SPEAKER CABLE

10/06/2015

A TRULY NEW HIGH PERFORMANCE

BONDED-PAIR AUDIO SPEAKER CABLE DESIGN

If you try and take a cat apart to see how it works, the first thing you have on your hands is a non-working cat.
— Douglas Adams

BELDEN
SENDING ALL THE RIGHT SIGNALS

ICONOCLAST™ SPEAKER CABLE SPECIFICATIONS

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Capacitance	48 +/- 5 pF/foot
Inductance	0.080 +/- 0.01 uH / foot
Resistance (10.0 AWG)	1.15 MilliOhms / foot
Conductors	48 x 0.020“
Polarity Size	9600 CMA x 2

AUDIO IS NOT A TRANSMISSION LINE

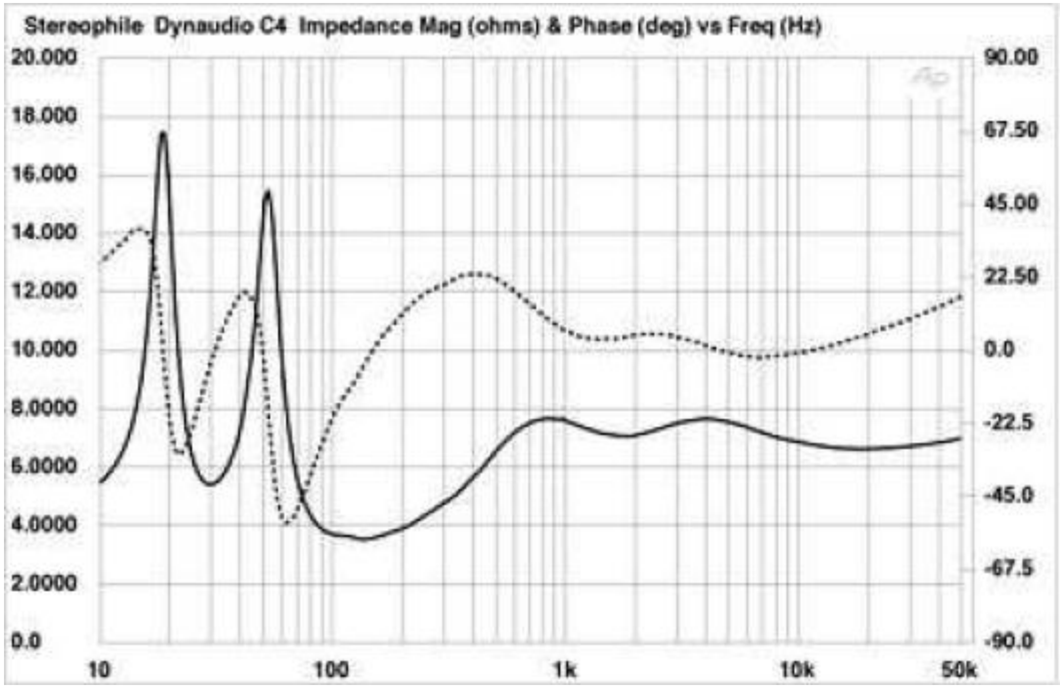
- Passive audio cable cannot match reactive speaker impedance, and cable impedance is also varying with frequency (rising considerably at low frequencies).
- No real passive speaker cable can match reactive circuits with passive components.

Transmission line
Matched 75-ohm output to 75-ohm cable.
Matched 75-ohm cable to 75-ohm input.

Audio line
Unmatched output (amplifier) to speaker cable.
Unmatched cable to input (speaker).

LOADS ARE NOT CONSISTENT

- TYPICAL SPEAKER IMPEDANCE PLOT



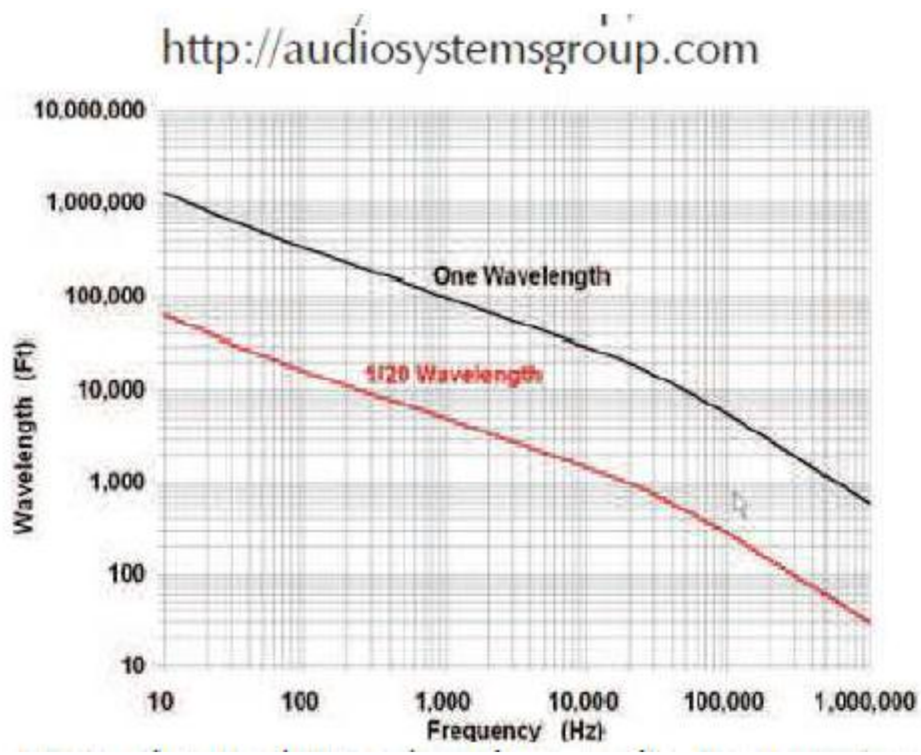
Above is an impedance trace of a typical high-end ported design loudspeaker, with less than 4 Ohm to over 17 ohm impedance swings.
SOLID = IMPEDANCE, DASH = PHASE

HOW FAST or LONG?

- 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 cable transit times are too fast for this to happen.
- 1/20,000 Hz = 0.00005 seconds or 50 micro seconds (10^{-6}), which is much slower than the end-to-end arrival time of .08 micro seconds (10^{-6}) in a 10 meter cable.

MAKE THE CABLE LONGER?

- Even at 20kHz (the SHORTEST WAVELENGTH) we see a cable would be tens of thousands of feet long.



REFLECTION OFF A LOAD DOESN'T MAKE SPEAKER CABLE A TRANSMISSION LINE.

- Speaker cables show reflections off a speaker load, but this is simple resonance, and NOT a transmission line mismatch. Calculated "lump" resonances occur ~10X above 20 kHz and would require active (variable) speaker termination loads to be effective but can it be heard?

- Very low capacitance (ESL) and inductance (Dynamic) speaker cable mitigate severe amplifier to speaker reactive load mismatches and optimize performance across almost all capacitive sensitive amplifiers.

- ICONOCLAST™ combines VERY low capacitance WITH low inductance for longer zero degree phase signal lengths for ESL and dynamic compatibility.

LOW FREQUENCY CABLE IMPEDANCE (open / short method)

Open and Short Impedance per ELP 423, Agilent E4980 Precision LCR Meter, Belden 4TP Cap/Ind Test Fixture

Freq (Hz)	Imp (Ω) 1313A	Phase (°) 1313A	Imp (Ω) - ICONOCLAST	Phase (°) - ICONOCLAST
20	1193.141	45.057	831.437	35.681
50	660.023	44.580	378.399	38.709
100	526.722	44.271	278.446	40.505
250	332.688	42.766	179.379	41.431
500	229.994	40.154	128.516	40.880
1000	165.054	35.417	91.512	38.573
2500	110.789	21.025	60.703	31.346
5000	100.582	13.876	48.525	22.146
7500	97.334	10.010	44.739	16.703
10000	97.020	9.638	43.188	13.234
15000	95.010	7.280	41.824	9.330
20000	94.445	6.244	41.337	7.224
50000	91.098	4.615	40.935	3.564
100000	91.197	3.760	39.607	2.693
500000	83.573	2.602	39.017	1.777
1000000	82.348	3.572	38.595	1.306
2000000	80.761	2.431	38.297	0.970

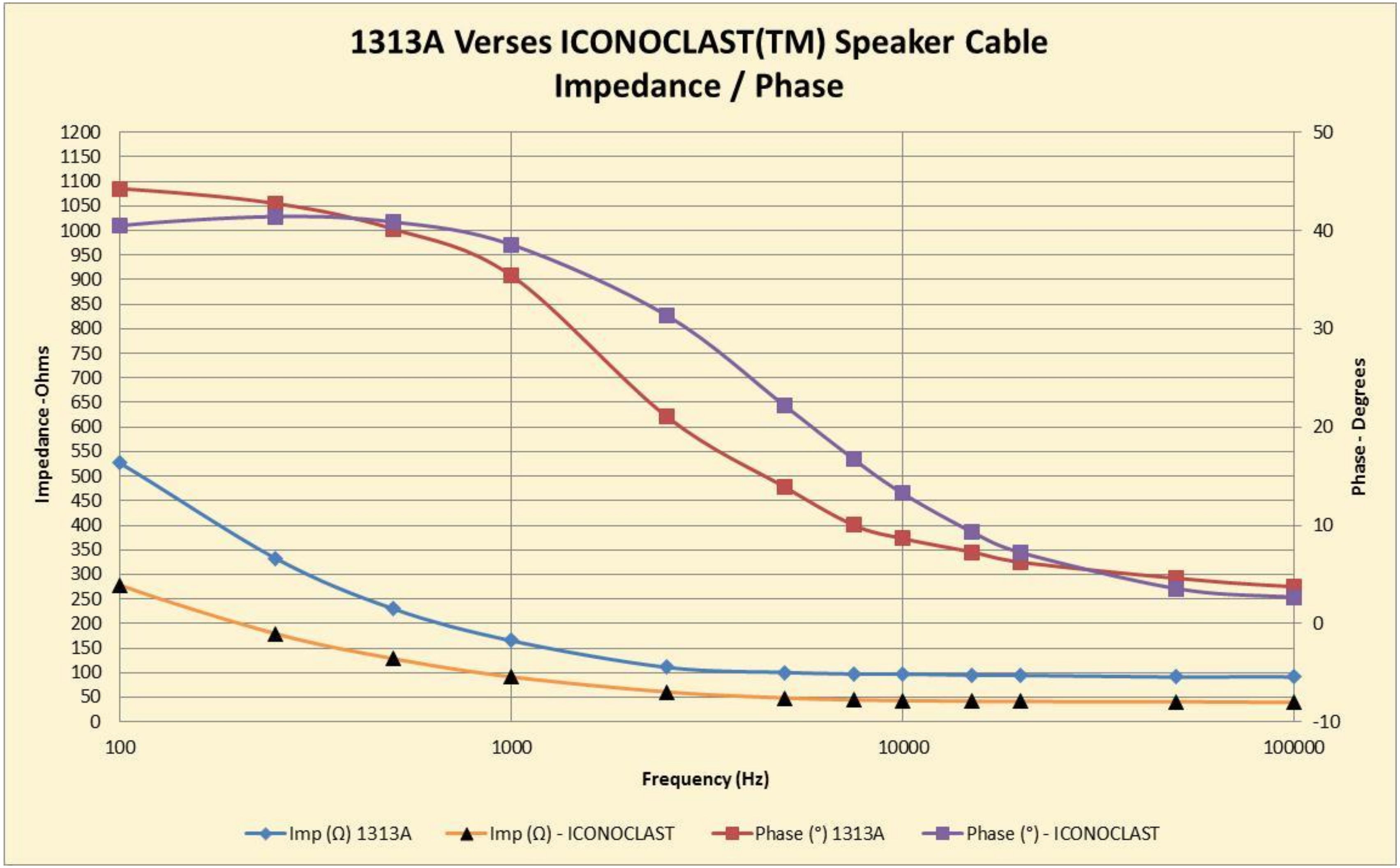
TDR method will show ~85-ohm (1313A) and ~40-ohm (ICONOCLAST™) @ RF.
MIL-C-17D resonance method will measure a 70% VP (1313A) and 68% VP (ICONOCLAST™).
Sample length for open / short is technically too short for true impedance values.

Impedance and Phase

- Low Impedance Audio Cables terminate into 4-16 OHM Average impedances.
- The closer a cable can be to this low impedance reduces simple reflections off the load.
- Audio range cables have rising impedances due to Velocity of Propagation (VP) changes.
- Careful design parameters can mitigate some, but not all, of this impedance change into dynamic speaker loads.

Impedance / Phase

- ICONOCLAST LOWERS and FLATTENS THE IMPEDANCE



Stable ICONOCLAST™ Reactive Electricals

- Measured Reactive (capacitance and inductance) Electricals. L and C are frequency stable.
- Cap is usually measured at 1 kHz to avoid Inductive influences.

	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

WHERE IT ALL STARTS

- SINCE the ICONOCLAST™ speaker cable has to use a superior DESIGN to achieve high performance into a complex load, we used Belden BONDED PAIRS.

THE ROOT COMPONENT

Bonded pair technology, developed for the premise wire industry, is a miniature parallel polarity cable when viewed from the audio perspective. What can Belden do with an almost electrically ideal (if you use a SMALL signal current and SHORT wire!) parallel cord component? Parallel polarity cable with two closely spaced wires has low inductance. That's it in a nutshell for inductance...the wires proximity has to be as close as you can. So again, the formulas for inductance don't really care about the dielectric, but the copper size, spacing and length matter. But a single BONDED PAIR is too small, so what do you do?

BONDED pairs are ETHERNET?

THIS IS ETHERNET CABLE, RIGHT?

Now that we have an OFHC BONDED pair with 0.020" wire and a thin wall FEP dielectric the comparison to an Ethernet cable will be made. The ICONOCLAST™ bonded pair is unique to audio. It uses OFHC and ETPC wire, it is uniquely insulated with a different and thinner insulation wall designed for INDUCTANCE spacing reduction, and not limited by 100-Ohm impedance, which FORCES a wall thickness. The ICONOCLAST™ Bonded Pair organic color pigment was chosen because it is electrically inert. And, the bonded pair is utilized in a single polarity configuration across BOTH wires (++ or - -). Ethernet is balanced, or opposite polarities between each wire of the bonded pair (+ - or - +).

ICONOCLAST™ pairs are far removed from Ethernet cable bonded pair, and even FURTHER in its final physical form.

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WHY USE BONDED PAIRS AT ALL?

- Low capacitance / inductance with theoretically OPTIMIZE COHERENCE with smaller wire AWG.

WHY A BONDED PAIR

For audio, an idealized “zip cord” is an electromagnetically sound (pun intended) design. The two wires in close proximity reduce inductance. Increased gauge size to carry current does not impact inductance as long as the wire pair is close together, and the capacitance can be managed with a good dielectric. That’s classic R, L and C but what about the phase and micro-dynamics effects that change imaging and resolution?

The problem is electromagnetically created when we consider all signals in a wire travel at different velocities in the audio band. The low frequencies travel slower than the higher frequencies, and the change in conductor size can impact the arrival time variations. What goes in at the same time does not arrive at the same time.

Small zip cord, for coherence, is too small for resistance, and one large zip cord is too large for optimized coherence. How can we maintain the advantages of a zip cord’s R, L and C design, and enhance the overall coherence capability of the speaker cable?

More WIRES

- In order to optimize current density from 20Hz -20kHz we use 0.020” wire to stay below the skin depth value at 20kHz. Larger wire theoretically compromises the coherence of signal arrival times.
- Audio can’t really use “one” formula, as the variables related to skin depth are changing at low freqs.

The skin depth is kept to a smaller wire radius than the formal definition of skin depth – A depth where the center of the wire has NO LESS than 37% of the energy at the surface. Remember, the higher frequencies want to leave the center of the wire more and more the higher you go in frequency.

FREQUENCY (KHz)	SKIN DEPTH (mils)	AWG
1	89.7	5.1
5	40.1	12
10	28.4	15
15	23.2	17
20	20.1	18

MORE ON ALL THOSE WIRES

- To avoid interacting with speaker cross-over circuits, an adequate AWG size is needed, so this means more smaller wires to meet DCR requirements.

VOLTAGE DIVIDER FORMULA
Vout = Vin x R2 / (R2 + R1)

EXAMPLE OF A VOLTAGE DIVIDER SPEAKER CIRCUIT
Here is an example with a typical 2 to 16-ohm swing with a 1.5-ohm resistance speaker lead.
Vout = Vin x 16.0 / (16.0 + 1.5), Vin x 0.914
Vout = Vin x 2.0 / (2.0 + 1.5), Vin x 0.5771
A 58% change in the output factor.

Change the wire to one-third the resistance;
Vout = Vin x 16.0 / (16.0 + 0.5), Vin x 0.969
Vout = Vin x 2.0 / (2.0 + 0.5), Vin x 0.800
A 21% change in the output factor.

So lower resistance (it matters HOW you get low resistance, though) is better but at some point the factor becomes inaudible (**consider the resistance of an eight foot set of leads!**).

Looking at it from an, "I can see the data" standpoint shown above, let's consider ICONOCLAST™ (1.00-ohms / 1000 feet). We have to go there and back, and assume we run a 15 foot speaker lead (about as long as recommended for L and C);
(1.00/1000) * 15 * 2 = 0.030 ohms

Vout = Vin x 16.0 / (16.0 + 0.030), Vin x 0.99812
Vout = Vin x 2.0 / (2.0 + 0.030), Vin x 0.98522
A ~1.31% change in the output factor, which is very small.

WHEN DO YOU STOP USING ALL THOSE WIRES?

- The need to address both skin depth AND DCR can be determined….and the use of solid wire removes all theoretical strand interaction issues.

The general rule of thumb is that you want the total speaker cable resistance to be less than 5% of the speaker impedance plus cable value to avoid speaker frequency response interactions;

VOLTAGE DIVIDER FORMULA

Vout = Vin x R2 / (R2 + R1)

ICONOCLAST™ total CMA size mitigates appreciable calculated frequency response changes, and stopped at twenty four 0.020" wires per polarity or 9600 CMA (10 AWG). This 0.020" size keeps skin depth requirement well below the roughly 18-mil radius, with an 11-mil radius value.

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48 wires!

- We use 24 SOLID 0.020” wires **per polarity** to reduce speaker frequency response to a practical minimum.

Too large an AWG impacts ESL type speakers so you must manage every other attribute effectively...and this is not usually accomplished with an effective overall design once a reasonable summed CMA wire size is achieved (10 AWG).

ICONOLAST™ cuts the calculated values of wire radius from 18-mils to 10-mils, over half, and makes sure we theoretically utilize the wires’ cross section as efficiently as we can while managing all the other variables.

To avoid the consequences of speaker output response, ICONOCLAST™ uses twenty-four 0.020" solid wires (10.0 AWG) per polarity, or TWELVE bonded pairs. The smaller 0.020” wire allows flexibility, while being small enough to force the high frequencies to be more linear in velocity compared to the lower frequencies inside the wire (fill the middle more with high frequencies), or improved skin depth.

SKIN DEPTH AT AUDIO FREQUENCIES
Small, but meaningful?

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

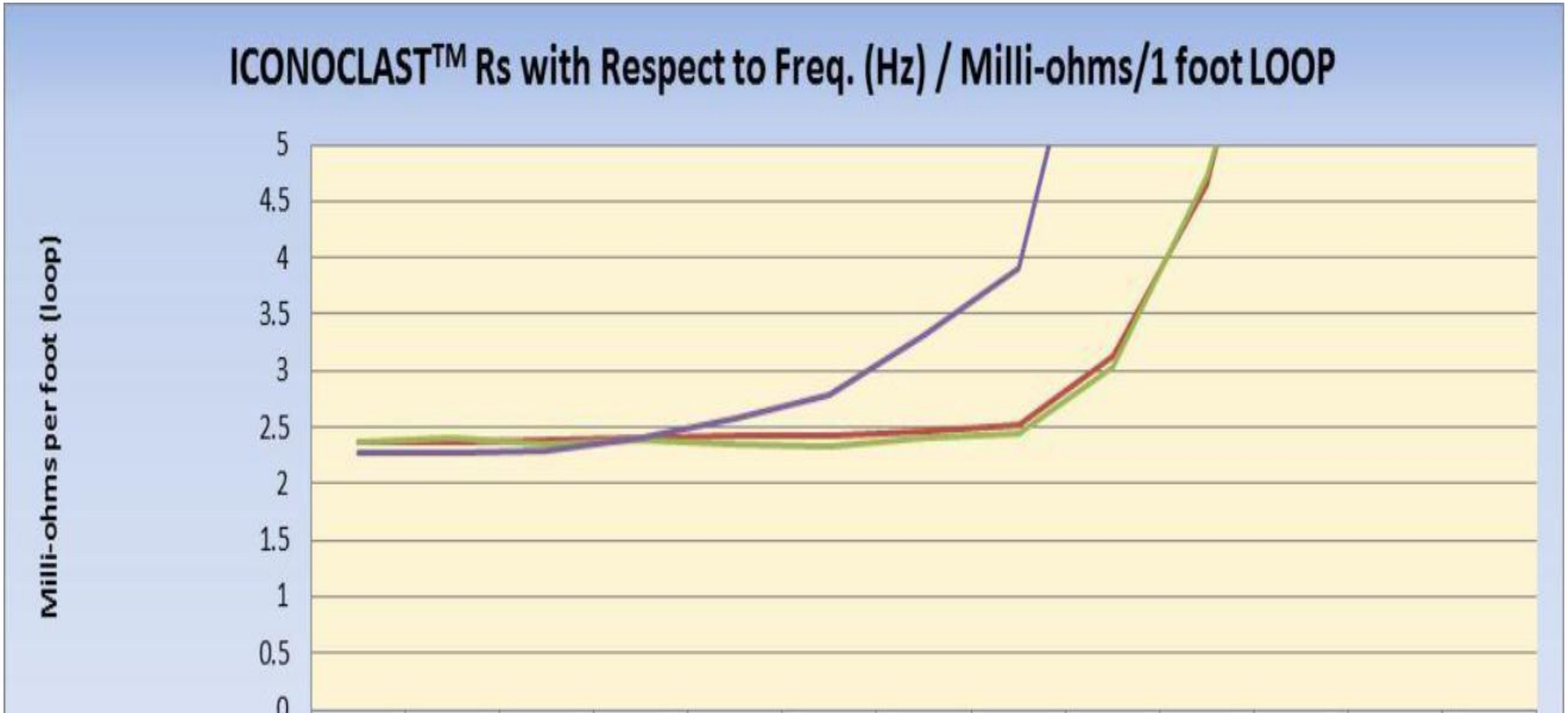
	Results				
				Impedance	
	Ls	Rs	Cp	Mag.	Phase
Units:	µH/ft.	mΩ/ft.	pF/ft.	ohms	degrees
Freq. (Hz)					
100	0.084	2.37	44.84	297.83	-43.81
1000	0.080	2.37	44.69	98.09	-39.50
2500	0.079	2.39	44.65	65.67	-32.43
5000	0.079	2.41	44.61	50.89	-23.07
7500	0.079	2.42	44.60	46.66	-17.17
10000	0.079	2.43	44.59	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		

Why NOT use larger and fewer wires?

- 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		

ACTUAL Rs Measured Values



	100	1000	2500	5000	7500	10000	15000	20000	50000	100000	200000	500000	1000000
ICONOCLAST(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(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

MORE IS NOT ALWAYS BETTER, WE MAKE IT BETTER!

WHAT TO DO WITH ALL THOSE WIRES?

This is where VERY critical design issues all overlap. Remember capacitance? Yes, we left it out for the most part. The bonded pair DOES have capacitance. The more wires you use the worse the capacitance and, the closer the wires are together the worse capacitance gets. Oops, I previously said we made the wire Center-to Center tight for low inductance! A funny thing happened when they made electromagnetic principals. If you push inductance down capacitance goes up. Not so funny now, is it.

HOW TO NOT MAKE A CAPACITOR

A capacitor is two closely spaced metallic elements separated with a non-conductive (in our case a FEP plastic) medium. The closer the two wires and the larger the surface area of the wires the worse the capacitance. Even worse, all those wires in parallel between each leg add up in the total capacitance value as capacitors in parallel add. This is not so good for us audiophiles.

MATERIALS MATTER

Why use FEP?

- Lowest dielectric constant of solid plastic @ 2.15.

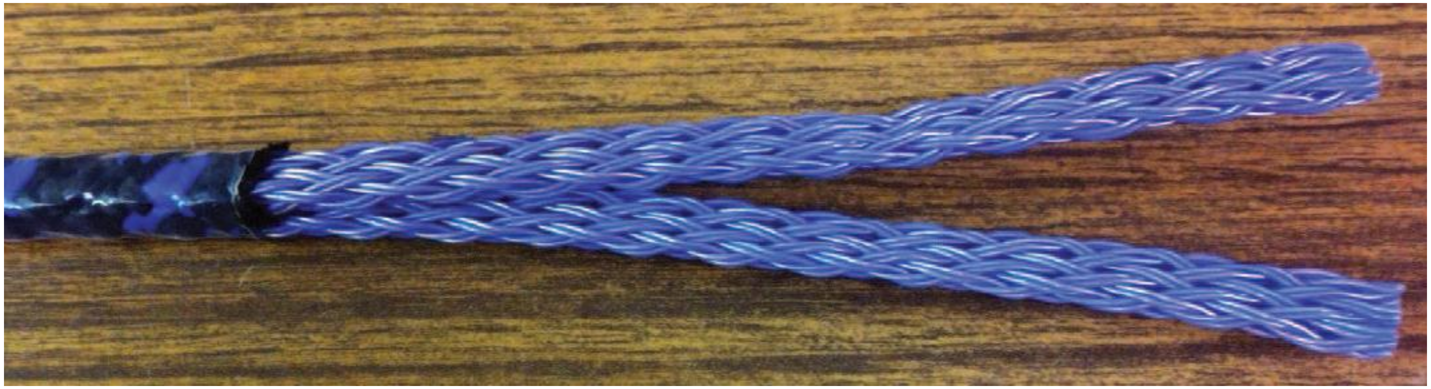
  Low dielectric constants allow lower capacitance designs for a given wall thickness.

- High dielectric strength, over 6500 V/mil, allows small wire spacing for Inductance.

- Dissipation factor (energy loss rate) and Loss Tangent (angle of the loss reaction to the electric field) are low, but less important at audio frequency ranges than RF.

THE ICONOCLAST™ DESIGN ADVANTAGE

- THE ICONOCLAST™ **DESIGN** MAKES IT BETTER EVEN WITH ALL THOSE WIRES!!



It pays to NOT be different.

- ICONOCLAST™ speaker cable DESIGN insures every wire looks like the EXACT same wire in length and electrical characteristics. The cable ACTS like two wires.

- The design uses a clever geometry to leverage the necessary physical parameters to address critical electrical parameters; skin depth, R, L and C.

- The design benefits each unique attribute without negative impacts on other physical or electrical variables.

SOME THINGS LIKE TO BE CLOSE.

- The average distance between each wire in each polarity to ground is the same average distance, and the same final capacitance.

IS EACH WIRE REALLY THE SAME?

- BONDED PAIRS AND MACHINES ARE INDEED CONSISTENT.
- One wire to all others connected to ground;

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	175.8863				
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				

WE DON'T HAVE DIFFERENCES.

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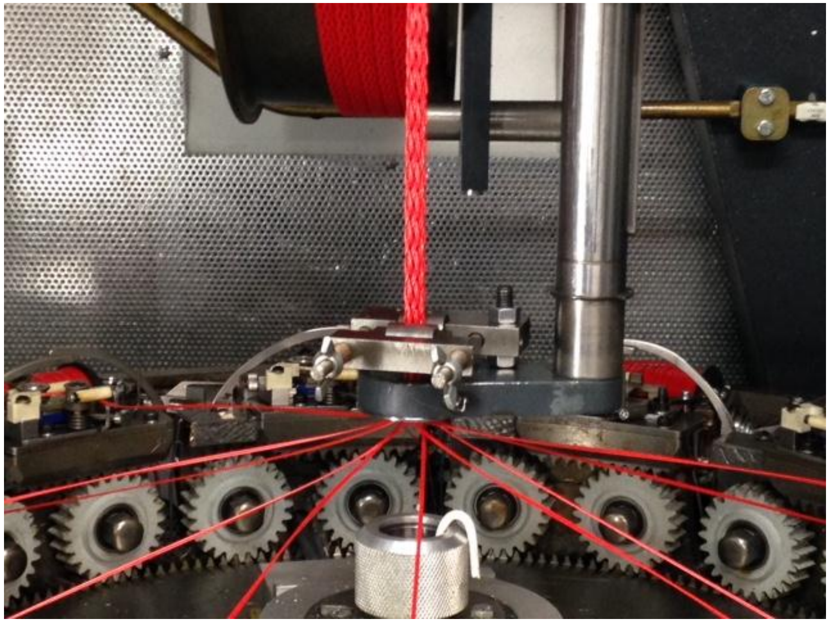
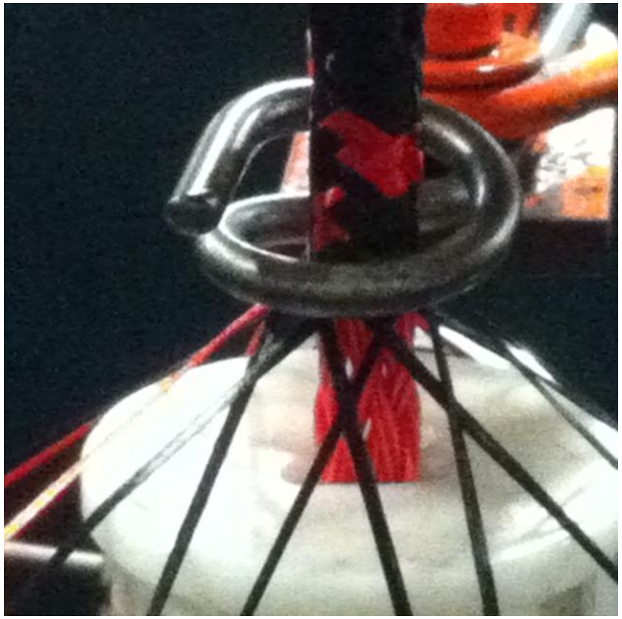
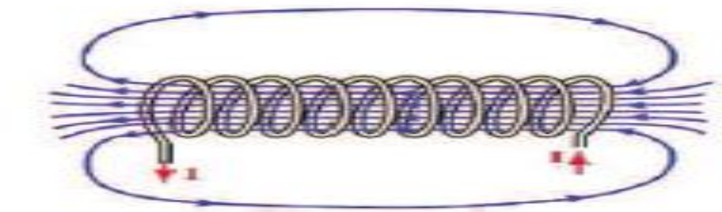
- ICONOCLAST™ speaker cable design is a symmetrical polarity design. Each polarity is EXACTLY the same electromagnetic electrical design, insuring truly balanced polarity signals, which improves coherence.





BUT WHAT ABOUT INDUCTANCE?

- The inductance of a single bonded-pair is about 0.196 uH/foot. But ICONOCLAST™ can do better than that.



- When we use mutual inductance reduction by forming the polarity legs into flat braided ribbons to collapse the inductive loop area, and by placing them one on top of the other, the inductance drops to 0.08 uH/foot nominal.

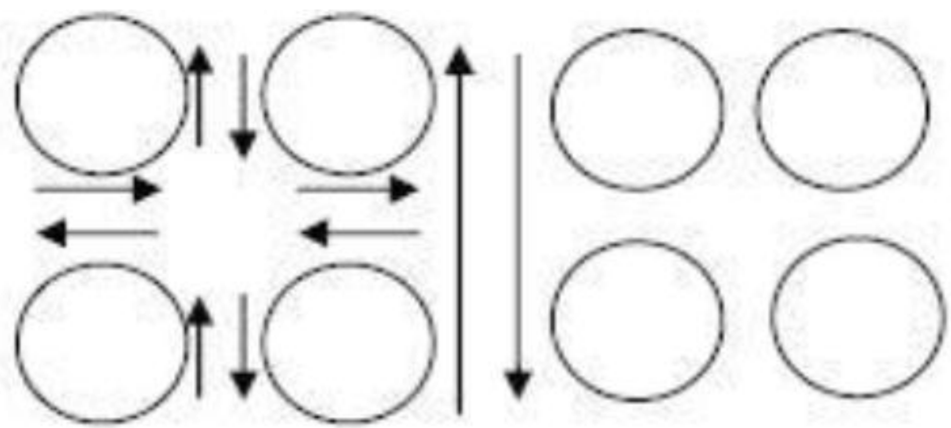
- Inductance tries to impede the magnetic field generation with signal current flow, an important variable in high current speaker cable design.

Negative Reinforcement!

- Inductance control is managed by geometrically arranging the fields to cancel one another as best possible, and as CLOSE as possible (tight outer braid).
- 100% inductive cancellation is unfeasible as the fields would need to share the exact same spot in a wire, and at the exact same time and opposite polarities.
- Right Hand rule defines the electromagnetic field’s direction and potential cancellation properties.
- Management of the electromagnetic fields reduces the overall mutual inductance of the cable.

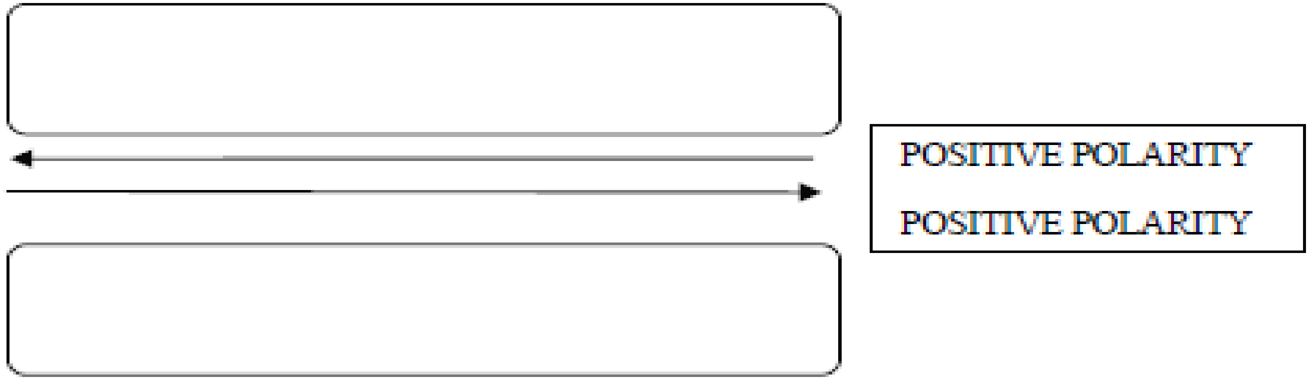
How's that work again?

- The right hand rule defines current direction.
- If the current is going left to right, the magnetic field is counter clockwise to the current direction.
- Imagine your RIGHT thumb is pointing in the current flow, your fingers wrap in the field direction.
- Twelve four wire groups, six per polarity.



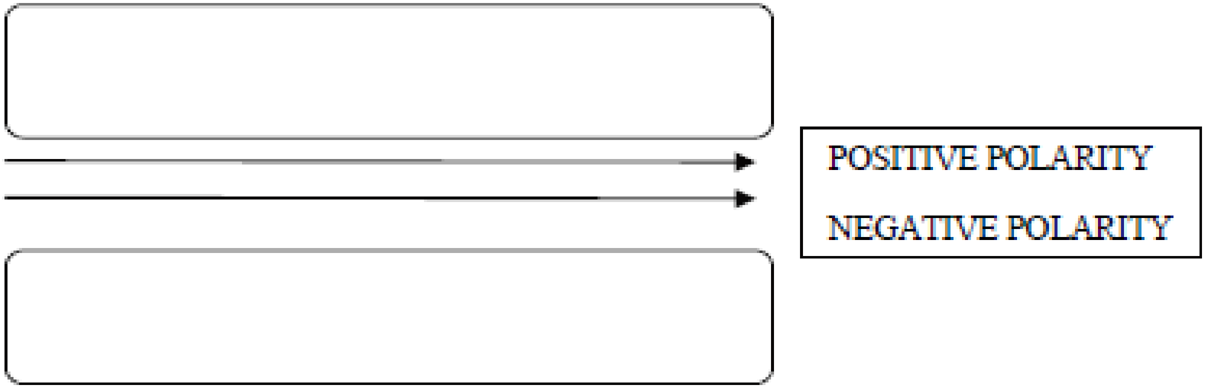
BONDED PAIR ADVANTAGE

- A bonded-pair results in a CLOSE proximity to each wire (little space between wires) for maximum field cancellation.
- The right hand rule defines the field cancellation.
- The (minus) means the field are in opposite directions. Equal and opposite field cancelation.
- (+) – (+) = zero ideal, but not in reality.



FLAT POLARITY ADVANTAGE

- The field cancellations in EACH leg are the SAME direction but OPPOSITE polarities.
- (+) means the same magnetic field direction. Fields in the same direction but opposite polarity add magnetic field cancellation.
- (+) + (-) = zero ideal, not in reality.



IS THERE MORE?

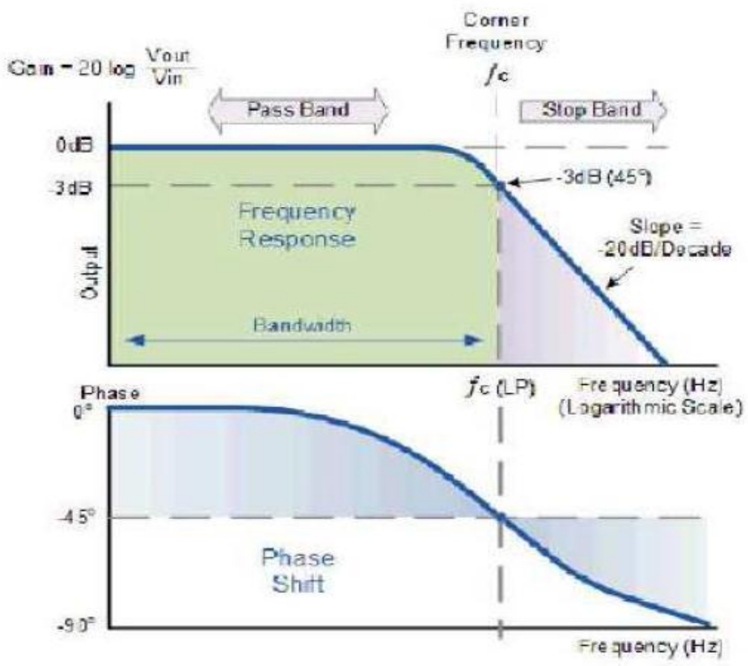
- There is always more.
  - Why even worry about capacitance if it’s not as critical to high current (20-30 amps) speaker cable?
  - Phase shift claims are heard at ~ 10 degrees and arrived at in lengths as short as 20-30 feet, and is capacitive driven.
  - Lower capacitance allows near zero degree phase shift in longer lengths, up to ~200 feet @ 20 KHz.

HIGHER BANDWIDTH

– LOW CAPACITANCE = BANDWIDTH

At the –3dB point (see 1st diagram), the phase has changed 45 degrees! The "audio" bandwidth should keep phase to less the one-fourth this value or less.

Frequency Response of a 1st-order Low Pass Filter



http://www.electronics-tutorials.ws/filter/filter_2.html

What about my amplifier?

- The low capacitance insures a zero phase operating bandwidth, but the more likely issue isn't bandwidth influenced phase change, but amplifier instability into high capacitance loads.

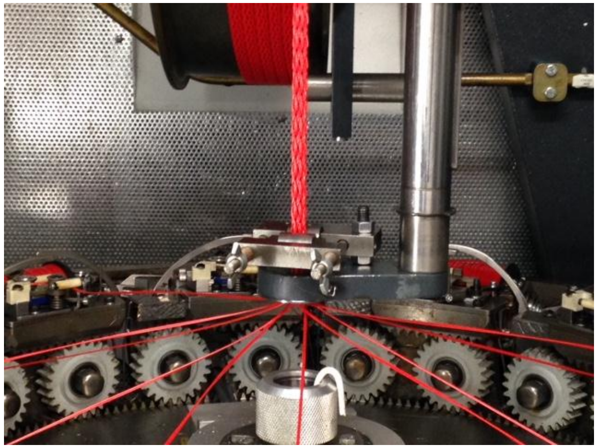
- ICONOCLAST™ speaker cable's very low capacitance is designed to provide superior phase, as well as to be as benign a load to amplifiers as possible.

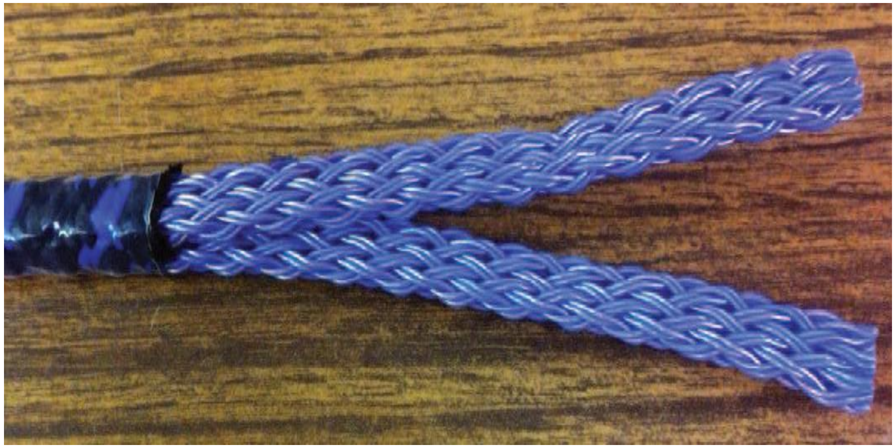
- Zobel networks for stability aren't necessary to protect electronics except with very LONG leads.

PASSIVE RF CANCELLATION

- IT PAYS TO BE CROOKED…SOMETIMES.

The complex looking braid forces like and unlike bonded-pair polarity crossings. As wires cross at higher angles it passively cancels RF energy through ELECTRIC field cancellation.





This helps remove EMI/RFI frequencies you don’t want, and to send only the signal that you do want.

EVERYTHING IS IMPORTANT

ICONOCLAST™ is a VERY unique design, and one driven by the electrical requirements of audio;

- SOLID SMALL 24AWG BONDED-PAIRS ARE FLEXIBILE AND ALLOW CLOSE SPACING.
- MANAGED SKIN DEPTH BY DEFAULT.
- VERY LOW DCR - 9600 CMA / ~10 AWG SIZE.
- VERY LOW CAPACITANCE (ESL / spacing of wires).
- VERY LOW INDUCTANCE (Dynamic / spacing of wires).
- ELECTRICAL POLARITY SYMMETRY.
- HIGH ZERO DEGREE PHASE BANDWIDTH.
- SAFE CAPACITIVE LOAD FOR AMPLIFIERS.
- PASSIVE EXTERNAL FIELD CANCELLATION.
- EASIER TO USE COMPACT AND SLIM DESIGN.

SUMMARY

- Belden used real world DESIGN benefits to achieve a superior sounding product with "passive" theoretical benefits.
- The DESIGN showed the most influence on the sound over exotic materials, but the use of high quality plastics was necessary to meet R, L and C.
- SMALL individually insulated bonded SOLID wires allow flexibility and stable processing while mitigating theoretical strand interactions and skin depth.
- Copper type is the only design change between ICONOCLAST™ cables, allowing true copper quality evaluations in YOUR system.
- Each assembly measured for; R, L and C.

CONDUCTOR QUALITY

- OFHC C10100 copper used for conductor.
  - The method of producing OFHC copper ensures extra high grade of metal with a copper content of 99.99%
  - We offer C11000 STD copper as the superior DESIGN allows superb performance with modern drawn wire.
  - ALL ICONOCLAST™ products (RCA, XLR and speaker) share the exact same electromagnetic designs and materials except copper grades so your own ears can be your guide and not hidden in the design and material differences.

ICONOCLAST™ speaker cable is 100% symmetrical balanced conductor layout for positive and negative polarity, avoiding different reference conductor values for either polarity in A/C signals.

Copper Grade Choices

Two Copper grades Available;

- TPC
- OFHC

From Concept to prototype to reality, the Belden way.

SOUND DESIGNS CREATE SOUND PERFORMANCE™!