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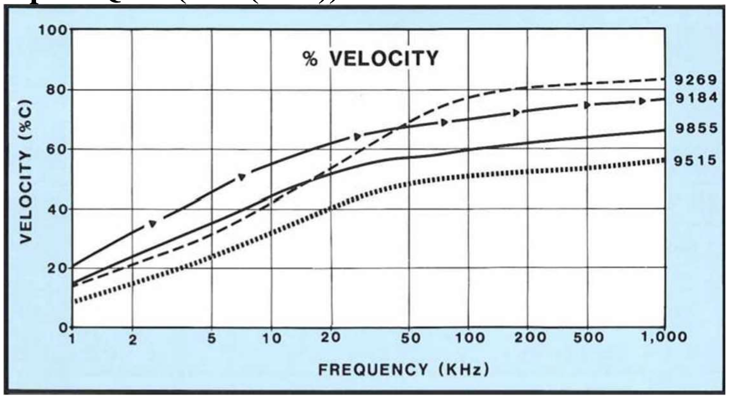
Date:	July 20, 2021 REV 6
To:	Kurt Denke, Bob Howard
From:	Galen Gareis
Subject:	ICONOCLAST Series II Speaker Cable.

BACKGROUND: I improved the series II RCA and XLR by realizing that the SIGNAL wire needs special parameters that I isolated in several listening tests early on. Both properties are connected;

-Wire coherence improvements. Same, or near the same current through the wire cross-section based on wire size getting smaller as a result of skin depth penetration.
- Improved Vp differential across the audio band based on a wire's resistive or capacitive properties being HIGHER. The earlier work below shows what is happening and this is now BACKGROUND work.

Vp = SQRT (2*ω/(R*C))



FREQ (Hz)	9515 - 24 AWG
20	0.01
50	0.02
100	0.03
200	0.04
500	0.06
1000	0.09
2000	0.13
2500	0.15
3000	0.16
4000	0.18
5000	0.21
6000	0.22
7500	0.25
7000	0.24
8000	0.26
9000	0.28
10000	0.29
15000	0.36
20000	0.41

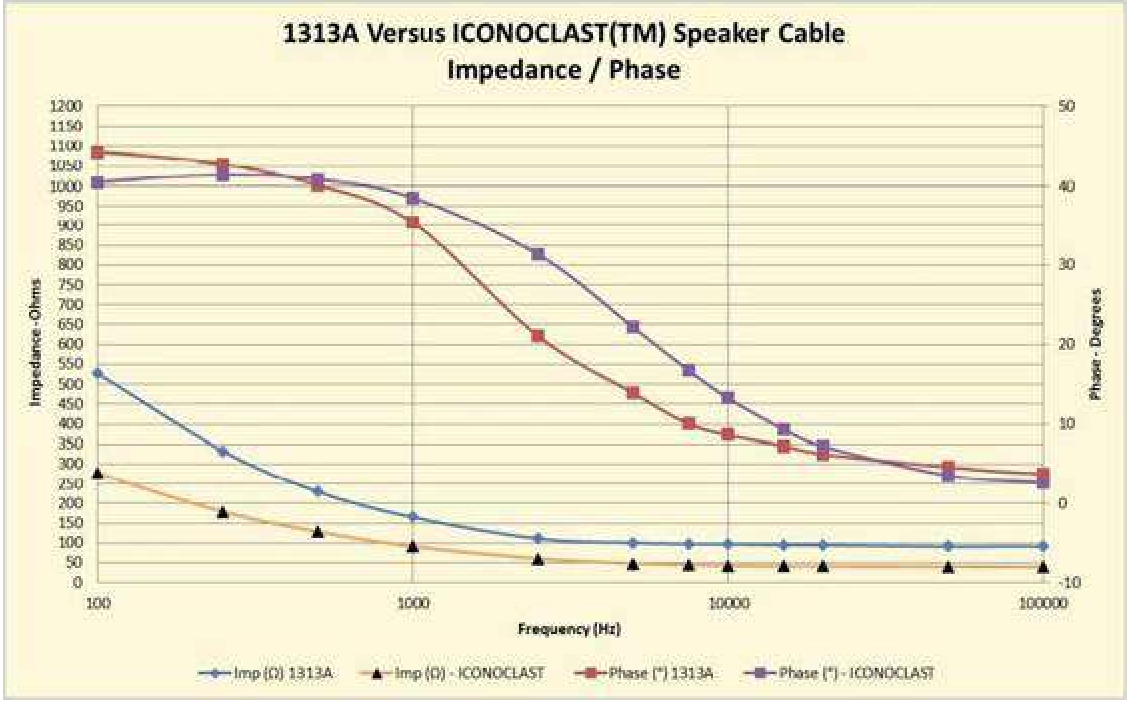
9515 Data

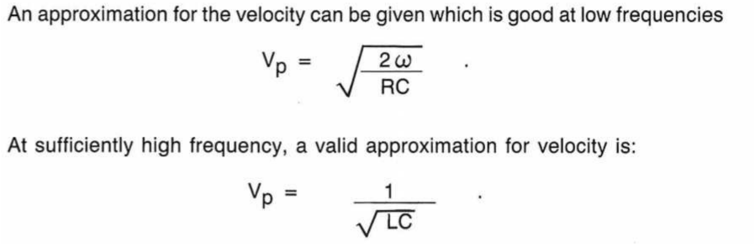
R = Loop/MT	0.1683952
C = Farads/M	9.84E-11
Vp = SQRT ((2*OMEGA)/(R*C))	
OMEGA = 2*Pie*Freq.(Hz)	
SPEED OF LIGHT = 3.0E8 mtr/sec	

We can see that in the low frequencies range, we need a different Vp equation than at RF to account for specific variables going to "zero" or "one" as we increase the frequency into the RF band. What can we do with this insight into the fundamental ability to CHANGE the Vp with frequency?

The above Vp versus frequency graph shows the Vp response of several audio cables. 9515 was used to show the calculation numbers in the graph to verify MEASURED to the CALCULATED values. We have a pretty good correlation. It can never be exact, as the traces are not linear. We need the basic properties defined, and how to CHANGE them.

The equation derived from the curves is;





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

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

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

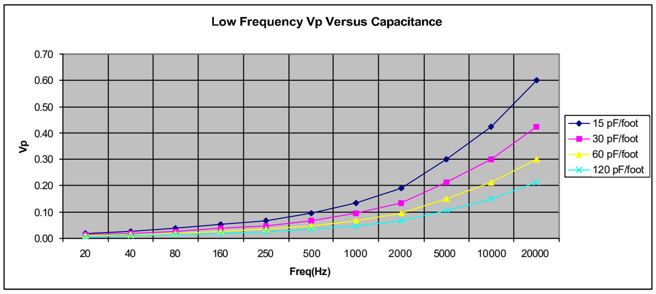
$$V_p = \frac{1}{\sqrt{LC}} \quad .$$

Our current ICONOCLAST does flatten the impedance trace improving coherence but the higher frequency end still drops in impedance as Vp goes UP with frequency to the dielctrics limiting value. Can we improve the impedance iniformity by keeping high frequency Vp lower to raise higher frequency impedance and smooth the Vp differential across frequwncy? What would the design look like? The current cable uses mostly higher capacitance to lower high frequency impedance.

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 or RESISTANCE.

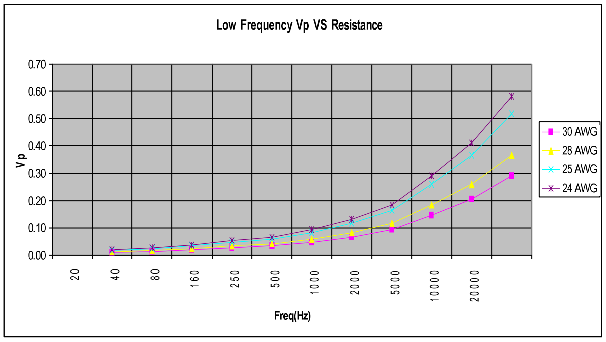
CAPACITANCE (pF/foot) FREQ (Hz)	15 pF/foot	30 pF/foot	60 pF/foot	120 pF/foot
20	0.02	0.01	0.01	0.01
40	0.03	0.02	0.01	0.01
80	0.04	0.03	0.02	0.01
160	0.05	0.04	0.03	0.02
250	0.07	0.05	0.03	0.02
500	0.09	0.07	0.05	0.03
1000	0.13	0.09	0.07	0.05
2000	0.19	0.13	0.09	0.07
5000	0.30	0.21	0.15	0.11
10000	0.42	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)



AWG (Loop/MTR/foot) FREQ (Hz)	30 AWG	28 AWG	25 AWG	24 AWG
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)

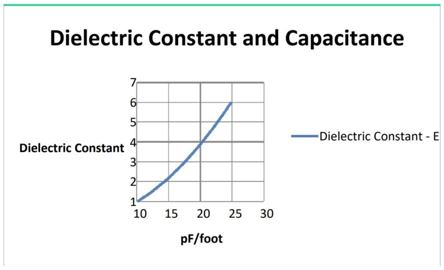


We can change capacitance with variable insulation size, or even the insulation material. For simplicity, we'll hold DCR the same to isolate capacitive effects.

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

In the example above we look at ONLY at capacitance. But, Inductance is LOOP AREA determined. I can arrive at the levels of capacitance several ways, and/or combinations of ways. If we want to retain LOW inductance for PHASE reasons across the frequency range, we need to hold loop area SMALL. Increasing capacitance with thicker insulation does not keep loop are a small.

To keep loop area as small as we can for low inductance we need to use the absolute most efficient dielectric (e) we can to lower capacitance at a given separation distance. 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 given capacitance. In this case, we want slightly HIGHER capacitance (wires are closer) and a closer LOOP area. We also want to use a plastic that does not act capacitive, or stores energy as little as possible. Teflon® fills that bill.



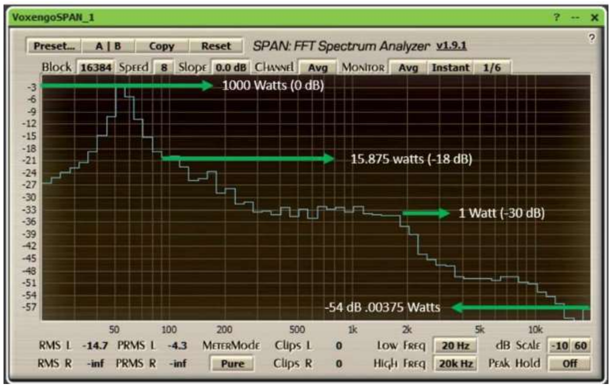
The above graph above shows how CAPACITANCE is directly related to the dielectric constant. "One" is air and higher values represents poorer and poorer dielectrics velocity factor. At RF;
Vp = (1/SQRT (dielectric constant)) or
Vp = (1/SQRT (L*C)).
L and C are "constant" through RF.

We certainly want to start with the lowest "e" value possible, and not just for capacitance alone. 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 graph shows what happens when RESISTANCE is varied, and we HOLD the capacitance at a low 15 pF/foot (we really want ZERO capacitance, remember).

The charts show that if we DECREASE the wire size and INCREASE resistance, we can also manage the Vp differential across the audio band. This allows us to use possibly 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. To avoid too high capacitance in our Vp equation shown earlier, we can also utilize the wire DCR.

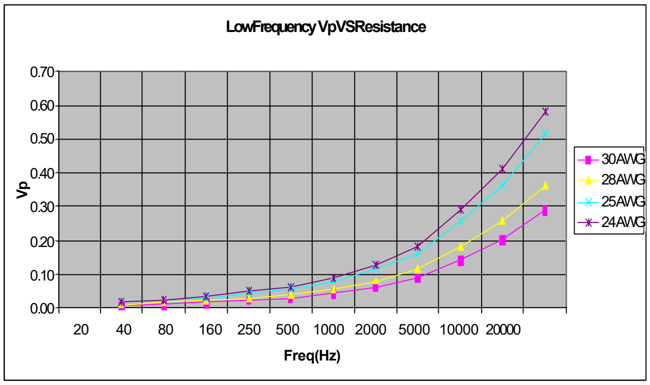
BODY: The review of the data and the graph below are our "solution" to a better series II cable system. Notice I said "system".



Block 16384 Speed 8 Slope 0.0 dB Channel Avg Monitor Avg Instant 1/6

RMS L -14.7 PRMS L -4.3 MeterMode Clips L 0 Low Freq 20 Hz dB Scale -10 60

RMS R -inf PRMS R -inf Pure Clips R 0 High Freq 20k Hz Peak Hold Off



What do the two graphs above show? Something I've known for many decades, that audio spectral density is highly frequency dependent. Most all the power is below 1 kHz or so (left graph). If we take into consideration what happens to the Vp differential in the frequency domain (right graph), we can see that the responses are INVERSED. BOTH are two separate issues above and below about 2 kHz. So what?

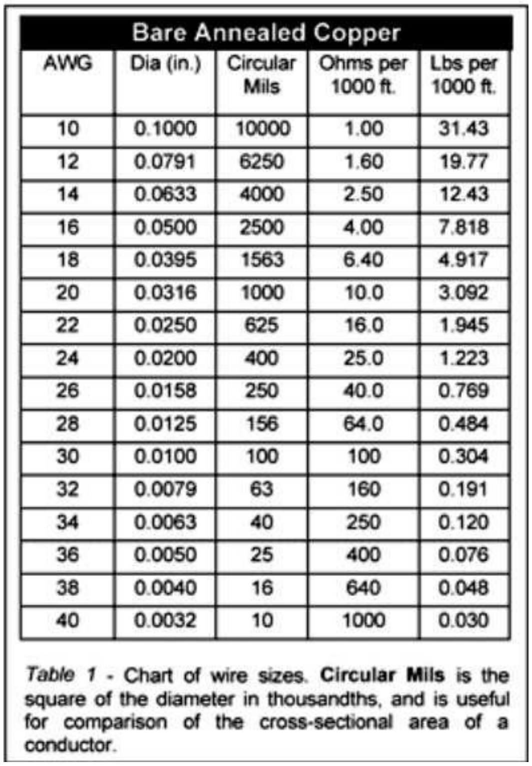
What this means is that we don't have any watts (work) or CURRENT above 2 kHz or so (left graph). It ALSO means that the Vp differential we need to "fix" is ABOVE the same 2 kHz frequency range (right graph). The Vp differential flattens out the lower you go, so we aren't really doing much below 2 kHz or so and we don't need super low DCR above 2 kHz with only about 1 watt of power spectral density!

This means we can SPLIT the current loops into TWO different loops with parameters tuned for each one, specifically. We already have a heavier 10 AWG ICONOCLAST cable now. What needs to be done is to design a SECOND cable JUST for the higher frequencies. But how do we use two separate cables? It's done all the time with bi-wire

- Most amplifiers have Bi-wire posts and can accept a Siamese spade on ONE post or two separate posts.
- Higher end speakers have bi-wire capability built-in. This is a requirement to use the "system".
- We use the current ICONOCLAST speaker cable for the high current low-end.
- We use a "new" ICONOCLAST design speaker cable for the higher end.
- ***This design polarity can be used INTERNAL on OEM speakers***.

DESIGN: A suitable polarity cable like what we have now, but using a much smaller AWG wire is needed. The SIZE can actually be pretty small as the CURRENT / power is zilch above a typical speaker's crossover range (200 Hz to the mid/tweeter in my T+A speakers). Most speaker have a 200 Hz low-end crossover so a less than ~30 watt power dissipation.

If we look at the American Wire Gauge Table we can see what we can do with the "superior" mid/treble cable polarity. We STILL need the heavy 10 AWG for the bass and the FREQUENCY will follow the path of least resistance and automatically divide up into the proper AWG cable. Current knows the easiest path to follow based on the crossover parameters with respect to frequency. The cross over "design" automatically splits the frequencies based on path impedance values. I ran several calculations to arrive at the 14 AWG aggregate AWG size for the new cable design.



Bare Annealed Copper				
AWG	Dia (in.)	Circular Mils	Ohms per 1000 ft.	Lbs per 1000 ft.
10	0.1000	10000	1.00	31.43
12	0.0791	6250	1.60	19.77
14	0.0633	4000	2.50	12.43
16	0.0500	2500	4.00	7.818
18	0.0395	1563	6.40	4.917
20	0.0316	1000	10.0	3.092
22	0.0250	625	16.0	1.945
24	0.0200	400	25.0	1.223
26	0.0158	250	40.0	0.769
28	0.0125	156	64.0	0.484
30	0.0100	100	100	0.304
32	0.0079	63	160	0.191
34	0.0063	40	250	0.120
36	0.0050	25	400	0.076
38	0.0040	16	640	0.048
40	0.0032	10	1000	0.030

Table 1 - Chart of wire sizes. **Circular Mils** is the square of the diameter in thousandths, and is useful for comparison of the cross-sectional area of a conductor.

We use a 24 AWG 0.020" diameter 400 CMA wires now.
We have 24 per polarity or 24*400= 9,600 CMA, about a 10 AWG.

We can significantly reduce the AWG effects by moving to 28 AWG 0.0125" diameter 156 CMA wires.
The total CMA is the same calculation as before 24*156 CMA = 3,744 CMA, about a 14 AWG.

The ICONOCLAST speaker cable uses 9,600 CMA
The proposed series II system uses 3,744 CMA

If we look at the RATIO of WATTS (work done) to CMA we see;
9,600 CMA / 1000 watts = 9.6 CMA/watt
3,744 CMA /15.875 watts = 235.8 CMA/watt

Clearly we won't have excessive voltage dropped across the 14 AWG leg compared to even the near 10 AWG leg. We want all the "work" done by the speaker, not the cable. Splitting the signal actually IMPROVES the power provided to the LOAD speaker (less voltage dropped across the speaker cables in aggregate).

Another benefit is IM, Intermodulation Distortion, is reduced. When more than one frequency is superimposed together it can create "beat" frequencies distortion that were not there before. Unlike radio transmission devices heterodyning and super heterodyning isn't good. Fewer frequencies at once in a circuit mitigates IM distortion.

Will this 28 AWG size provide the correct Vp linearity adjustment we ALSO need at the same time as just voltage divider rule properties?

I question the ability to manufacture a smaller bonded pair than 30 AWG wire and achieve consistency. The graphs also show that most of the Vp linearity change advantages, if we hear them, are at 30 AWG.

The DCR factor is the other variable that we are interested in. The 14 AWG aggregate of 24 x 28 solid wires is PLENTY to handle the power we are applying to the upper frequency circuit. How much do we need to increase the DCR to flatten the Vp? THAT is the objective once we are satisfied with the AWG requirement. BOTH path DCR and voltage divider properties have to work at the same time.

If we look at the DCR of ONE isolated insulated wire, what the circuit sees we have;

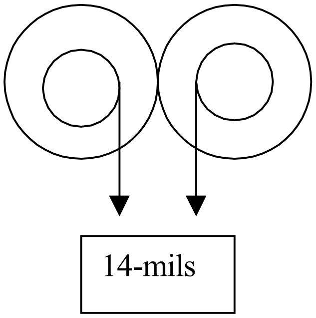
25 ohm/1000 feet for a single 24 AWG wire + 25(X) = 64 ohms/1000 feet for a single 28 AWG wire
X= 1.56 or a 156% increase in DCR going from a 24 AWG wire path to a 28 AWG wire path.
Check - 1.56(25)+25 = 64

The new polarity design would weave twelve 28 AWG bonded pairs (24 wires per polarity) at a 45 degree angle to cancel magnetic fields to lower inductance as well as use FEP to keep the loop area as small as possible.

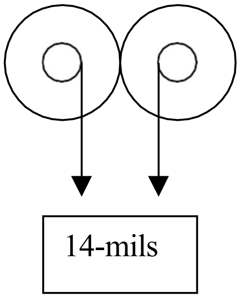
>>>EDITOR'S NOTE:
After this memorandum was written, the design was modified during prototyping -- the number of conductors was doubled to 48 wires in 24 bonded pairs, 28 AWG, resulting in the same per-wire DCR but a halving of the overall measured DCR for the cable as a whole. <<<

The total measured inductance doesn't need to be theoretically as low as the bass section as the CURRENT is far less. There is little voltage (50V or so peak in a BIG amplifier) in the "system" so we are working with big current values. The voltage will be the same on both speaker leads, but the current will DIVIDE between them.

A limit is imposed on FEP INSULATION thickness of 7-8 mils or so. This will define the capacitance, inductive loop area and field cancellation factor. We will still see the same "plate to plate" distance for capacitance and the same loop area inductive distance so the end cable SHOULD be very close to what we have now, or slightly less. We can MEASURE a sample to see ABOUT where we fall on a 28 AWG variant.



24 AWG SOLID



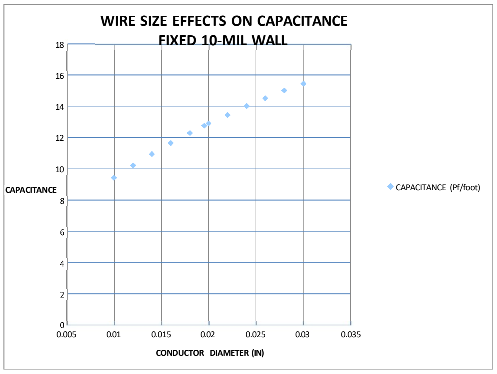
28 AWG SOLID

UNSHIELDED PAIR IN AIR

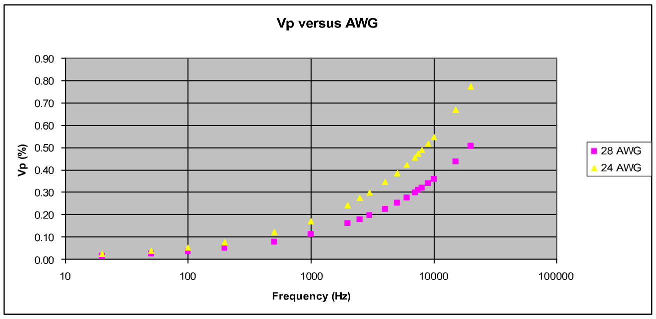
CONDUCTOR DIAMETER:	0.02 in.
INSULATION DIAMETER:	0.034 in.
# STRANDS:	1
VELOCITY:	69 %
STRANDING FACTOR:	1
DELAY:	1.472463768 ns/ft
DIELECTRIC CONSTANT:	2.100399076
DO/DI:	1.7
CAPACITANCE:	**15.13791155 pF/ft**
IMPEDANCE:	**97.26994133 Ohms***

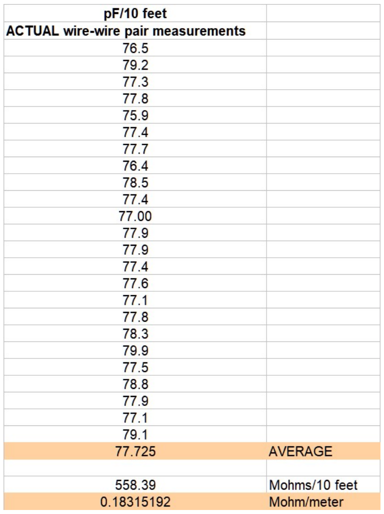
UNSHIELDED PAIR IN AIR

CONDUCTOR DIAMETER:	0.0125 in.
INSULATION DIAMETER:	0.0265 in.
# STRANDS:	1
VELOCITY:	69 %
STRANDING FACTOR:	1
DELAY:	1.472463768 ns/ft
DIELECTRIC CONSTANT:	2.100399076
DO/DI:	2.12
CAPACITANCE:	**12.24887958 pF/ft**
IMPEDANCE:	**120.2121188 Ohms***



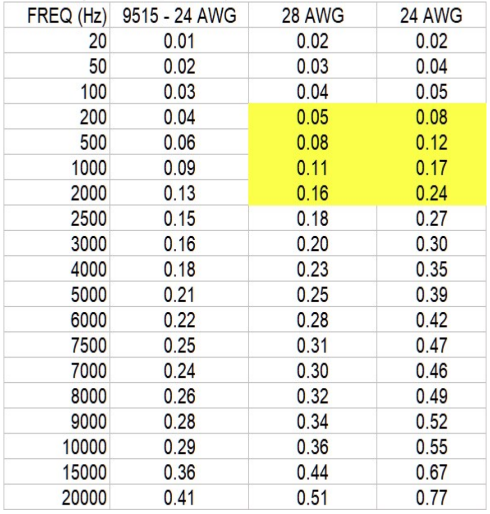
The LOG Vp versus AWG chart below shows what happen when we "splice" the two wire designs together. The crossover region (yellow) is essentially the same at the 200 Hz or the whereabouts a woofer section is crossover to the mid/tweeter. Three-way speakers will cross over somewhere in the 100 Hz- 500 Hz range. The chart used the MEASURED capacitance and resistance loop data from an actual cable.





pF/10 feet	
ACTUAL wire-wire pair measurements	
76.5	
79.2	
77.3	
77.8	
75.9	
77.4	
77.7	
76.4	
78.5	
77.4	
77.00	
77.9	
77.9	
77.4	
77.6	
77.1	
77.8	
78.3	
79.9	
77.5	
78.8	
77.9	
77.1	
79.1	
77.725	AVERAGE
558.39	Mohms/10 feet
0.18315192	Mohm/meter

Vp @ Frequency



FREQ (Hz)	9515 - 24 AWG	28 AWG	24 AWG
20	0.01	0.02	0.02
50	0.02	0.03	0.04
100	0.03	0.04	0.05
200	0.04	0.05	0.08
500	0.06	0.08	0.12
1000	0.09	0.11	0.17
2000	0.13	0.16	0.24
2500	0.15	0.18	0.27
3000	0.16	0.20	0.30
4000	0.18	0.23	0.35
5000	0.21	0.25	0.39
6000	0.22	0.28	0.42
7500	0.25	0.31	0.47
7000	0.24	0.30	0.46
8000	0.26	0.32	0.49
9000	0.28	0.34	0.52
10000	0.29	0.36	0.55
15000	0.36	0.44	0.67
20000	0.41	0.51	0.77

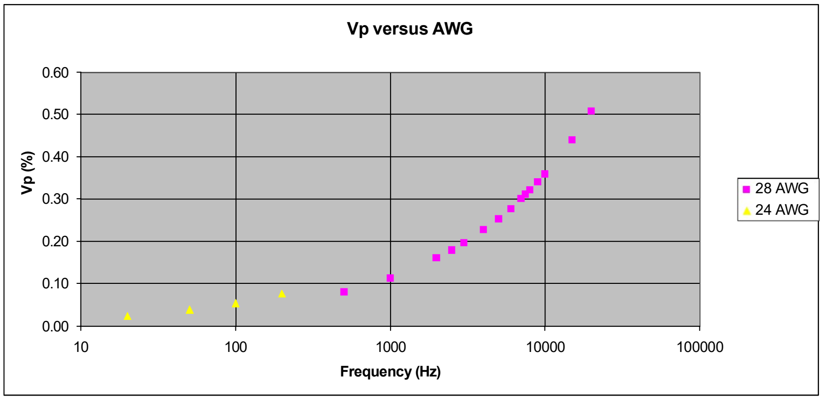
Two-way speaker crossover higher, up to 2.5 kHz (yellow region in the above chart), so applications will be more system oriented for "perfection". An 8% difference in the low-end is acceptable, however. Where we get the best benefits is higher, where we see up to a 26% "flattening" of the Vp differential at 20 kHz. Better still, Vp linearity is a theoretically substantial 9% better at 10 kHz.

How much does the Vp linearity really change or improve with smaller wire? We can't be exact, but the general formula verified against 9515 is encouraging. To get better we need to CHANGE the way frequencies use the speaker cable just like we CHANGE drivers to suit different frequencies.

The math says we can indeed do this and BENEFIT IM distortion, voltage divider properties, wire coherence efficient (closer to the same current through the wire at all frequencies) improvements AND make Vp linearity better across frequency with the changes in a "system" of cables.

I have not seen anyone else try to do this, and use the known properties we've defined as true, to make a better audio cable system. It is more complicated, I grant you that, but it is doable and better on paper. Can we hear the changes? Are we already there yet (you can't hear that!)? Does our system THEORETICALLY work on most speakers with crossover between 200-500 Hz or so? Even up to 2 kHz used on two way designs we see an acceptable Vp "splice" of just 8%.

If we SPLICE the two cables leg and look at the Vp differential we see a pretty good crossover region at 200 Hz (just a 3% difference), or about where most three way or higher speakers have the woofer to mid/tweeter transition. Yes, this is an awful lot of math and introspection as to what is happening in an audio cable but the physics supports SPLITTING the two cables just like drivers are adjusted, to match the frequency range. The speaker's cross over already does this for us…so why not take advantage of it with a properly engineered set of cables? The added coherence and proper time alignment of frequencies can't be a bad thing.



SUMMARY: *The answer to a better audio cable was the realization that we can build a "system" of cables. This avoids the complexity of a MONO cable design that needs to SPLIT the requirements between DCR on the low-end and Vp coherence on the high-end and can't. I can ISOLATE each* ***system*** *and optimize it where it is needed most. The lower frequencies don't need as much Vp linearity adjustments, mostly low DCR for damping factor. The upper range needs significant Vp linearity adjustments and not too much in the way of lower DCR. 30 AWG from 24 AWG takes the best advantage of Vp linearity based on DCR changes. 30 AWG would be VERY hard to process and would fall below the more acceptable 14 AWG total CMA requirement.*

As Vp goes DOWN, the impedance goes UP. Decreasing the Vp at the higher frequencies moves the impedance value "up" to better match the lower end where Vp drops so much, increasing impedance at higher frequencies. The overall effect should be to see the impedance trace flatter across the audio band and with a more coherent (same at all frequencies) Vp and thus less frequency differential.

>>>**EDITOR'S NOTE:**

Following this memorandum, we worked with the Belden Engineering Center to produce a prototype spool of the cable. As mentioned above, the decision was made to load all of the bobbins on the braider and run 24 pairs, rather than 12, into each polarity, bringing the total AWG closer to that of the Generation 1 speaker cable while keeping the individual conductor size the same. The resulting cable tested within expectations and was then ordered for regular production.