ARGENTUM ACOUSTICS

Engineering Truth

Elegant • Evocative • Existential

Technical White Paper

Cables as Components

Most people believe that audio and video cables just hook components together and little else. That is correct in theory. Just as any component in a system should do all and only what it is designed to do, the same applies to cables: The theoretically perfect cable should carry signal without affecting system sound or picture quality in any way.

However theoretical ideals are *theoretical* ideals; in fact making them a practical reality strains current technology. The perfect cable – utterly passive, absolutely neutral – is extraordinarily difficult to design and build in the real world. In fact cables of *all* kinds almost always have an effect on system performance.

Passive or Active

Engineering Truth number one: Cables are *never* totally passive. They are, in fact, *active* components in the signal path. Passing current through a wire produces well-documented electrical phenomena. Argentum Acoustics® minimizes these effects and as a result sounds better. We have the experience, the resources, the wherewithal and the commitment to make advanced designs a reality, coming *very close* to the theoretical ideal without reaching for outlandish "solutions".

AC/DC and Conductor Basics

Unlike others who limit themselves to one preferred material[1] for conductors, Argentum Acoustics selects among several stranded and solid-core materials, choosing the best for each cable's intended purpose, and then we cryogenically treat[2] them for significantly improved performance. Argentum uses only 99.99997% pure UP-OCC (Ultra Pure – Ohno Continuous Cast) copper[3] in interconnects, speaker cables and power cords, and silver in our high frequency digital datalinks.

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[1] Usually copper or silver, although some use aluminum, steel, or in one case carbon (the same material from which some resistors are made) thus exhibiting a high resistance factor. Others use exotica like 24K gold. In fact gold proves a poor choice as it is about 40% as conductive as copper or silver, and is only used – and even then only in very thin layers – as connector plating to prevent corrosion.

[2] Cryogenic treatment subjects conductor materials to liquid nitrogen temperatures of -270°C for 24 hours resulting in a rearrangement and regularization of component molecules improving electron flow.

[3] UP-OCC is the latest manifestation of a process invented in the United States in the 1920s called "zone refining" used in metallurgical and physics laboratories to produce very small quantities of ultra-pure copper for experimentation. As originally practiced, zone-refining used a special crucible heated at one point only, into which ordinary copper was introduced for melting and purification. As the copper melted the impurities flowed to and stayed at the hottest point, while pure copper flowed out through a controlled off-side opening in a process of "continuous casting". Because the hot purified copper was cooled very slowly, it annealed with very few and extremely long crystals, some up to 700 feet! The crystal "junctures" between crystals are where the remaining impurities – including ferrous metals and sulfur – gather and interfere with signal flow. The fewer crystal junctures there are, the better the copper's performance as a conductor.

Although silver (argentum) is listed in textbooks and engineering manuals as the most highly conductive of all metals[4], that applies only to Direct Current (DC). Engineering Truth: None of the signal ever conducted in any audio, video or digital application is ever DC! All signal information is always in Alternating Current (AC) mode, bringing an entirely different set of rules into play.

Whenever current passes through a conductor, an electromagnetic field forms around it and remains in place for as long as the current flow continues. With DC current, the flow is constant and the electromagnetic field becomes irrelevant to current transfer. With AC current[5], however, the field forms, collapses, re-forms, and re-collapses each and every time the current changes direction. It results in a phenomenon called self-inductance[6] that reduces the effective conductivity of the metal.

The degree to which self-inductance will affect signal flow through a conductor is directly proportional to the frequency of the signal (the higher the frequency, the greater the effect), and the material of which the conductor is made. (See note #4.) As silver is more self-inductive than copper despite its lower DC resistance, it has a higher total impedance[7] than copper, thus copper is the better conductor for signals at audio frequencies. At higher digital and video frequencies, silver, for different reasons entirely, is the better conductor, and we specify ultra-pure (99.99994% or better) Laboratory Grade silver.

Silver for Digital & Video Conductors

The fact that silver is a better conductor material for digital and video cable does not directly relate to inductive reactance, but to a factor in part resulting from it. As electrical current is actually electron flow, and as all electrons have the same negative electrical charge, they repel each other[8] and stay as far apart as possible when passing through a conductor. Frequency-related inductive reactance complicates the situation, resulting in lower frequencies passing, to the extent possible, through the entire cross-section of a conductor – from center to surface – while higher frequencies are forced to travel at a depth farther and farther away from the conductor's center until the highest frequencies are restricted to passing through and along the conductor's outermost surface.

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[4] The noted conductivity of silver is 1.0 or 100%, the standard against which all other conductive materials are rated. ETP (Electro Tough Pitch) copper – from which pennies are made – is said to have a conductivity of 0.9, which is 90% of that of silver.

[5] Direct current always flows in the same direction, alternating current constantly reverses its polarity (Positive [+] or Negative [-]), and thus its direction of flow. The rate at which these reversals of polarity occur is the "frequency" of the AC signal.

[6] Whenever an electromagnetic field collapses, an electric current is *induced* in any conductor within range of the collapsing field. When the conductor in which that current flow is induced is the same conductor as the one around which the original field was formed, the phenomenon is known as "self-inductance". Currents resultant from inductance are always of the same polarity as the current which formed the original field, and are thus of opposite ("out-of-phase") polarity to the incoming phase of an AC signal. This out-of-phase characteristic is known as "inductive reactance", and, similarly to resistance, impedes (hence the term "impedance") the incoming flow of current.

[7] In this case, total resistance plus total inductive reactance. Impedance may also or instead include capacitive reactance as a result of capacitive discharge effects.

[8] As ever, opposite charges attract and like charges repel.

At this point the specific similarities and differences between silver and copper come into play: Both are subject to oxidation, and the surface of any conductor made of either material (unless it has somehow been preserved in an oxygen-free state since the first moment of its formation) will not be pure base metal, but instead covered by a more or less thick layer of either silver or copper oxide, depending on how long and to what degree the conductor has been exposed to air.

The crucial difference between the two metals is that copper oxide film may, depending on thickness[9], either act as an insulator or a semi-conductor, and may have a negative effect on high frequency signal transmission. Silver oxide's film, regardless of thickness, remains conductive at any frequency.

When designing for digital or video applications where megahertz-range signals pass through or along the very outside of the conductor – the oxide layer – silver is the conductor of choice for maximum performance.

Dielectrics, Energy Storage, and Capacitive Discharge Effects

Another basic engineering truth proving cables are never totally passive is that they are actually capacitors![10] That is to say all cables consist of one or more pairs of conductors ("plates" in a capacitor) separated by non-conductive material (insulation or a dielectric). When signal (current) is passed through the conductors, capacitance causes signal energy to be stored in the surrounding dielectric material that's either turned into heat or quickly released.

The amount of energy stored depends on a number of factors, the most important: 1) The total amount of signal energy available (the amplitude of the signal), 2) The physical distance separating the conductors[11], and 3) The dielectric constant(s)[12] of the conductor's insulating dielectric materials used as forming members (if any), and in the overall jacketing of the cable. More energy is stored when more energy is applied, when the conductors are closer together, and when the dielectric material has a high dielectric constant.

The amount of stored energy is important because, although it remains stored for the entire duration of one (positive or negative) half-wave of signal[13], it will not stay there

[9] Thick films of copper oxide (like a penny or bare wire that has turned green) are non-conductors (insulators), and will not pass electrical current at all. Thin films of copper oxide, on the other hand, are semi-conductors (diodes) and will allow current flow freely in one direction but resist current flow in the other.

[10] Short-term energy storage devices

[11] Capacitance and inductance are both always present in a reciprocal ("seesaw") relationship in any pair of conductors. The closer the conductors are together, the greater the capacitance and the less the inductance. As the conductors move farther apart, the opposite occurs: capacitance declines and inductance increases. The thickness of the insulation on the conductor is the most common determinant of the minimum distance between conductors and the twist (if the pair of conductors is twisted) and the outer jacket is the most common determinant of the maximum.

[12] The "dielectric constant" of any non-conductive material is the amount of energy that can be stored in one cubic volume of that material. The lower the dielectric constant, the less energy is stored, and the better the material for cable applications. The very lowest dielectric constant possible is 1.0, for a "hard" vacuum. By comparison, air has a dielectric constant of about 1.25 and the very best commercially available plastic materials have dielectric constants in the range of 2.0 to 2.3 for DuPont™ Teflon® and Teflon derivatives. PVC, a commonly used insulating and jacketing material in budget cables, has, depending on the type and amount of plasticizers used in manufacturing, a dielectric constant of anywhere from 4.5 to as much as 9.0. TPR ("thermoplastic rubber") another commonly used material for mass-market cables may have a dielectric constant as high as 14.0!

[13] A single wave of a single frequency represented as starting from a "zero line" (zero amplitude) rising in a regular sinusoidal curve to a positive peak (peak positive amplitude) declining in an identical but opposite curve back to the zero line, crossing the zero line

forever: As soon as the signal changes polarity[14] (positive to negative or *vice versa*), incoming energy acts like a switch and *dumps the entire amount of stored energy into the signal path out-of-phase with the incoming signal!*

The negative effects of this dumped-in out-of-phase energy is often (depending on the relative strength of this energy and the incoming signal energy at the moment of polarity change) signal loss from cancellations, a very noticeable reduction in low-level detail, smearing, and out-of-phase artifacts causing spurious sound or picture distortions.

This is the Capacitive Discharge Effect and Argentum Acoustics turns their long experience and cable engineering know-how to eliminating it. Every bit of insulation, every cable forming member, every outer jacket and dielectric of our cables and proprietary connectors are made from materials like Teflon and Teflon-variant fluoropolymers specifically chosen for their low dielectric constants, incorporating air[15] or other low dielectric constant materials, or both, so that as little energy is stored as possible. Ensuring that whatever energy remains is dumped with as little signal damage as possible, all dielectric materials are selected for the fastest possible *dump rate*.[16] Argentum cables feature low stored energy and fast dump rates that *always* leads to better sound and picture.

Cable Winding Geometry

The outstanding performance of Argentum Acoustics® cables is due to careful selection of the very best materials for each specific application, and from advanced design based on the latest research from our own testing and development facilities.

One of the basic concerns in designing any cable is the *winding geometry*, the way in which each of the cable's signal-bearing conductors is arrayed relative to all others. More is involved than just the simple passage of electrons: The cable's conductor winding and spacing affect both its inductance and its capacitance.[17] Capacitive reactance and inductive reactance[18], in turn, combines with resistance[19] to produce

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and continuing in another sinusoidal curve downward to a negative peak (peak negative amplitude) then rising, again along a sinusoidal curve back to the zero line, with all curves being the product of both frequency and amplitude. From zero to positive peak to zero is one half-wave. From zero to negative peak to zero is another. Both half waves constitute one entire full wave. Single-frequency, symmetrical waveforms like sine waves are not common in music. Most music waveforms are actually composites of multiple frequencies and many are highly asymmetrical, often with significantly more negative than positive or more positive than negative duration and/or amplitude.

[14] The signal is AC, Alternating Current, so it is constantly changing polarity.

[15] One important reason for the sleek-looking braided jackets on Argentum Acoustics® cables is that open-braid jacketing always has a lower dielectric constant than solid jacketing of the same material.

[16] The "dump rate" of a dielectric material is the rate at which it discharges stored energy; the faster it releases energy the better. Dump rates vary from material to material, and is often but not always proportional to the material's dielectric constant. PVC, for example, a relatively high dielectric constant material, has a very slow dump rate making it problematic. Teflon, on the other hand, with a dielectric constant only a few percentage points lower than polyethylene (another very fine dielectric material), has a dump rate many times faster. A faster dump rate is preferred because, while dumped out-of-phase energy will always be deleterious to the transmitted signal, the faster the dump occurs, the smaller and less noticeable portion of the signal waveform is affected.

[17] See Note #12, above.

[18] See Notes #7 and #8, above. Both forms of reactance arise from generated (if inductive) or stored (if capacitive) currents opposing the flow of incoming (signal) currents.

[19] The characteristic of any material opposed to current flow. If resistance is too great, current stops flowing and the material becomes an "insulator". If current *does* flow the material is a "conductor" Resistance is measured in units called "ohms" (after Georg Ohm [1789 – 1854], the first person to describe them. The two basic determinants of resistance in any conductor are the

filtering effects at audio frequencies[20], or combines with both resistance and signal frequency to produce *characteristic impedance*[21], which, for very high (digital or video) frequencies, or for very long lengths of cable, can be of crucial importance. Even resistance, just by itself, is a serious concern and can, in speaker cables, have a significant effect on *damping factor* – the ability of an amplifier to control driver motion in a loudspeaker.[22]

There is also the simple fact that cables are *always* made from insulated wire! That means there is always (at least one) *electromagnetic* field forming around the conductors as current flows through the cable[23], and there is always (at least one) *electrostatic* field forming on and around the cable's insulation.[24] The interaction of a cable's electromagnetic and electrostatic fields is strongly affected by the cable's winding geometry, and has a significant effect on signal flow. Argentum Acoustics recognizes the existence and importance of both of these fields, and maintaining the optimum relationship between them is a vital part of every one of our designs.

Speaker Cables

Central to designing good speaker cables is that they must be capable of carrying very high current – sometimes as much as 50 amps or more on peak music passages when driven by the very best amplifiers.[25]

To manage this without resistive losses turning a portion of the signal energy into heat[26] requires either a large diameter cable or one composed of an array of smaller conductors.[27]

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conductor's material and its construction factor – the thickness, with thicker conductors (which might include multiple thin strands) offering less resistance, with the better and thicker conductors offering the least resistance for any given length.

[20] Resistance plus capacitance produces a "high pass" filter that cuts bass frequencies. Inductance plus resistance makes a "low pass" filter passing bass and cutting highs.

[21] The "characteristic impedance" of a circuit is the impedance that, if terminated with that value will cause a uniform transmission line to appear infinitely long. A uniform line terminated in its characteristic impedance will produce no standing waves, no reflections from the receiving end, and a constant ratio of voltage-to-current at a given frequency at every point on the line. Mismatched characteristic impedances produce standing waves and reflections, which can affect digital or video signals, or, if the transmission line is very long (telephone lines), can even affect audio signal transmission.

[22] Achieving low resistance to maintain a high damping factor without corresponding "skin effect phase shift" is one important function of winding geometry in speaker cables. See Note #30, below.

[23] Electromagnetic fields are formed and controlled only by current flow alone. Voltage potential has no effect and, even in the presence of high voltage, no electromagnetic field will form without an actual current flow.

[24] Electrostatic fields are formed and controlled only by voltage. As long as voltage is present, there is no need for current flow for an electrostatic field to form.

[25] One of the greatest differences between inexpensive amplifiers or receivers and the very best of the breed lies in how they make their claimed power. Amplifier output is rated in watts and a watt can – at least as offered for sale by some amplifier manufacturers – be almost anything. Choosing an amplifier can be confusing: The textbooks define one watt as "…an amount of current flow (amperage or "amps") at an amount of electrical pressure (voltage "volts") such that the total product of their measured units equals 1.0." One watt could therefore be 1 amp at 1 volt or 10 amps at 0.1 volts or .001 amps at 1000 volts or any other combination of voltage and amperage that would come to the same total. In practice, most types of loudspeakers (other than electrostatics) are dependent on current flow instead of voltage for their operation, but high levels of current are much more expensive to produce than high levels of voltage. Amplifier manufacturers know this and some take advantage by offering cheap amplifiers with impressive but meaningless output specifications. At a rated output of, just for example, 300W per channel, produced as 0.1 amp at 3000 volts, a low-priced receiver could make impressive claims of power and still lack any real performance. The best amplifiers, on the other hand, typically offer, in addition to other advantages, genuine high-current power, and that same 300 Watts of output could be produced as steady-state performance of 50 amps at just 6 volts, with more current available to meet peak demand.

Another prime reason to design for low resistance (and thus *effective* large diameter) in a speaker cable is the need to maintain the amplifier's *damping factor*[28] as high as possible, ensuring against uncontrolled speaker driver movement.

The thicker the cable's conductors, the lower the resistance, but the greater the "skin effect phase shift"[29] that interferes with accurate signal transmission. There are a number of ways in which this apparent paradox can be resolved. Argentum's unique solution uses a composite approach with multiple primary conductors of varying diameters formed into arrays of secondary conductors arranged in an alternating pattern over a single large diameter core. This multiple-shielded "best of both worlds" solution reduces both self- and mutual inductance, allowing very low effective resistance, and providing perfect time alignment for signal information.

AC Power Cords

Although most people now recognize the need for using high performance interconnects and speaker cables, AC power cords still remain controversial for some. To understand why power cords are of great importance, let us take a *backwards* look at how the components in a typical home entertainment system are powered.

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[26] The 24 AWG "speaker cable" sold by mid-fi dealers and hardware stores has actually been known to glow red and melt its insulation under high current loads!

[27] Consider the size of "jumper" cables used for the high current/low voltage (12 volt) task of starting a car.

[28] The damping factor of an amplifier is an expression of its ability to control the movement of a loudspeaker. All loudspeaker drivers have mass, and the greater the mass and the greater the movement of the cone in a moving-coil driver, the greater the inertia that must overcome in accelerating and decelerating to follow the audio signal from the amplifier. Because the biggest (most massive) drivers in a speaker system are its woofers, and because bass signals require the most cone movement to produce, it is to accurate bass reproduction that amplifier damping is most important. The calculation of amplifier damping factor (as typically stated on amplifier specification sheets) is very simple: It is just 8 ohms, the nominal "standard" loudspeaker impedance, divided by the output impedance of the amplifier. As an example, an amplifier with an output impedance of 0.01 ohm would be said to have a damping factor of 800 (8 divided by 0.01 = 800), which is very good but not exceptional for solid-state amplifiers. In reality the calculation method just given overlooks two very important facts: First, not all (or, presently, even most) loudspeakers have a nominal impedance of 8 ohms; and second, and even more importantly, *no true calculation of amplifier damping factor can be done without consideration of the speaker cable.*

There are actually three elements involved in powering a loudspeaker: The speaker itself, the speaker cable, and the amplifier. All of these must be considered in calculating true amplifier damping factor. Just to make things even more interesting, the three elements act as if they were just two, and, surprisingly, the two are not what you might think: Instead of the loudspeaker and the cable being one element, and the amplifier being the other, in reality it is the loudspeaker that stands alone, and the combination of the speaker cable and the amplifier that comprises the other element. This means that, for purposes of calculating amplifier damping, *the figure that must be used as the effective amplifier output impedance is <u>the sum</u> of the output impedance of the amplifier <u>plus</u> the resistance of the speaker cable.*

To understand how this affects the amplifier's true damping factor, and thereby the sound of the system, consider this: The resistance of a 10 foot run of a typically cheap 24-gauge "speaker cable" is about 0.51 ohms. Adding this to the 0.01 ohm output impedance of the amplifier mentioned earlier, we come up with an effective output impedance of 0.52 ohms. Dividing this into the "standard" speaker impedance of 8 ohms, we get a true damping factor of only 15.4, instead of the 800 shown on the specification sheet. Making matters even worse, if the speaker's true nominal impedance is 4 ohms instead of the "standard" 8, the true damping factor is reduced even more to just 7.7! (4 divided by 0.52 = 7.7) And that is why using cheap and badly-made speaker cable results in flabby and uncontrolled bass...because it *is* uncontrolled! By contrast, a 10-foot run of XLO Ultra 6, which is a 10-plus gauge cable, has a total resistance (both legs) of just 0.02 ohms. This, plus the amplifier's output impedance of 0.01 ohm is only 0.03 ohms, which, divided into the 8 ohm standard speaker impedance gives a true damping factor of 267 – better than 17 times the speaker control available from the lesser cable!

[29] A type of signal distortion where an "AC resistivity gradient" caused by inductive reactance causes different frequencies to pass through the same conductor at different levels and different speeds. Higher frequencies travel on or near the outer surface of the conductor, hence the term "skin effect". All Argentum Acoustics® cables are time aligned to eliminate phase shift distortion.

Let us begin with a stereo amplifier as the last electronic component sending AC current to the speakers. The driving current comes from the output devices of the amplifier and, other than being at much higher power, must be as nearly identical as possible to the original source material.[30]

The output devices (transistors if solid-state) pull their power (the energy used to drive the speaker drivers) from a set of large Direct Current (DC) energy storage power capacitors.[31]

As signal energy is transferred to the speakers from the output transistors, it draws down the storage capacitors *in the exact amount of the outgoing signal energy.* The capacitor drawdown must be identical in amplitude and waveform to the energy transferred to the speakers.

As this occurs the storage capacitors try to maintain full charge by drawing energy (normally 12 or 24 volt DC) from the power supply rectifier(s)[32] The rectifiers, in turn, draw 12 volt AC (converted to DC) from the power transformer[33], and the power transformer draws current through the AC power cord from the wall, with, because amplifiers are "zero sum" devices, the demand at the wall being *identical in both amplitude and waveform* to the signal transferred to the speakers.

That is the case with every device in the system: The output signal of a device, no matter what it may be, ultimately comes from the wall and must be identical in every respect to the device's output, and *must travel through the power cord!*

Seen in this light it is more obvious that AC power cords are fully as important as any other cable *because ultimately they must carry the same signal!*

That is why in amplifiers, receivers, CD or DVD players, flat panel HD monitors, video projectors, and other high performance audio, digital and video equipment, premium power cords make such a clear and obvious difference. Whether for their ability to carry massive levels of current (amplifiers or subwoofers), or to duplicate the megahertz-range waveform of digital or video devices, or for *any* of a dozen other important reasons, quality power cords – especially those from Argentum Acoustics! – are crucial to ultimate system performance.

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[30] It must be, in short, an exceedingly complex series of waveforms to duplicate the sound (the pressure patterns created by one or more voices or instruments) of music or speech as picked up by one or more microphones and converted into electricity.

[31] A typical solid-state amplifier powers the positive and negative half-waves of the AC signal separately and combines them at the output terminals into full waveform signals. To provide separate amplification, two different sets of output transistors (one positive and one negative) are used, each drawing DC current of the correct polarity from its own set of positive or negative storage capacitors.

[32] A rectifier is a device for converting AC to DC. Normally a rectifier will be a network of diodes (devices that will pass current in one direction [of one polarity] and not the other) arranged to separate the AC waveform into its positive and negative components. DC current from the rectifier(s) is then fed to storage capacitors of the same (+ or -) polarity.

[33] A transformer is a device that converts AC current of one Voltage/Amperage to AC current of a different Voltage/Amperage, always keeping wattage the same. In the case of a power transformer, it will (in the United States) convert 120 volt AC "wall" current to 12 or 24 volt (typically) AC to be converted by the rectifiers for use by the following circuitry. If the piece of equipment draws, for example, 100 Watts of total power, 0.8333 amps of current will be drawn out of the wall at 120 volts (0.8333 amps x 120 volts = 100 watts) and converted to 8.333 amps of current at 12 volts. (8.333 amps x 12 volts = 100 watts)

The Argentum Acoustics® Proteus-12™ AC power cord is designed around a genuinely advanced technology protected under U.S. Patent No. 5,110,999. It is a counter-spiral wound, multi-gauge, multi-core design with 6N UP-OCC copper and UL approved low-dielectric constant insulation and jacketing. They are double shielded and double grounded for noise-free operation, and terminated with Furutech™ Alpha Pure Copper™ AC plugs and IEC connectors featuring Argentum's own proprietary precision-machined metal shells. A twelve-gauge (AWG) version is available for the best life has to offer.

Premium Connectors for Every Application

Argentum Acoustics cables are manufactured with the very best materials, processes and dielectrics available, hand terminated with beautifully engineered, industrial designed connectors and an elegant black jacket. Audio interconnects feature RCA, XLR or BNC connectors; RCA and BNC connectors for video.

The connectors are non-magnetic and of minimal conducting mass, ensuring low self-inductance and feature direct 24K gold-plated contacts. Speaker cables are terminated with interchangeable 8.0mm billet-cut spade lugs made from CDA alloy 101 (99.994% pure) copper and all are direct gold plated, with no intervening layer of nickel to spoil the sound. You can also choose quality Deltron-style banana plugs. All Argentum Acoustics® cables are cryogenically treated during the manufacturing process.

About Ultralink/XLO Products Inc.

Ultralink/XLO Products, Inc., headquartered in Ontario, California is an industry-leading manufacturer of high-performance audio and video cables and UltraPower™ AC power products, Canada's market share leader in the field. In early 2002 Ultralink Products, Inc. acquired XLO Electric Co., Inc. – a well-known brand of audiophile reference cables and interconnects. Ultralink also introduced the elegant "Engineering Truth" Argentum Acoustics™ line of cables and accessories. Ultralink is a member of PARA, CEDIA and the CEA. For more information on Ultralink/XLO and their product brands call (909) 947-6960 or find them at **www.ultralinkproducts.com** or learn more about XLO at **www.xloelectric.com**.

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