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Subject: BAV Power Cable Performance.

BACKGROUND: The BAV series of power cords is designed to offer best in class performance at the best possible price. Not an easy target to hit. We need to fully leverage measurable variables to arrive at a reference level power cord that is very good, and to use this reference as a difficult benchmark to exceed during the ICONOCLAST design stage(s). Comparison to known existing cords is helpful to metric where, and if, improvements have been made and both with well known materials (ROMEX) and very expensive legacy power cords.

DESIGN: The ROMEX is a standard parallel 12/3 solid bare copper with paper tape insulated ground and THHN (Nylon / PVC) insulated singles, this provides 20A service to the wall outlet. Belden 19105 is a high performance EPDM insulated and jacketed 10/3 105x30 AWG Bare Copper portable cordage design with fillers.

BODY: Many designs and dielectrics were tested, and condensed to the best of the bunch for comparisons. Belden 1910X series Heavy Industrial EPDM power cords, surprisingly shot to the head of the pack.

For testing, we used the following connectivity to test worst case with connectors installed.
The 10/3 19105 was designed as an assembly with properly terminated ends matching typical service outside the wall outlet.

1	Hubbell Wiring Device-Kellems Insulgrip Straight Blade Plug Pin Cont 5-15P NEMA 3 Cond 2 Poles Screw	70116454	HBL5266C
1	Marinco Power Products Female Connector; 15A 120V Iec 320 C15	71657730	320IEC15

The Romex® was standard 12 AWG/3 conductor and tested bare for theoretical maximum performance as the terminations are removed, providing a WORST case test situation for the 19105 assembly.

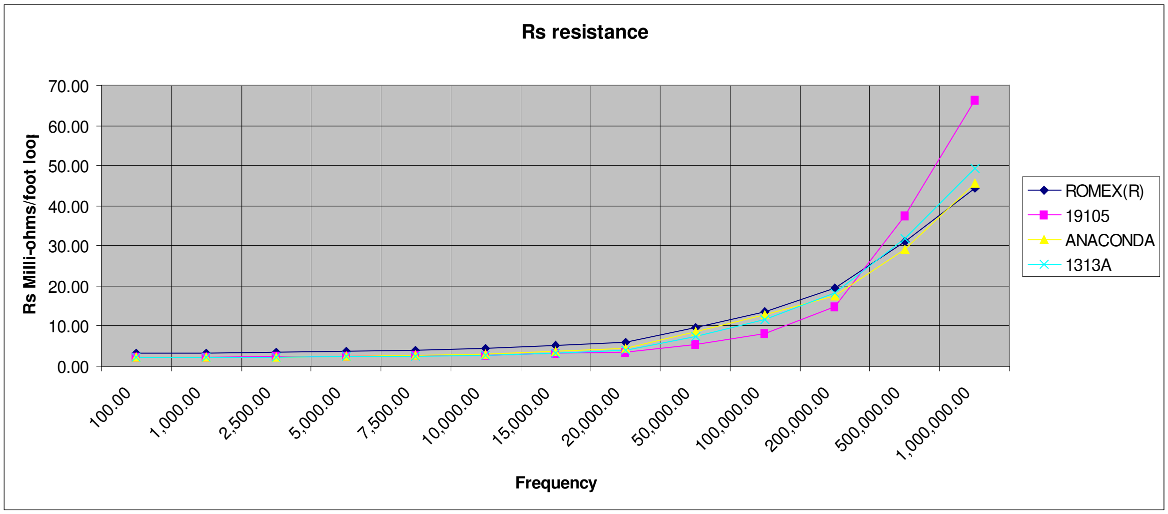
Data was collected with an AGILENT E4980A high precision LCR. The calibration was double verified tested with the ROMEX® against the values provided with a VALHALLA 4176 precision DCR meter. Each cable was tested for Impedance to frequency, Rs, where lower values represent a less resistive path for the signal at that frequency.

1 foot LOOP sample data in milli-ohms.

L	2.27 uH	1.99 uH	0.860 uH				
C	124 pF	208.4 pF	114.64 pF				
FREQUENCY	**ROMEX(R) - 10'**	**19105 - 10'**	**ANACONDA - 6'**	**per foot loop ROMEX(R)**	**per foot loop 19105**	**per foot loop 1313A**	**per foot loop ANACONDA**
100.00	32.70	23.10	13.57	3.27	2.31	2.27	2.26
1,000.00	32.90	23.20	13.59	3.29	2.32	2.27	2.27
2,500.00	33.70	23.50	13.92	3.37	2.35	2.30	2.32
5,000.00	36.30	24.50	14.85	3.63	2.45	2.40	2.48
7,500.00	39.90	26.00	16.11	3.99	2.60	2.57	2.69
10,000.00	44.00	27.80	17.68	4.40	2.78	2.78	2.95
15,000.00	52.40	31.50	21.46	5.24	3.15	3.31	3.58
20,000.00	60.30	35.00	25.89	6.03	3.50	3.90	4.32
50,000.00	96.10	53.10	51.77	9.61	5.31	7.30	8.63
100,000.00	136.70	82.40	76.17	13.67	8.24	11.67	12.70
200,000.00	194.80	148.80	105.02	19.48	14.88	18.35	17.50
500,000.00	311.00	373.80	174.29	31.10	37.38	31.78	29.05
1,000,000.00	442.60	663.00	272.96	44.26	66.30	49.24	45.49

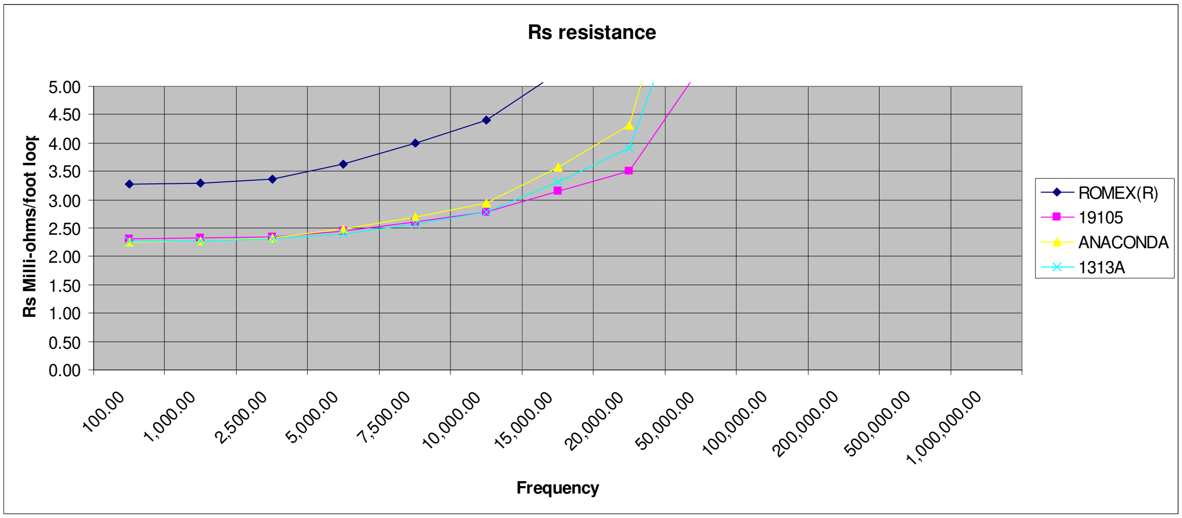
The 19105 swept Rs numbers are very close to the 1313A swept Rs numbers. Both are 10 AWG stranded designs, so this is not unexpected. The 1313A uses PE verses 19105's EPDM, accounting for the higher Rs with the 19105.

We actually want the 19105 EPDM to offer higher impedance to RF for better passive EMI/RFI attenuation. EPDM is almost 190 times higher RF loss tangent that PE. Is this ideal? From a low pass signal perspective, yes, it is. We want to optimize the performance in the 60 Hz pass band and restrict extraneous signals above that from passing down the cable efficiently. The 1910X series is the best passive RF defense at higher frequencies.

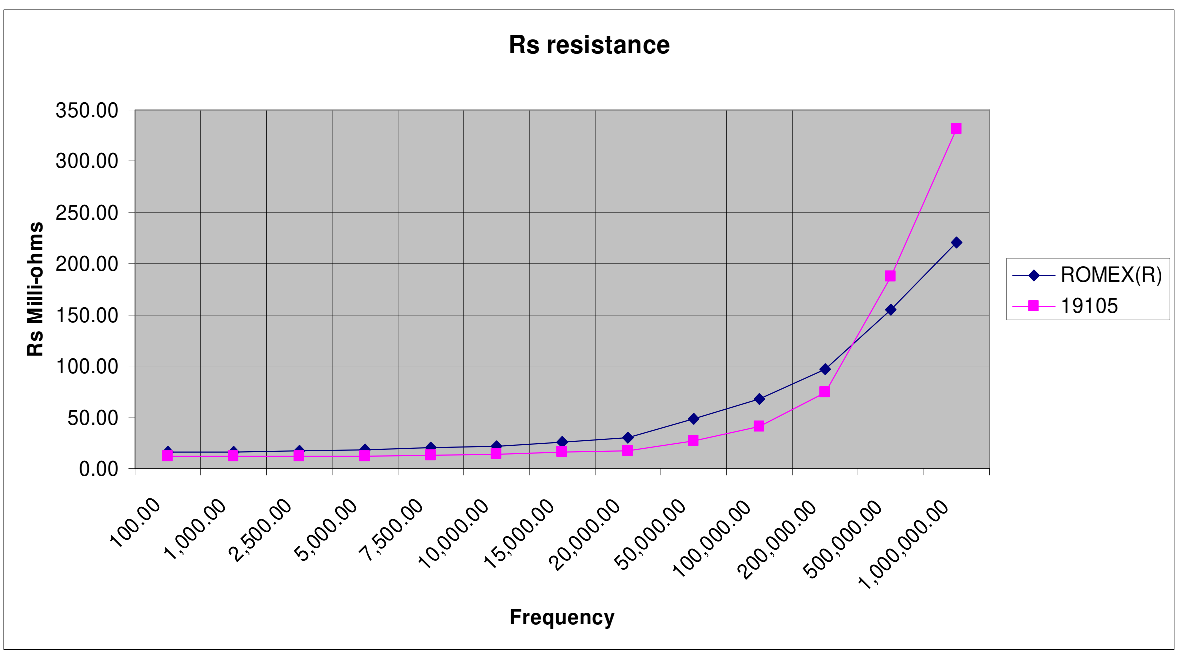


The BAV series EPDM is effectively offering higher impedance to RF energy, especially above 500,000 kHz where EMI and RFI are most equivalent. At higher frequencies we see an advantage to EPDM. This is an expensive dielectric as it is a thermo-set (heat cured) material but test very well for audio power applications, as we shall see in the next graph.

The Rs graph below shows a close-up in the lower frequency range. The Y-axis is expanded to just 5.00 Mill-ohms/foot loop DCR so we can see the length adjusted performance of each cable. Ideally we want the "best" cable to be the LOWEST impedance in the signal pass band, or through the audio range.



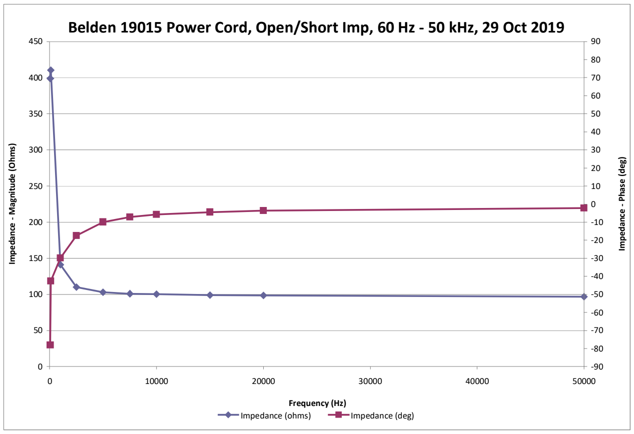
Below we look at what's in the wall, ROMEX, and the 19105. Are we a bottleneck to the wall supply? The data supports superior support from the wall with 19105 BAV cordage. We pass with less impedance at the low-frequency end yet offer better RF immunity at the high-frequency end.

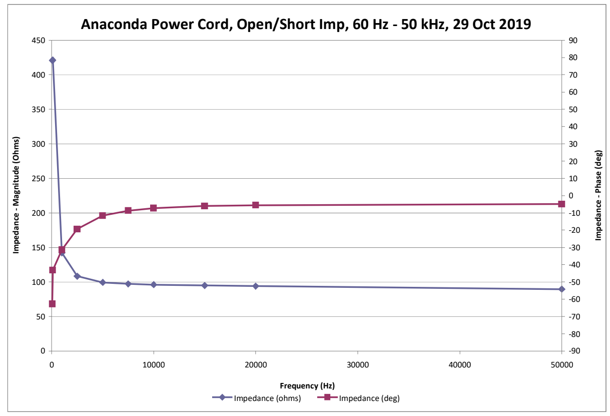


The Rs data above shows that the 19105 exceeds every option through the audio band. And the 19105 higher frequency Rs, even with a far larger AWG size, ramps up significantly, indicating a higher impedance assembly for passive EMI/RFI attenuation.

IMPEDANCE OF POWER CORDS: Are there significant differences in power cable IMPEDANCE between esoteric cords and BAV series? We tested to find out and the answer is no: both exhibit the expected rise in impedance at lower frequencies as the Vp DROPS the lower we go thus, we see the RISING impedance trace shown below for BOTH cables. Each cable shares almost identical impedance through the audio ranges.

The input impedance of the transformer stage is considerably higher than the cable by several orders of magnitude so the voltage divider drop across the cable is inconsequential.





Neither design above offers a vastly different, if different at all, cable impedance at 60 Hz.

REACTIVE VARIABLES: A power cord should be a near short circuit to current impedance, or inductance.

	Inductance / foot	Capacitance per foot
ROMEX bulk	0.227 uH	12.4 pF
19105 Cord assembly	0.199 uH	20.8 pF
ANACONDA Cord	0.143 uH	19.1 pF

The data table shows very good inductive performance for the BAV cable, exceeding the wall outlet. More exotic inner constructions can LOWER inductance at 10X the price. Capacitance is inconsequential to power cords as this value is in series with a massive capacitor bank in the power supply thousands of times higher in value than the cord. And, the 60 Hz is rectified to DC. Initially full wave DC, anyway, and then filtered with the capacitor banks to near perfect DC. We need current to pass unrestricted at 60 Hz.

GROUND DIFFERENTIAL The advantage of low DCR power cables is sometimes overlooked, and that is minimizing ground plane differential in our systems. A perfect ground is ZERO to any other ground point in the system to a reference. This is usually the wall. Any "wire" we put between that and the LENGTH and AWG will alter the uniformity of the ground, and this is how ground loops are created. Fortunately, power cables are short, but higher current circuits need lower DCR cords to mitigate this effect as well as to not drop excessive voltage across the cord. A power cord is a component in series with the wall voltage, and it will absorb power before it can get to the wall based on its DCR.

Since the voltage drop on the power cord is a PRODUCT of current in the cord and the cord's DCR to create a voltage. The voltage drop should always be ZERO ohms, ideally. We do need to manage the cord's DCR. We don't always need a 10 AWG cord. If we have 1/10th the current we can have 10X the cord DCR and arrive at the exact same voltage drop in the same DCR cord. This can be a lower number AWG cord that is LONG, or a shorter, higher number AWG cord, for instance.

SHIELDING Shielded power cords are nearly ALWAYS FCC shielded for EGRESS, or RFI leaving the device under use, not INGRESS from the external environment.

"The FCC label or the FCC mark is a certification mark employed on electronic products manufactured or sold in the United States which certifies that the electromagnetic interference from the device is under limits approved by the Federal Communications Commission."- FCC standard UNDERSTANDING THE FCC REGULATIONS FOR COMPUTERS AND OTHER DIGITAL DEVICES, OET BULLETIN NO. 62.

If it needs a shielded cord to pass, the cord is required to be CAPTIVE such that the device can't be used otherwise. If a device has an open IEC, or like, socket it has passed the stricter FCC HOME use emissions tests and any cord can be used. The class A and B standards must be met to be rated as such.

Class A digital devices are ones that are marketed exclusively for use in business, industrial and commercial environments. Class B digital devices are ones that are marketed for use anywhere, including residential environments. Section 15.3(h) Section 15.3(i) Examples of Digital Devices.

If a device near a power cord is sensitive to even FCC emissions limits, a proper shield is needed to mitigate that interference even further. A shield GROUNDED at BOTH ends is required to make sure the shield current is near ZERO. If a shield is zero DCR, it can be infinitely LONG and current flow in the shield will generate ZERO interference voltages. The efficiency of a shield is called transfer impedance, and rates a shield's impedance to RF current flow. A good shield is ideally a single POINT of reference, thus at that point no voltage can be induced as there is no current.

Floating shields, open at one end, preferably at the wall outlet, are an ANTENNA ground and INDUCE current to ground BY DESIGN. These will create a VOLTAGE drop, which can inductively (low frequencies) or capacitively (high frequencies) couple to the signal wires under the shield. In a system with a BROKEN ground (high impedance resistance to ground) an antenna ground can be a better option IF YOU DON'T OR CAN'T FIX THE GROUND differential! It is NOT the proper way to mitigate NOISE; proper ground impedance is.

We have a paper on SHIELDING for more information on this. The BAV cords are UNSHIELDED as almost ALL audio devices, digital or analog have IEC open receptacles and pass FCC emissions levels for trouble free operation. Adding a shield is $$$ and seldom solves a problem over FUD. Shields add capacitance to ground, but the cable's inductance remains essentially the same as it ignores dielectric effects. Adding a shield can alter the geometry some, changing the loop area and inductance.

CONCLUSION: Belden 19105 Rs is superior to in wall ROMEX®. The 19105 EPDM and stranded copper design will mitigate RF much more than standard solid copper ROMEX at high frequencies and offer a lowest case DCR. BAV surpasses even an esoteric design in that passive RF dielectric impedance values based on the Rs measurements are better.

The inductance variables are also superior to ROMEX and overall electrical values nearly mirror high-end reference grade after market power cord with proper connectivity on both cords at one-tenth or less the price.

The input impedance (inductance) of the device transformer determines the ultimate performance, not really the power cables assuming we use adequate AWG to mitigate voltage drop and ground differential current. The power supply's input resistance is what limits the inrush current and is value is several orders of magnitude higher in inductance than the cable's at turn on transient.