (used to improve copper's PHYSICAL properties).
Grain direction (music is AC. Which polarity do you like first and at what frequency?).

I don't use wire "quality factor" as a design element since every contemporary draw science for wire is vastly better quality than ever. Sure, some processes are more $$$ but there is scant repeatable measurement that I can do other than conductivity, a passive resistive measure that will influence resistance. The conductor type is an option for the customer to listen to, only. There are differences. Belden just isn't in the position to create a pet project to define what isn't yet scientifically defined. That's not our thing. What can be measured is leveraged into every design to the lowest values possible using Belden technology.

Belden offers the three fundamental copper grades; ETPC, OFE and UP OCC, as they DO sound different in the exact same electromagnetic R, L and C referenced design. No changes other than the copper, so we know what the culprit is (copper draw science / process). What we don't know, is precisely WHY it is the culprit. Instead of making up a big old story, again, about the material, we don't. It is what it is in use and we leave it that way.

What we don't offer is what I can't hear as a designer. Sorry, but I've yet to hear CRYO treatments, intended to improve the wire's PHYSICAL strength or grain consistency and direction, change the sound. As far as grain direction goes, you can flip the leads in any direction you want, as the wire's grains all go the same way due to the manufacturing process that we use. If you can hear the direction switch, flip them any way you like. We won't send you a bill for that!

Any material used in a superior design SHOULD sound as good as it can, and cost isn't a direct line to better sound. I ignored cost when I designed ICONOCLAST™, either high or low. If my system didn't allow me to hear it, I didn't use it (materials) or do it (process / design).

This isn't a paper on conductors, although I may have some things to say about alternatives to copper later on in another paper based on some measurements and calculations I've done. We're talking copper in this paper as it is the very best economical solution that we have right now, and based on skin depth and resistivity.

Copper has a very low DCR, a reasonably deep skin depth to manage current coherence, is pretty high in tensile strength for processing, and in most applications resists severe oxidation. The grain structure is clearly visible in form, but that alone is NOT what makes the different grades sound different. It is a trait of the draw science, but does not have, as much effect on the sound as you would be lead to believe.

Use solid or stranded wire? This, at least, is easy. Is stranded better for the way the cable is used? Is stranded more, or less, expensive? Is stranded easier or harder to process? Is the termination of the cable better or worse with stranded wire versus solid? Are any gremlins that I call tertiary variables (stuff there isn't a measurement or calculation for) removed if the truly measureable variables are accounted for between stranded and solid?

ANSWER – Solid wire wins hands down for this application. Every question is in solid wire's court. End use, costs less, processing cost, ease of termination and lack of tertiary elements (all those diode effect "arguments" between strands and more).

On that, though, a note: the first generation of Iconoclast interconnects use single solid wires for the signal-carrying conductors and that's what's discussed in this paper. Our second generation product (suitable for analog but not for digital due to impedance issues) uses a star-quad arrangement of four separate wires, placed around a separator, in place of each of these conductors for improved inductance; for details see the fourth paper in this series. Other than this change in the signal conductors, the "Gen 1" and "Gen 2" interconnects are the same.

1.1 Copper Size / RCA

We now have SOLID copper wire. The size selected sets the foundation for the whole thing if we consider that the cable's structure is supposed to allow a conductor to be as near zero R, L and C measurement cable as we can design. Practical current demand issues allow much smaller wires, with higher DRC to be used very effectively on interconnect leads.

You can't use a conductor you can't process. For the RCA cable, we want as small a wire as we can process as this will force the best current coherence through the wire (same current magnitude at all frequencies through the wires cross section). The exact skin depth calculation is a tool we use to gain the *knowledge* to reduce the wire size in audio cables. At RF, we use it to tell us how much copper to put over a STEEL support structure to maximize RF attenuation. Audio is not RF, and the ENTIRE wire is used to move the signal and at ALL frequencies concurrently, not the same issue at all in RF cable design.

RCA cables terminate into a theoretically infinite (47K-120K or there about) input resistor. We say impedance, but it is really as resistive as it can be made at the input op-amp level. Yes, purist will point out that input impedance DROPS some at higher frequencies, but this is inconsequential in a good design.

If the impedance is very high and the current is very low (it looks like an open circuit) just use as small a wire as you can! Well, yes and no. It has to be reliably terminated and secure in the end product, and it has to process evenly under tension and not fracture from surface issues.

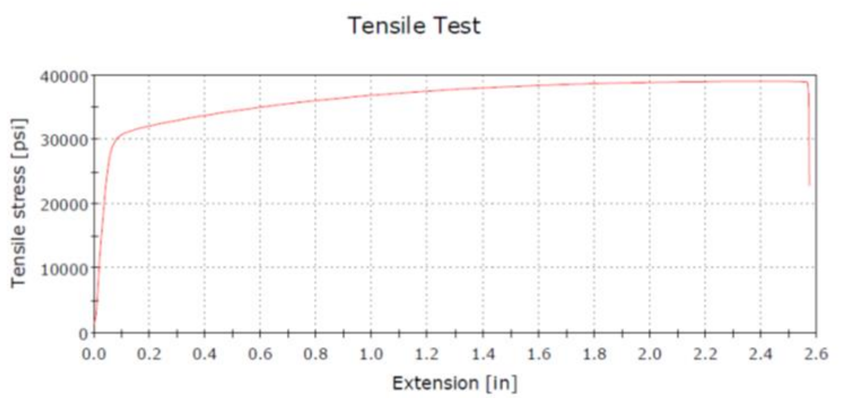
A review of the end of process design backs into the initial design requirement. Calculations and testing selected a 0.0176" diameter wire for ICONOCLAST. The process has to handle less than 4-3/8 pound tension to avoid permanent wire stretching. Wire was tested for the process requirement.

- 30,000 PSI x ((0.0176” x .5)^2 x 3.14) x 0.6 safety factor = 4.374 Lbs.

Adhesion Testing Results

	Specimen ID	Diameter [in]	Load at Break (Standard) [lbf]	Tensile stress at Break (Standard) [psi]	Extension at Break (Standard) [in]	Max Load [lbf]
1	25AWG OFHC	0.01760	9.48	38,964.30	2.56	9.50572
Mean		0.01760	9.48	38,964.30	2.56	9.50572
Std Dev		-----	-----	-----	-----	-----

	Tensile stress at Maximum Load [psi]	Extension at Maximum Load [in]
1	39,072.39655	2.41433
Mean	39,072.39655	2.41433
Std Dev	-----	-----



The 0.0176” diameter wire (0.0088” radius) is one half the diameters necessary for one full 18-mil skin depth at audio, so we have significantly improved current coherence through the wire @ 0.0176” diameter wire. Skin depth is FREQUENCY driven for a given material. The smaller the wire the larger the inner current magnitude will be relative to the surface current. We want as good a shot of that as we can get.

The RCA cable’s loop DCR will essentially be the center conductor in an RCA, if it is made right, and ICONOCLAST is. The center wire governs attenuation. The outer conductor is, in theory, infinitely low impedance so it nearly drops out of the loop DCR calculation and leaves the center wire. The length of the cable relative to the input impedance allows a SMALL wire at audio. At least attenuation works in our favor at audio as it is a LOG relationship and gets really high very quickly as you go up in frequency. For audio, we can relax a bit on attenuation as it is low for the lengths we use and is in the right frequency range to stay low. Attenuation is a passive “distortion” and is VERY hard to hear over TIME based distortions.

2.0 Dielectric Material(s)

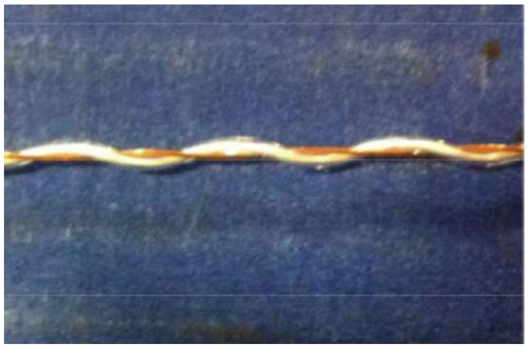
We’ve already made a critical choice in our cable. The wire material and size. We’ve used good engineering practice to KNOW what the decision will yield. Now, how to RETAIN all that the material / size wire can provide? That’s easy, just stick it in air and find an infinitely low ground potential for our unbalanced / single ended wire!

OK, this IDEA is easy. The execution isn’t. I don’t care about speed of the process and / or costs as I’ve used REASONABLY affordable material as my conductor. We can always go back and break the bank on conductor materials. AIR is free, but expensive to get. Air is by far the best dielectric to have, and especially nearest the wire were the influences are the worst on group delay. The closer to the wire the dielectric is, the more it influences the overall velocity of the composite structure (wire / beading/ then plastic tube thickness / then braid)

I decided to go the tough route and use air. We can use RF as a HINT at what to do overall. We have used designs called semi-solid core dielectric RF cables. These partially suspend a wire in a tube with a spirally wrapped thread. The problem is that the wire SIZE and the core tube properties aren’t suitable for audio frequencies. Even the choice of materials isn’t as important at RF as we can reach a set impedance vector (real + the reactive inductive and capacitive parts all added together) by tweaking the thread and tube dimensions.

3.0 Dielectric geometry

The audio signal is very sensitive to the dielectric effects of the plastics near it. I chose a specially made beading thread to get the job done.

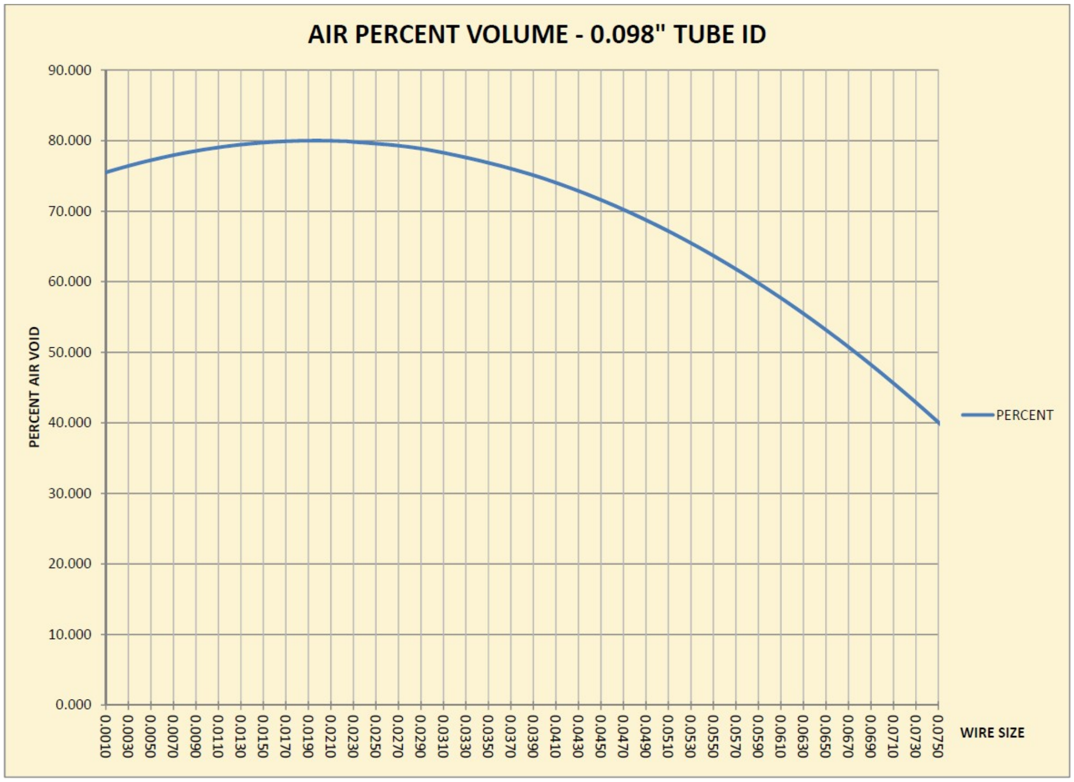


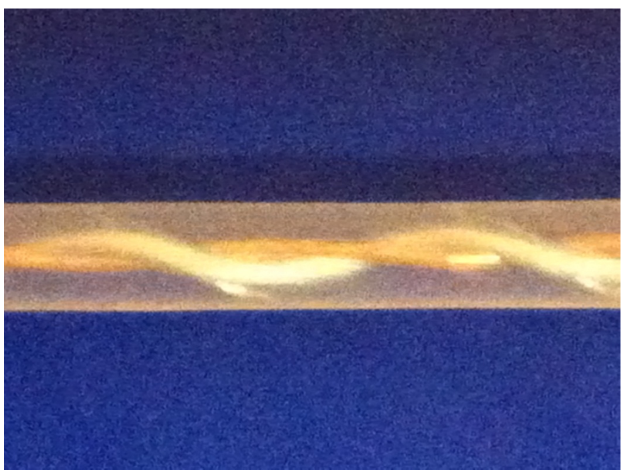
The above picture beading around the wire is a glass thread coated in pure TEFLON®. I use a ROUND beading shape versus square, as it touches the wire at the tangent points for the very LEAST effect nearest the wire. The electromagnetic field sees the entire cross section of the plastics and material between the wire and the inner braid, so I use GLASS thread inside the beading as it is a good dielectric, too. Why is the glass there? A solid TEFLON® bead can't be processes at this size and keep consistent dimensional linearity. The glass is the true STRENGTH member in the beading, not the plastic. The plastic is to set and hold the shape. The glass lets me process the beading at production speeds.

Why TEFLON®, really? OK, I'll tell you. It has the lowest dielectric constant of any solid plastic. It is TOUGH in thin walls for end product dynamic stability; the bead should STAY round under side-wall pressure. This is a SMALL bead, so I need that toughness. TEFLON® has high T and E's (tensile and elongation) properties for process toughness. We don't have much process room, as I've calculated backwards how big this bead would need to be in this design and wire size.

How big should the conductor be based on a tube ID? There is ONLY one optimum asymptotic wire size driven MAX AIR volume (%) based on the tube ID. The ratio of the tube ID with the 80% air void to the inner braid surface will determine the capacitance. Maximizing the air content will improve the efficiency of the dielectric so the smallest loop area for inductance will also yield the smallest measured capacitance.

TUBE ID	WIRE SIZE	BEAD DIAMETER	TOTAL AREA TUBE ID	TOTAL AREA WIRE	TOTAL AREA BEAD	TOTAL AREA AIR	WIRE PERCENT	BEAD PERCENT	AIR PERCENT
0.098	0.0175	0.0403	0.007542964	0.000240528	0.00127239	0.006030042	3.189	16.869	79.943
0.098	0.0180	0.0400	0.007542964	0.000254469	0.00125664	0.006031858	3.374	16.660	79.967
0.098	0.0185	0.0398	0.007542964	0.000268803	0.00124098	0.006033183	3.564	16.452	79.984
0.098	0.0190	0.0395	0.007542964	0.000283529	0.00122542	0.006034018	3.759	16.246	79.995





Here is what happens when we CHANGE the wire size;

TUBE ID (IN)	WIRE SIZE (IN)	AIR PERCENT (%)
0.070	0.0140	80.00
0.098	0.0200	80.00
0.123	0.0220	80.00
0.150	0.0300	80.00

As the wire gets bigger or smaller inside a given tube ID, it crowds out the air. We COULD go drastically big in the ID of the tube and wire size (0.150" tube ID)…but we want to hold INDUCTANCE and signal coherence in check. Inductance is the loop area between the wire and the inner braid, and that needs to be infinitely close, the opposite of capacitance. For a given tube ID size we want the maximum amount of air void and the smallest possible wire to braid distance. This means the conductor wire size has to be as small as you can process, and with the desired capacitance. As the tube ID gets larger, cap will drop but inductance will rise, and the opposite with a smaller tube ID. The design target is 11.5 pF/foot on the bulk cable to assembly capacitance would be 12.5 pF/foot.

Using too large a wire hurts frequency coherence so we pushed the wire size DOWN until inductance was moving off spec relative to capacitance. A balance was sought between wire size (coherence) and reactive variables (L and C).

I can do a quick check to see how I'm doing by applying a test ground over a ten foot sample. Using RF frequencies as a "constant" since the velocity has stabilized to an asymptotic maximum, we measure really high VP values, ~ 87%. This is good as it allows me to reference to end capacitance, too. I just treat the cable like an RF cable and work the capacitance backwards from the open – short Impedance; Z = 101670 / Cap * VP. This is about 104.6-ohms so capacitance calculates to 11.2 pF/foot versus a measured value of 11.19 pF/foot.

We know from the previous paper that Capacitance and Inductance are FLAT with frequency, and are actually measured at 1 KHz. Our 11.19 pF/foot bulk cable value is true at 20Hz-20KHz. Inductance is a low 0.15 uH/foot through the audio band as well.

Lab Report	Description
134778	PDB1610 B24

	Length(ft)	Freq#1 (MHz)	Freq#2 (MHz)	Freq#3 (MHz)	K1	K2	K3	VP1%	VP2%	VP3%	Avg. VP%
1	10.25	104.01	145.88	187.85	5	7	9	86.67	86.83	86.97	86.8

Capacitance @ 1 MHz per ELP 423, Agilent E4980A Precision LCR Meter, Belden's Cap/Ind Test Fixture

Spec for Cap @ 1 MHz: 12.5 +/- 1 pF/ft
PDB1610 B24 Cap @ 1 MHz: 11.1947 pF/ft

Characteristic Impedance per MIL-DTL-17H (ELP 142) using the included equation:

Char. Imp per ELP 142: $\text{Imp} = \dfrac{101670}{\text{Cap x VOP}}$

Spec for Impedance: 100 +/- 5 Ohms
PDB1610 B24 Impedance: 104.631 Ohms

SEMI-SOLID PDB1610 finished "assembly" with RCA
CAP 12.25 pf/foot
IND 0.1450 uH/foot

Inductance isn't as critical in high impedance leads as current, which is ride time limited by inductive reactance, which is near ZERO, but in my listening test, cable with near zero on BOTH L and C attributes sounded best, and a BALANCE needs to be considered. The cable isn't big or small; it is what it needs to be to WORK. The wire size we start with sets this all into motion.

The FEP tube is critical to get right. Special processes are used to keep it on-sized and ROUND over the beaded center wire.

4.0 Shield material and design considerations.

We have a core tube and know the electricals, so now what? The braid is much more important than people think, and for a different reason than people think. No, it isn't shielding, either. True, a double 90%+ braid have 90 dB RF shield properties but, I sure hope your equipment isn't THAT sensitive to RF. Foils are much better and more economical for RF than a single 80% braid and the shield reaches the 90 dB mark far more cheaply.

RF cables are "shielded" to RF noise and IMMUNE to low frequency nose (outside their pass band) because the shields have a low resistance to RF, measured as transfer impedance. This is sort of like low DCR at audio frequencies, but relates to how high frequencies work. Audio cables are not RF cables!

We need to look at how unbalanced circuits work. They SHARE a ground…or do they? They are SUPPOSED to SHARE a ground. They don't. RCA unbalanced cables use the CHASSIS as a ground to the wall outlet or it is floating in some cases but the REFERENCE between the grounds is still there. In ALL cases, there is that pesky WIRE thing called the SHIELD between the ground points on every piece of RCA equipment you use. That wire has RESISTANCE and that resistance creates a ground potential difference so current starts to flow between the two end grounds. E=I*R, remember that? A VOLTAGE is impressed against the center wire and the magnitude of that voltage is the current times the resistance. We can CONTROL the "R" by using TWO 98% copper braids. This is $$$ to do, but it is the RIGHT thing to do.

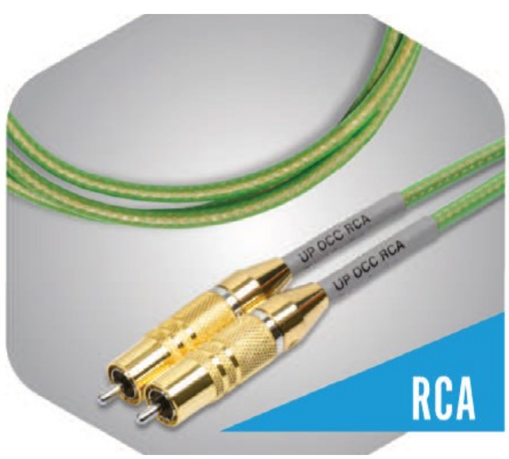
No, those braids won't shield MAGNETIC interference. The HUM you hear is more than likely ground loop current through the braids resistance called SIN; Shield Induced Noise. The lower the braid DCR is the better the SIN rejection. You need low permeability shield to block low frequency magnetic waves (anything below about 1 MHz starts to have a considerable B-field bent over E-field). Good audio RCA cables ARE NOT going to shield B-fields. They will shield E-fields and reduce SIN noise.

To shield magnetic B-fields a MAGNET needs to be able to STICK to the shield. This is an indicator that the material is "influencing" the magnetic field flux lines INTO the metal and OUT OF the air. We can manage the SIN noise with a good ground, but true extraneous magnetic noise is still tough with unbalanced cables. Now you know why. It's the ground system it uses.

5.0 Jacket design and material considerations

ICONOCLAST uses an FEP jacket for some good reasons. FEP is the most chemically inert material there is, protecting your cables from chemicals and UV exposure through those nice picture windows in your house. Lesser plastic material isn't as stable, or inherently flame retardant. Nor can many materials be used in thinner walls.

Plasticizer migration out of the cable, especially near heat, is a real issue in contact with polyester or nylon carpet that would love to be the same color as your cable laying on it! My previous cables were. FEP does not have this issue and will look nice for decades to come. Yes, it costs some more but these cables are an investment into the future and can follow your system several steps above where you may be now. Based on durability, stability and inertness to solvents, FEP is the best choice for the long haul.



RCA SUMMARY - Knowing that RCA cables aren't as "shielded" at audio as we think, what can we do about that? If you don't have the problem, you're good to go! RCA is a great sounding cable by fundamental electromagnetic design. This is why it was created. It does have magnetic noise immunity issues, though. There is no magic to good cables; it is adherence to strict design rules that also encompass those “magic” tertiary variables called wire science. The same design adjusted for a new material’s skin depth properties can be made to the same “ratio” and match the electricals with differing wire. The layers of the onion and their thickness can be altered (L and C values) depending on what is most audible. Tests won’t tell you that, this comes from design experience. This does NOT mean that either L or C can be thrown to the wind. Both L and C cause TIME based distortions and neither is welcome in good cable.

Then there is the next cable I’m going to talk about that does exactly that, except it is far, far harder to make as good as an RCA electrically. It is called the XLR cable.

XLR DESIGN BRIEF

XLR

1.0 Conductors.

1.1 Copper Size.

2.0 Dielectric material(s).

3.0 Dielectric geometry.

4.0 Shield material and design considerations.

5.0 Jacket design and material considerations.

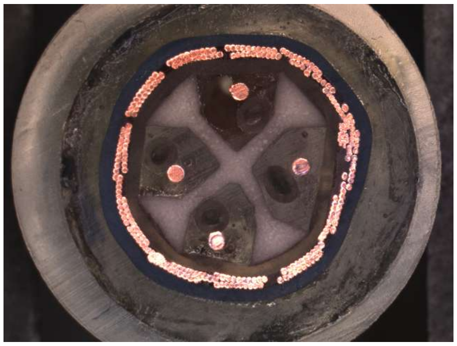
1.0 Conductors.

1.1 Copper Size.

BOTH of the copper conductor and size considerations were answered when we started the RCA cable. We don’t want to change the current coherence with a differing conductor diameter if we are to mirror the reactive variables, too. We need the same exact wire to shield reactive L and C parameters in each cable in the end configuration design. The geometry of each cable is entirely different so how to you do that? That is, assuming you *want* to match the RCA and XLR properties and maintain the same signal quality…and we certainly do. There is no reason to copy a bad sounding RCA cable when designing an XLR, so the RCA is designed FIRST.

20. Dielectric material(s).

One difference in the XLR is that we are going to use FOUR wires in a star quad configuration. (Note: in our "Gen 2" XLR product, there are sixteen wires -- four wires making a star quad in place of each single wire in the design shown below. For more detail, see the last paper in this series.) Four wire XLR cables use two cross-connected wires for each polarity, which doubles-up the wire AWG for lower attenuation. Two 25 AWG have the DCR of a single 22 AWG yet has way better signal coherence by using smaller wire.



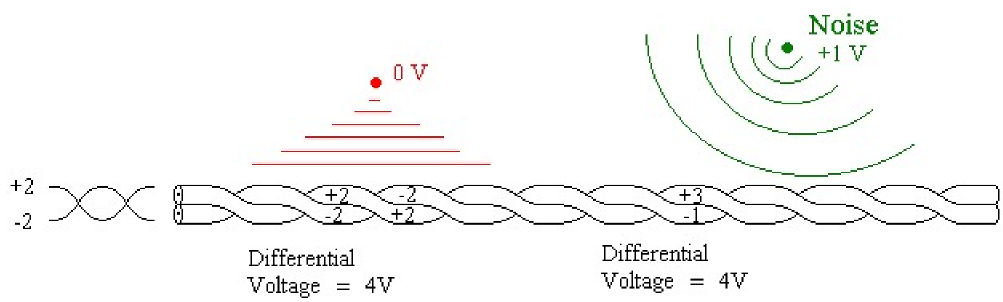
I could have used a cheaper and easier two wire XLR design but the inductive and signal coherence benefits of a star quad are too good to pass-up. If I can get the materials and quad design to achieve a high enough level of performance it is a better cable design.

Star quads have a higher degree of CMRR (Common Mode Rejection Ratio) when properly signal balanced. There are three primary reasons for this;

- The two or four wire stranding "twist".
- The differential encoding.
- The outer shield properties, but only at RF frequencies.

Two wires of a star quad are a "positive" voltage, and two wires are a "negative" voltage (180 degrees out of phase), hence the term "balanced". If the cable were a teeter-totter, it would sit level. Some call this differential mode since each signal is equal but different.

Differential Mode Transmission
Perfect Wire Balance Equals Less Noise



In the example above we show two wires, but the system is the same in a star quad. The signal we WANT is encoded as +2 volts and -2 volts. The noise can't "change its spots" relative the cable's twisted pairs and shows up as the same voltage on each wire, +1V noise in this example. The TWIST ratio helps make sure that the wires see the noise the same amount of time and this is vital to the function of the circuit.

Here is where the balance is so important; the signal IDEALLY becomes the superposition of ALL the voltages, or +3 volts and -1 volt. No more, no less. The signal voltages are STILL exactly 4 volts "apart" from each other; +2 to -2 with no noise and +3 to -1 volts with the noise. The signals are fed into a difference amplifier that, you guessed it, looks at the "difference" between the two voltages and see's 4 volts with, or without, the noise. The noise is absent in a perfect world at the difference amplifier's output.

In order to do this, every wire has to be presented to the noise in the exact same way via the cable twist and has to be the same length so the signal stays TIME aligned down the wire and has to have the same attenuation. The difference amplifiers need to be nulled perfectly between gain halves. Believe it or not, this gets done really well with good quality products.

The control tolerance of the copper is 0.0005", so attenuation issues are mitigated and CUB (Capacitance UnBalance) tests insure we see MIL standard quality in the finished cable. All quality types of copper can be used in the XLR design. It is the overall structure that is the most "magic" and not as much the copper itself, although the copper draw process does influence the sound.

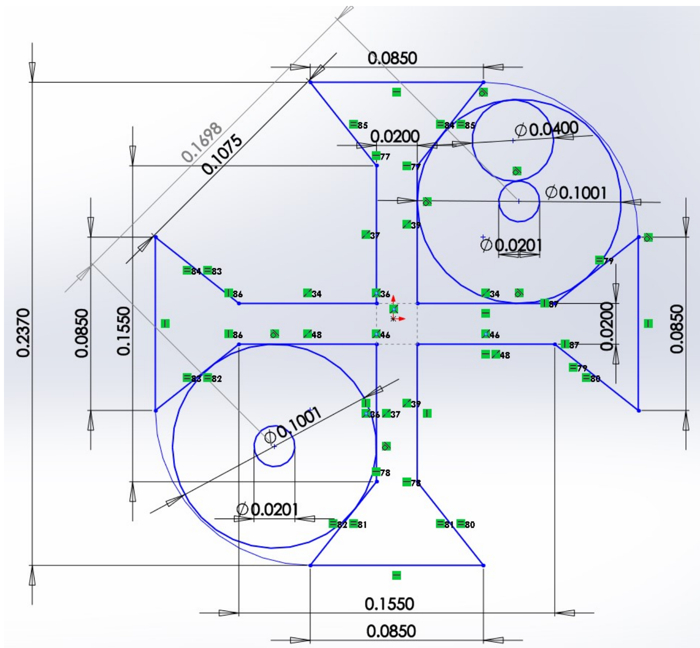
We have several variables that aren't present in a coaxial cable design to contend with;

- CUB, Capacitance Unbalance or, each wire shows a differing capacitance to ground.
- DCR unbalance, each wire has to be the same DCR.
- CMRR remainder, the differential signs have to NULL to the exact same point neither above nor below reference ground.

3.0 Dielectric geometry.

Lots of words, time for a picture;

ICONOCLAST™ XLR END VIEW



The above CAD drawing is what we have inside our XLR design so far (well, I ignored two wires in the drawing).

Remember I wanted to make L and C reactive variables EXACTLY the same for each cable with EXACTLY the same wire size and draw science? What else do we know? I also said that CAPACITANCE is sensitive to the distance to a conductive plate area, and that means ALL the way around the wire. The coaxial cable is easy; we purposefully put a ground around the wire at a known distance that defines the capacitance ground plane reference distance and inductive loop area.

Iconoclast_RCA.ai

Iconoclast_RCA_CrossSec.ai

Iconoclast_XLR.ai

Iconoclast_XLR_CrossSec.ai

In the coaxial cable, the center of the wire to the inside of the tube is 0.098" / 2 = .049". Ok, so what? This is what. The capacitance is a squared law property and predominantly sees the ground closest to the wire. The shield on the opposite side of the XLR cable, to a first approximation, falls a way. We actually measure the capacitance BETWEEN the two cross paired wires but the ground location still influences the capacitance. Also, we have four wires that are capacitors.

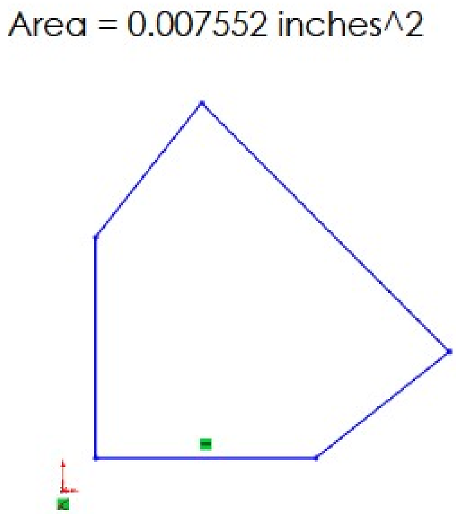
This doesn't "sound" good, does it? We have four times as many wires and all have capacitance. Somehow this is supposed to come out around 12 pF/foot (with connectors), same as the RCA!

Now for the inductance part, L. Inductance is loop area defined. It could care less about the dielectric, but the graph above shows a HUGE ~0.170" loop area! How is THAT going to get to the 0.15 uH/foot inductance of the coaxial cable? I could make something up, but that isn't as neat as what's really going on.

To get capacitance as low as I need it to be to match the coaxial cables, I use DISTANCE between the wires. And yes, this DIRECTLY sets what the inductance will do…hold on a minute. By using AIR, I can set the C-C of the wires to meet my capacitance target needed for the final tested value with two cross wires connected and tested between them. AIR lessens this distance for a given value of C so I can also manage inductance now. For inductance, L, the smaller the wire loop area the better for a given value of total capacitance. Air gets me far closer than any other dielectric.

How much air? Well, EXACTLY the same as the coaxial cables! How do we do that? The standard answer is, "very carefully". Let's look at a drawing;

ICONOCLAST™ XLR CHAMBER VOLUME



Still, so what? Yep, I agree, until we compare this area to the area in in the RCA cable air dielectric; 0.00754 in^2. OK it isn't exact; I missed by ~0.000009" in^2. I use the exact same thread design around each identical wire so it's all the same area in the chamber as in the RCA.

TUBE ID	WIRE SIZE	BEAD DIAMETER	TOTAL AREA TUBE ID	TOTAL AREA WIRE	TOTAL AREA BEAD	TOTAL AREA AIR	WIRE PERCENT	BEAD PERCENT	AIR PERCENT
0.098	0.0175	0.0403	0.007542964	0.000240528	0.00127239	0.006030042	3.189	16.869	79.943
0.098	0.0180	0.0400	0.007542964	0.000254469	0.00125664	0.006031858	3.374	16.660	79.967
0.098	0.0185	0.0398	0.007542964	0.000268803	0.00124098	0.006033183	3.564	16.452	79.984
0.098	0.0190	0.0395	0.007542964	0.000283529	0.00122542	0.006034018	3.759	16.246	79.995

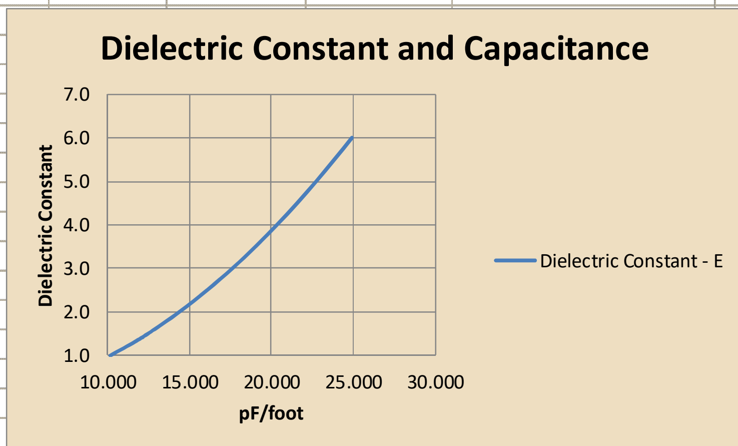
Let's do some reality checking as to what it SHOULD be based on MEASUREMENTS and calculations.

- We have the EXACT (can I say that as close as it is?) same velocity of propagation based on the composite (air and plastic inside the ground plane) dielectric; 87% at RF reference.
- I measured the IMPEDANCE at RF @ 100 ohms, same as the coaxial cable.
- The dielectric constant can be calculated and from that the VP, VP = 1/ SQRT (E).
- And from that composite dielectric I also know what the capacitance has to be.

Capacitance (remember that chart on dielectric value and capacitance earlier?) is directly linked to the group dielectric constant. I know VP, and I know the impedance, so I can calculate the capacitance and then get the dielectric constant from that.

101670 / (C * 87) = 100 ohm
C = 11.68 pF/foot.

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



What does the cable actually measure on capacitance? The chart below shows 11.767 pF/foot. Notice that the capacitance values between each of any two wires has to be ~ 5 pF/foot to "double-up" the two wires capacitance and still to arrive at a final ~11 pF/foot! Yep, that's LOW capacitance. Capacitance adds in parallel so this is a significant issue when a design uses four wires.

Capacitance @ 1 kHz per ELP 423, Agilent E4980 Precision LCR Meter, Belden 4TP Cap/Ind Test Fixture
Both 1000ft sample & 10ft sample were tested for each code, the Raw data was meaured in nF/1000ft & pF/10ft

PDB1610	Length (ft)	Raw	Corrected (pF/ft)
Cond v Shld	1000	10.92974	**10.930**
Cond v Shld	10	111.2989	**11.130**

PDB1610	Length (ft)	Raw	Corrected (pF/ft)
Cond 1&3 v Cond 2&4	1000	11.76690	**11.767**
Cond 1&3 v Cond 2&4	10	91.76503	**9.177**
Cond 1&3 v Shield	1000	17.82036	**17.820**
Cond 1&3 v Shield	10	175.22850	**17.523**
Cond 2&4 v Shield	1000	17.66173	**17.662**
Cond 2&4 v Shield	10	177.57120	**17.757**
1 v Shield	1000	9.53848	**9.538**
1 v Shield	10	93.12552	**9.313**
2 v Shield	1000	9.44992	**9.450**
2 v Shield	10	93.80666	**9.381**
3 v Shield	1000	9.62435	**9.624**
3 v Shield	10	96.43203	**9.643**
4 v Shield	1000	9.61803	**9.618**
4 v Shield	10	95.04978	**9.505**
1 v 3	1000	5.16865	**5.169**
1 v 3	10	31.42651	**3.143**
2 v 4	1000	5.16590	**5.166**
2 v 4	10	31.80540	**3.181**
1 v 2	1000	5.46633	**5.466**
1 v 2	10	34.99666	**3.500**
2 v 3	1000	5.55822	**5.558**
2 v 3	10	35.90727	**3.591**
3 v 4	1000	5.49521	**5.495**
3 v 4	10	34.39183	**3.439**
1 v 4	1000	5.52196	**5.522**
1 v 4	10	35.58809	**3.559**

Unbalance (pF/ft)	Length
0.159	**1000 ft**
0.234	**10 ft**

Below is the measured and calculated imbalance of the capacitance between 1-3 and 2-4 cross wires' conductors as a "pair"; 2.02% unbalance, very low.

ELP359	Capacitance & Cap Unbalance (pair with shield) Mil-C-17-G (two-terminal)								Unbalance		
	C_A	first conductor of pair to be measured				$C' = 2(C_A + C_B) - C_C/4$			$400(C_A - C_B)/2(C_A + C_B) - C_C$		
	C_B	second conductor of pair to be measured				C_A	18.61050		C_A	18.611	
	C_C	all other conductors plus shield (if present) connected together				C_B	18.84454		C_B	18.845	
						C_C	28.59881		C_C	28.599	
	measure	HIGH	LOW	GUARD		C'	11.58	pF/ft.	C_{UNB}	2.02	%
	C_A	conductor 28	conductor 1	not connected							
	C_B	conductor 18	conductor 2	not connected							
	C_C	conductor G	conductors 1&2	not connected							

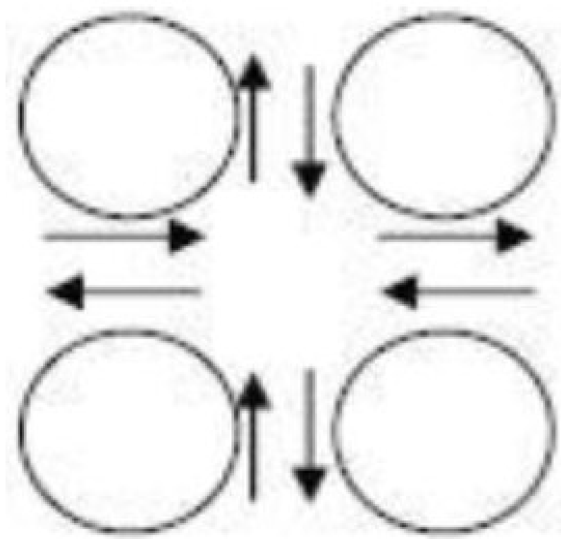
We seem to have the capacitance and VP looking much like the coaxial cable. Remember, measurements include ALL the approximations in the soup.

So what about inductance with that WAY larger loop area? Isn't that going to really kill this thing? No, because of some properties of magnetic fields. Magnetic fields CANCEL if they see each other in OPPOSITE directions. Inductance is the "reactance" or "resistance" to instantaneous flow of current. If we can REDUCE the magnetic field lines, we can directly reduce the measured inductance.

We also know from the basic equations that DISTANCE between the two wires is important. Keeping BOTH distance and magnetic field line magnitude small lowers inductance.

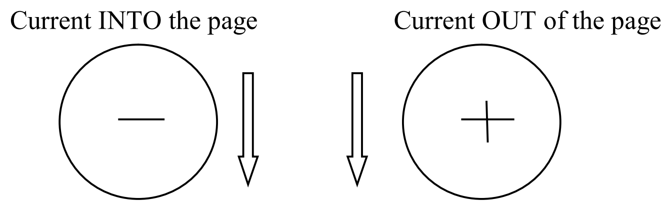
The picture below shows what's going on…sort of. For now, we'll pretend the fields ONLY go "inwards", or inside the wire, and stop there (they don't). If we draw arrows that represent the DIRECTION of the circumferential magnetic field waves AROUND each wire we get what is shown below. We have TWO different voltage polarities so we have TWO different current directions.

If you grasp a wire with all four of your fingers, and point your right hand THUMB in the CURRENT direction, your fingers will point in the field's circumferential direction around each wire. The arrows are a "part" of the field lines "inside" the four wire group.



Where the arrows are OPPPOSITE each other in direction between any two wires, the field lines cancel. ACROSS from any TWO wires we also induce field cancellation with a star quad design. This allows larger wire-to-wire spacing in order to lower capacitance and also keeps inductance low. Inductance is managed with field line cancellation geometry.

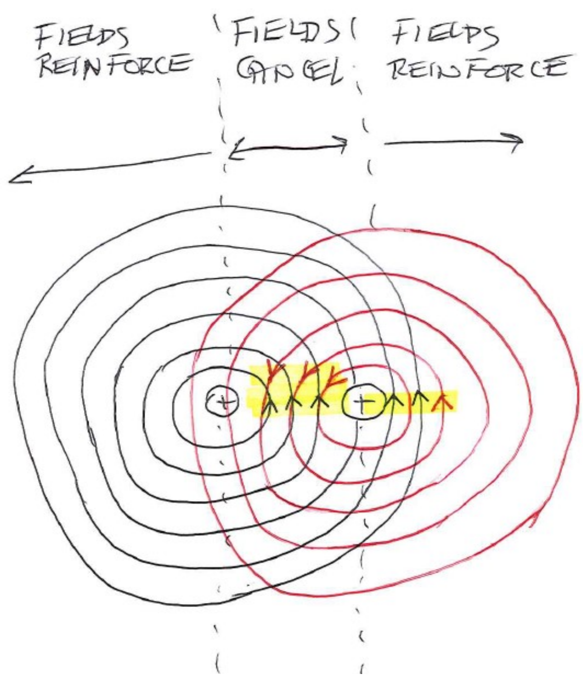
NOW we know why I didn't use a two wire system! Let's look at that situation. Below is a simple picture of the field cancellation between two wires with opposite polarities.



REDUCE LOOP AREA TO REDUCE FIELD COUPLING.

What do we see? The field lines DO NOT cancel, so we are left only with reducing loop area as a way to reduce inductance because we can't cancel any of the field lines. This limits the ability to reduce capacitance for a given inductance.

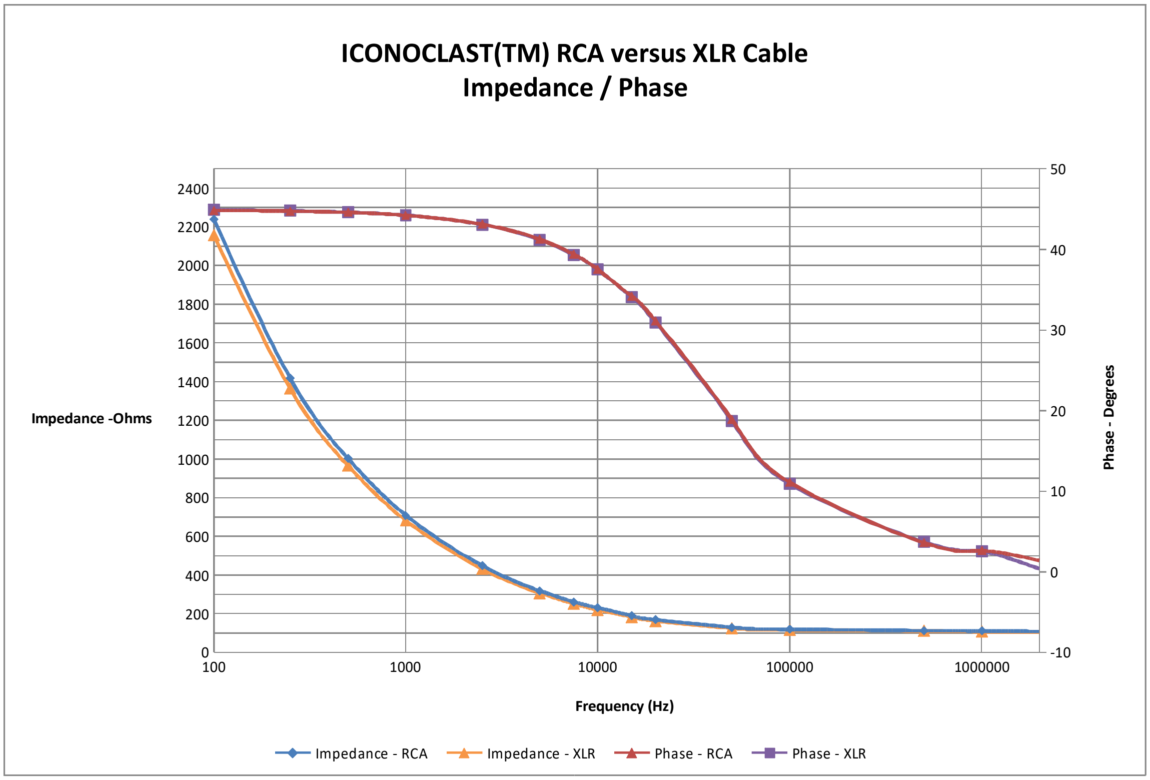
If the lines that extend outside each wire do the OPPOSITE as the field INSIDE the wires, they reinforce the field! It is generally accepted that the flux lines concentrate substantially BETWEEN the wires.



So, after all that explaining, how does the cable measure up? Tests at 1 KHz show the following values below. The inductance between the two cross wire pairs of the star quad are 0.15 uH/foot inductance…same as the RCA.

Inductance at 1 kHz					
	µH/length	µH/ft. (per foot of cable, not loop length)			
1&3	10.053	0.39			
2&4	9.834	0.38			
1&3 to 2&4	3.84	0.15			

So what does the "reactive" picture look like comparing the RCA and XLR? How close are they to being the same? This swept test is the real deal. There are no approximations to fudge.



What we see above is impedance / phase for the XLR and RCA superimposed one on top the other. Note that there are four separate lines. We have two identical cables with exceptional reactive variables.

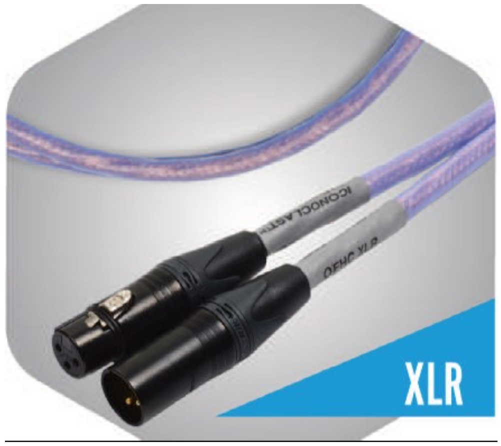
4.0 Shield material and design considerations.

There is yet one last thing to consider in the XLR design; the outer shield. A 95% BC (Bare Copper) braid is used. Audio cables are not RF designs, and the braid shield will NOT shield low frequency magnetic interference. The CMRR of the XLR is going to do that for us. Excellent CUB, DCR unbalance and twist ratio all aid CMRR. The braid DOES knock down RFI by 80 dB, so that's a given. The shield isolation @ RF mitigates NULL balance at high frequencies only.

Like it or not, 20-20K is a predominantly magnetic field frequency range where the B-fields decay at a ratio of 1/x^3. DISTANCE is the best solution for isolation of cables with magnetic properties.

5.0 Jacket design and material considerations.

All ICONOCLAST cables use FEP as the jacket to reduce UV sensitivity, plasticizer migration and provide chemical resistance. The cables are designed to last decades.



I hope that this design summary of ICONOCLAST RCA and XLR interconnect cables shows how important good design is for ALL your audio cables, and that every manufacturer has to manage all the same variables to produce these results. There is little "magic" in the design of good cables. There are indeed tertiary variables that we can't measure, but those should not influence the ones we can measure, or at least not excessively so. Mother Nature abhors complexity, so the better managed the known variables in a cable are, the more properly it may highlight "unknowns."To put it another way, the more we put knowns into their proper place, the better we may distinguish the effects of the unknown. Wire draw science, for instance, can be heard better, and more fairly, in a superior electromagnetic design.

Belden appreciates your interest in how quality interconnects are made, and how / why ICONOCLAST RCA and XLR cables were physically derived as you see them in their production form. We have no special sauce or magic in our products, and I think that the cables perform as well as they do BECAUSE we did not design around "unknowns" and then make it appear as though we had unique influence on those unknowns in the design.

Truly low R, L and C cables are difficult to make when consideration is given to all three variables to manage them in a truly balanced fashion. The designs can be frustratingly simple looking but hard to manufacture, as processes are pushed to the limits of current capabilities. Belden's focus is to make real measured values as low, and properly balanced, as we can. ICONOCLAST interconnects represent the pinnacle of low frequency measurements and electrical balance between the RCA and XLR (same electromagnetic properties).

The next design analysis will look at the SPEAKER cable.