3216 16th Avenue West
Seattle, WA 98119

**Phone: 206.284.2924**
Fax: 206.284.2931
www.bluejeanscable.com

**Date:** January 10, 2024 REV 3
**To:** Kurt Denke, Bob Howard
**From:** Galen Gareis
**Subject:** ICONOCLAST Cable Length

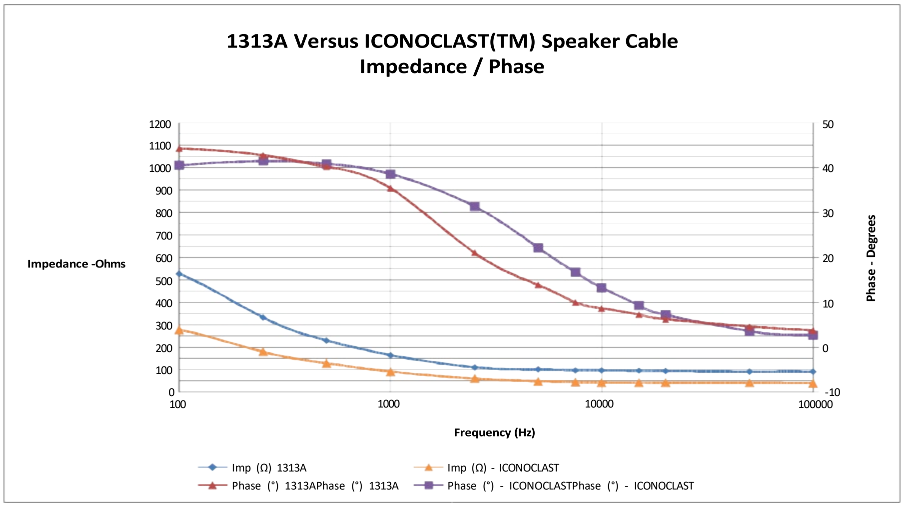
## Speaker and Interconnect Cable Critical Parameters for Length Recommendations

A question always will arise, “how long, and which cable should be long, speaker or IC?” This is a good question and needs a pretty through look at what parameters effect the answer, and why the answer is so generalized. We have the necessary hard data to support the differences between Speaker and Interconnect (IC) cable so let's take a look at them one by one and the unclear answer becomes most clear.

**SPEAKER CABLE –** Usually we have shorter speaker cables , and for good reasons. We want to keep reactive elements, Inductance and capacitance low as well as DCR. This is to make sure the signal sees the load (speaker) and not the reactive cable properties in series / parallel with the load.

Most important to understand is how a cable reacts at analog frequencies, and what that means to the amplifier driving the load. Amplifiers don't like reactive loads and are most linear into a solid and dependable load that limits the stresses on the amplifier. Too low a load or too reactive (L and C) a load will impact the amplifier's performance.

If we examine the data graph below, we can see that the cable PHASE for both cable examples is most capacitive reactive as frequency drops. This caused by the rise in impedance as a result of the cable's velocity of propagation, Vp, dropping with frequency. As we approach DC the cable impedance is undefined or infinity. DC can't pass an AC signal.



The equations for reactance suggest that this is the case; reactance magnitude gets larger with lower frequencies and inductive reactance does the opposite. The negative denotes a capacitive reactance value.

$$X_C = -\frac{1}{2\pi f C}$$

$$X_L = 2\pi f L$$

Do these equations make sense in practice? The equations show that as frequency drops, the capacitive reactance goes up and the inductive reactance goes down. The opposite with increased frequency.

This is what we see testing actual cable. Look at the open and short IMPEDANCE magnitude values in the table below. We see 4.81E07 capacitive (open) reactance magnitude and 2.96E-2 inductive (short) reactance magnitude at 20Hz. If we go up in frequency to 20 KHz we see a switch in magnitudes. The magnitude values decrease for the impedance Open values and INCREASE for the impedance Short values.

The associated PHASE values are shown to the right and we see a negative phase for the OPEN (capacitance) and a positive phase for the Short (inductive).

In theory the total cable Open capacitive phase is -90 degree at DC.
In theory the total cable Short inductive phase is 0 degree at DC.

The cable's total reactance (the two averaged) phase will be zero at RF as the two reactance phase cancel each other out. The table shows a -2.431 total phase at 2 MHz. This is why an RF cable has no phase associated with the impedance magnitude and we can use Zo = SQRT (L/C).

| **1313A (9 ft)** | **Impedance** | | | **Phase** | | |
|---|---|---|---|---|---|---|
| **Freq (Hz)** | **Open (Ω)Open (Ω)** | **Short (Ω)Short (Ω)** | **Imp (Ω)Imp (Ω)** | **Open (°)Open (°)** | **Short (°)Short (°)** | **Phase (°)Phase (°)** |
| 20 | 4.81E+07 | 2.96E-02 | 1193.141 | -90.4698 | 0.3563 | -45.057 |
| 50 | 2.00E+07 | 2.18E-02 | 660.023 | -90.3453 | 1.1852 | -44.580 |
| 100 | 9.82E+06 | 2.82E-02 | 526.722 | -90.3686 | 1.8263 | -44.271 |
| 250 | 3.92E+06 | 2.83E-02 | 332.688 | -90.0467 | 4.5145 | -42.766 |
| 500 | 1.98E+06 | 2.68E-02 | 229.994 | -89.9460 | 9.6386 | -40.154 |
| 1000 | 9.90E+05 | 2.75E-02 | 165.054 | -89.7825 | 18.9478 | -35.417 |
| 2500 | 4.07E+05 | 3.02E-02 | 110.789 | -89.7190 | 47.6699 | -21.025 |
| 5000 | 2.01E+05 | 5.04E-02 | 100.582 | -89.6549 | 61.9023 | -13.876 |
| 7500 | 1.34E+05 | 7.08E-02 | 97.334 | -89.6116 | 69.5925 | -10.010 |
| 10000 | 1.00E+05 | 9.37E-02 | 97.020 | -89.5907 | 70.3138 | -9.638 |
| 15000 | 6.67E+04 | 1.35E-01 | 95.010 | -89.5655 | 75.0060 | -7.280 |
| 20000 | 5.06E+04 | 1.76E-01 | 94.445 | -89.5846 | 77.0976 | -6.244 |
| 50000 | 2.03E+04 | 4.09E-01 | 91.098 | -89.5782 | 80.3490 | -4.615 |
| 100000 | 1.08E+04 | 7.70E-01 | 91.197 | -89.5977 | 82.0787 | -3.760 |
| 500000 | 2.04E+03 | 3.42E+00 | 83.573 | -89.6801 | 84.4757 | -2.602 |
| 1000000 | 1.02E+03 | 6.65E+00 | 82.348 | -89.7118 | 82.5675 | -3.572 |
| 2000000 | 5.07E+02 | 1.29E+01 | 80.761 | -89.7418 | 84.8804 | -2.431 |

An amplifier sees the cable placed between it and the speaker. Speaker cables are mostly capacitive reactive and, especially at low frequencies. We can see this in open-short impedance testing graphs. At 20 Hz, we can see that the cable's reactive portion is almost entirely capacitive. As we go to RF, the inductive portion increases until the phase magnitudes equal each other and cancel. Again, this is why RF impedance doesn't have a phase angle associated with it, it is resistive.

We don't get that benefit of a resistive load through analog. We have a highly reactive element right where most of the power is being distributed and where the equivalent cable+speaker load is also very low.

Our measured open-short data table above on a typical zip cord, 1313A, shows our conundrum for an exact length spec value. The 1313A PHASE at 20 Hz is -45.057 degrees, or capacitive. Notice that the two 20 Hz individual measurements, open = -90.4698(capacitive reactance) and short = 0.3563 (inductive reactance) are averaged to produce the final phase. The 2,000,000 ( 2 MHz) value is nearly a purely resistive phase, -2.431 degree.

The reactance through analog frequencies means an amplifier is driving a high capacitive load at low frequency, and right where we are trying to transfer the maximum power as the graph shows below illustrates. The graph shows ~ 1000 watts distribution at ~50 Hz and only 1 watt distribution at ~2 KHz.

The power data helps to explain why we want to keep cable reactive elements low. As a cable gets longer the capacitance magnitude increases with length and the reactance phase angle only slowly drops as frequency rises. Remember, the reactances are frequency dependent. We know this because the L and C reactance equations shown above use omega, which equals 2*pi*F.

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

1000 Watts (0 dB)

15.875 watts (-18 dB)

1 Watt (-30 dB)

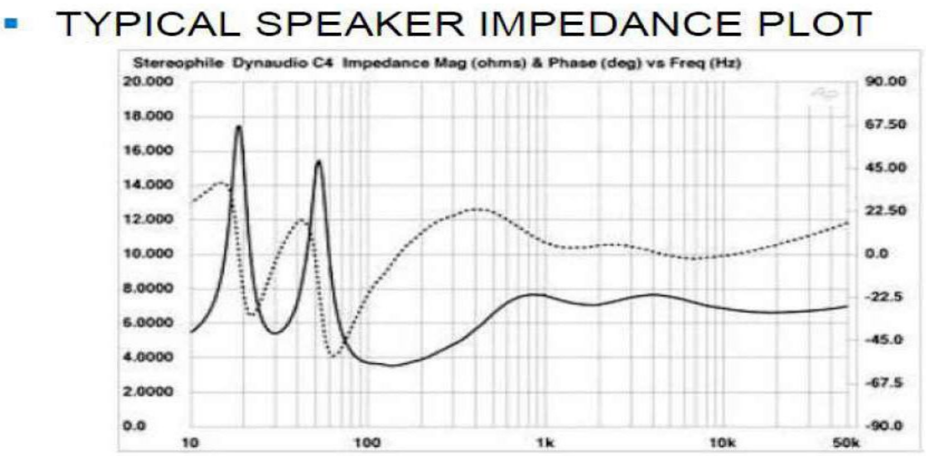
-54 dB .00375 Watts

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

The last speaker cable length factor is DCR. Ideally we want all the power to the load and none used up by the cable. This is most easily managed with the cable aggregate AWG. Lower is better. Power is lost through $I^2R$ equation and since we have a lot of current into a low impedance speaker load we need to keep speaker cable R very low because current is squared.

**The SPEAKER** - What about the other half of the problem, the speaker load? Below is a typical Stereo Review speaker plot.



The graph shows two lines, the SOLID impedance trace, and the DASHED reactance trace. An amplifier doesn't see the solid line impedance by itself. Like a speaker cable it really sees the reactance vector sum that is frequency dependent, too, and is a much better representation of the load the amplifier has to drive.

The term used and developed in Stereo Review to describe the vector addition of the two traces is called EPDR, equivalent power dissipation resistance or the same resistive load that would represent the complex two reactance vectors added and that EPDR value lower than the resistive magnitude by itself. The speaker EPDR value dips to a minimum impedance in the lower frequencies and coincides with the highest power delivery frequency range.

It would be nice to see the EPDR trace as well as this is a far better indication of the load the amplifier will see and with added speaker cable length. To be fair the cable would always be the same.

**The AMPLIFIER-** Now we can piece together the problem of cable length. We aren't really driving just the cable, but the speaker too. The complex vector of the speaker and cable isn't truly known as so many speakers and cables exist. We have no standard(s) for either. We have measurement standards, true, but not what the values have to be. Amplifiers are measured into a referenced speaker cable to be consistent and a two to eight ohm load and if possible, holding the AC line voltage constant. That's about as easy as it gets for an amplifier though. In the real world we drive a reactance and this is a tougher effective load than resistors. Worse, it is frequency dependent and lowest where the maximum power is being applied.

The speaker's properties are largely responsible for the speaker cable length. To make sure we are stable, keep speaker cables shorter is the best answer. With low capacitance cable, assume less than 100 pf/foot, be cautious above 30 feet or so. Some cable's are long capacitors (parallel plate type cable) and need extra care when used. They may have low inductance but really high capacitive reactance and again, right where we really don't want it. Low inductance isn't great if we have too high load capacitance to get it.

A speaker cable is a signal voltage transfer function (capacitance distorts the voltage) but it is driven in the POWER domain (inductive properties distort the current). We like to have both as low as we can get them because of this transfer function property is watts, and watts = current times voltage across the time domain.

What is done to fix the reactance (cable length and speaker) problem amplifiers are faced with?

- The data suggest we can add INDUCTANCE phase to an amplifier's output stage to offset CAPACITANCE phase. This is a pure estimation of the “average” capacitive load the amplifier may drive.
- Some speakers use ZOBEL reactive networks that are tuned to cancel capacitance and inductance and thus to negate a speaker's total reactance.
- Some cables build-in a ZOBEL network to mitigate the cable reactance.
- Systems can be designed to isolate all variables (amp+cable+speaker as a closed system).
- Eliminate the speaker cable! Use powered speaker's and isolate each amplifier to a closed frequency range.

**IC, Inter-connect, CABLE -** We need to be aware of a switch in theory for IC cable. The generalized summary is as such
Amplifier ------> Speaker cable -----> low impedance speaker load.
Amplifier------> IC cable------------> High impedance input load.

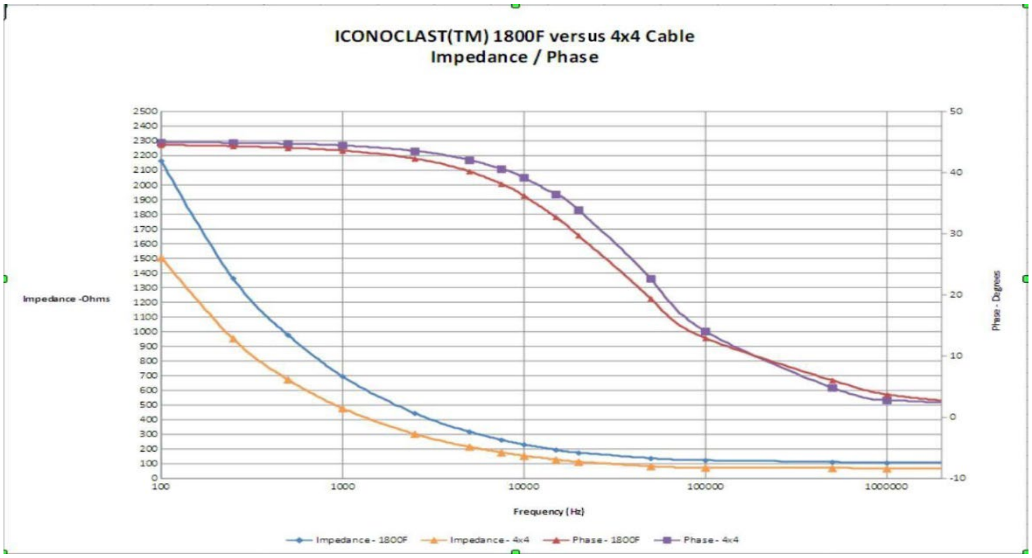
IC cable have better standards and why these are able to be driven over longer distances. IC cable is a voltage transfer function versus a primarily a current transfer function on a speaker cable. This changes things.

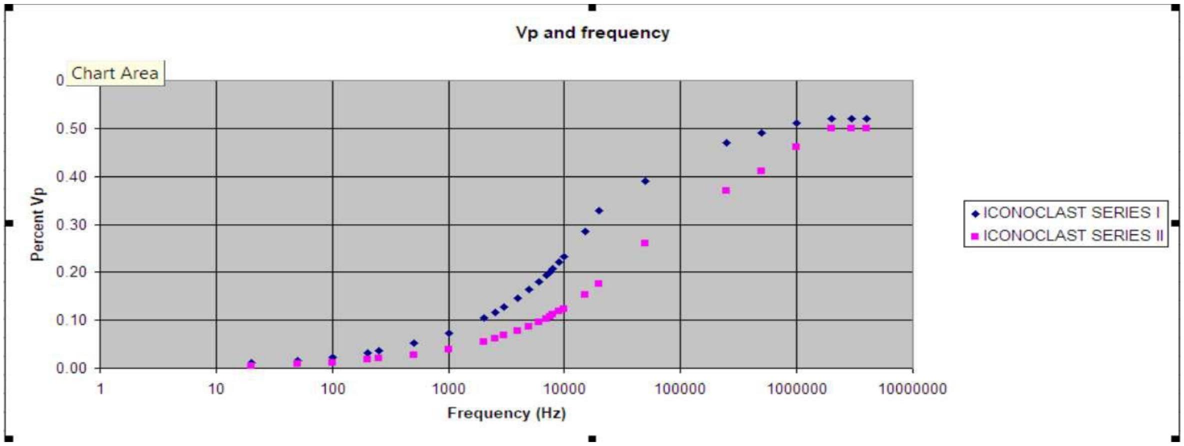
The 1800F IC cable data shows that the 20 Hz total reactance phase angle is also -44.761 degrees (theoretically -44 degrees). The 20 Hz inductance phase angle is still low at 0.404 degree so that aspect is the same as the speaker cable. We approach a theoretical zero phase angle at RF, or -2.644 degrees in this data set.

The Open and Short magnitudes also act the same as the speaker cable, Capacitive magnitude drops as we go up in frequency and inductive value magnitudes increase as we go up in frequency.

| 1800F | Impedance - 1800F | | | Phase - 1800F | | |
|---|---|---|---|---|---|---|
| Freq (Hz) | Open (Ω)Open (Ω) | Short (Ω)Short (Ω) | Imp (Ω)Imp (Ω) | Open (°)Open (°) | Short (°)Short (°) | Phase (°)Phase (°) |
| 20 | 5.27E+05 | 4.39E+01 | 4808.458 | -89.561 | 0.040 | 44.761 |
| 50 | 2.12E+05 | 4.39E+01 | 3049.726 | -89.353 | 0.086 | 44.633 |
| 100 | 1.07E+05 | 4.39E+01 | 2162.846 | -89.168 | 0.168 | 44.500 |
| 250 | 4.30E+04 | 4.31E+01 | 1361.938 | -88.958 | 0.418 | 44.270 |
| 500 | 2.17E+04 | 4.39E+01 | 976.710 | -88.831 | 0.834 | 43.999 |
| 1000 | 1.10E+04 | 4.39E+01 | 694.086 | -88.742 | 1.661 | 43.540 |
| 2500 | 4.44E+03 | 4.41E+01 | 442.516 | -88.649 | 4.154 | 42.247 |
| 5000 | 2.24E+03 | 4.46E+01 | 316.095 | -88.541 | 8.229 | 40.156 |
| 7500 | 1.50E+03 | 4.54E+01 | 260.891 | -88.412 | 12.160 | 38.126 |
| 10000 | 1.13E+03 | 4.65E+01 | 228.858 | -88.268 | 15.884 | 36.192 |
| 15000 | 7.51E+02 | 4.95E+01 | 192.718 | -87.937 | 22.570 | 32.684 |
| 20000 | 5.61E+02 | 5.33E+01 | 172.923 | -87.569 | 28.181 | 29.694 |
| 50000 | 2.10E+02 | 8.68E+01 | 134.921 | -84.447 | 45.678 | 19.384 |
| 100000 | 7.84E+01 | 1.88E+02 | 121.525 | -72.576 | 46.763 | 12.907 |
| 500000 | 5.00E+01 | 2.40E+02 | 109.457 | -8.462 | -3.538 | 6.000 |
| 1000000 | 1.50E+02 | 7.29E+01 | 104.509 | 12.654 | -19.990 | 3.668 |
| 2000000 | 9.66E+01 | 1.22E+02 | 108.468 | 6.495 | -11.783 | 2.644 |

1800F IC IMPEDANCE is 4808.458 ohm at 20 Hz and 2162.846 ohm at100 Hz. The speaker cable data above is 1193.141 ohm at 20 Hz and 526.722 ohm at 100 Hz. Why? The Vp still drops with frequency (graphs below) in IC, same as speaker cable, so that physics stays with us. The Vp is in the denominator of impedance equations so as it decreases, impedance increases. The capacitance is also in the impedance equation denominator so as it capacitance down it also pushed impedance up.





What also stays with us is that an IC cable is ideally a voltage transfer function only. No current, in theory, need "apply" to the load which is infinity in theory. There can't be a current when a cable is terminated into a true "open". In practice the load is a suggested 47 K ohm. Here we at least have a suggested standard for the load. With the speaker load we don't have this suggested standard load value across frequency.

The IC 47 K ohm load data illustrates why we need to keep capacitance LOW, to not distort the voltage transfer function values across the load. Since the lower the capacitance drives impedance HIGHER, we need to make sure that the load is far higher than the cable impedance. That's done with the 47 K ohm resistive load value. The signal is seen across the load (high impedance) and not the cable (still a much lower impedance) and with lower signal distortion the lower the capacitance.

**CONCLUSION –** The general rule to keep speaker cables 30 feet and shorter is now better understood. We can't rely on a known, or easy, load for the amplifier. The cable and speaker are both open to their own designs and are highly unpredictable. We have a high current situation to address (low DCR cable) and cable+speaker reactive properties superimposed onto that situation. Both are seen by the amplifier and should be minimized as best possible (shorter speaker cable).

Interconnect IC cable has a very solid recommended high-impedance resistive 47 K ohm load target and as such, the voltage driver amplifiers can depend on a "reasonable" total capacitive load and into a high resistive load impedance. That high and resistive impedance allows a far, far easier time for the driver op-amp to run longer lengths. Knowing the load's properties really helps! Some IC cable loads drop to about 20Kohm at 20 KHz but inconsequential. Input loads are often frequency dependent but remain high relative to the cable's impedance and that is maintained.

XLR can drive 120 feet because they have CMRR circuits that reject common mode noise. The two wires with equal and opposite voltages have a common ground that floats between them, so we don't have the ground potential difference with longer lengths. Capacitance is desired to be low as this is a voltage transfer function circuit. XLR do have CUB, capacitance unbalance as each signal wire isn't identical to ground. This can have a residual distortion but is a far better trade than magnetic noise.

RCA is recommended to 30 feet for noise mitigation because it is possibly susceptible to low frequency magnetic noise as RCA get longer. This is because of the shield current between devices increasing with length as magnetic signals passing through the shield. RCA do not have CUB, capacitance unbalance, so in ideal lengths a meter or so, they have minimal voltage distortion from unbalance (there isn't any).