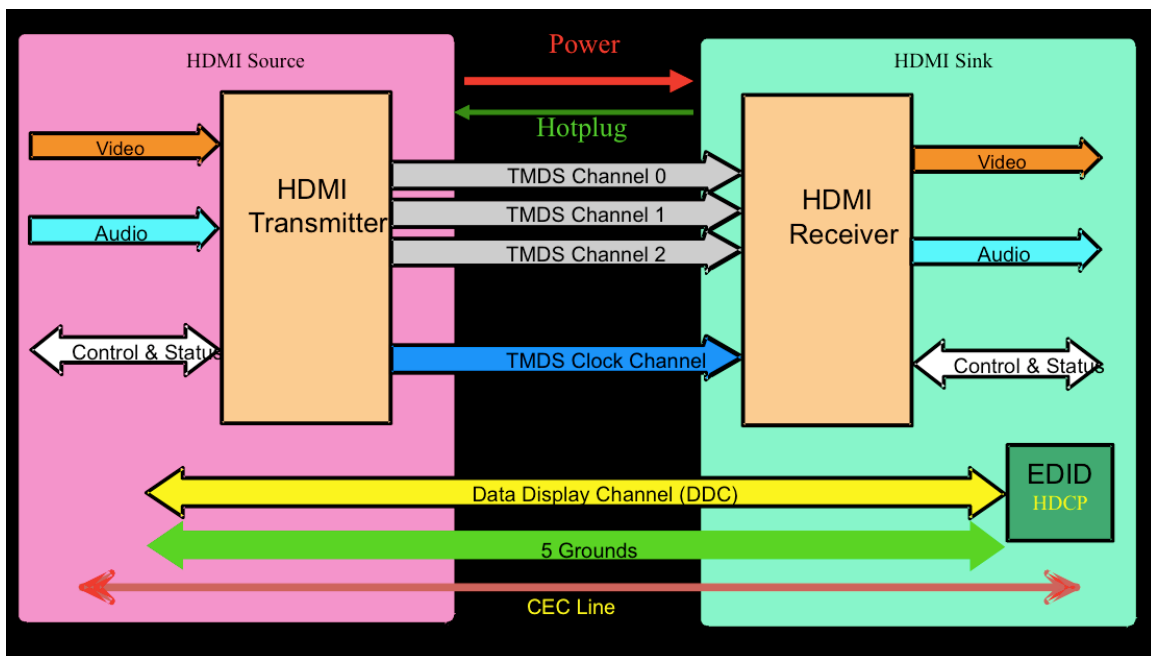


Pushing the 4K/UHD Digital Envelope 18Gbps and Beyond

Overview

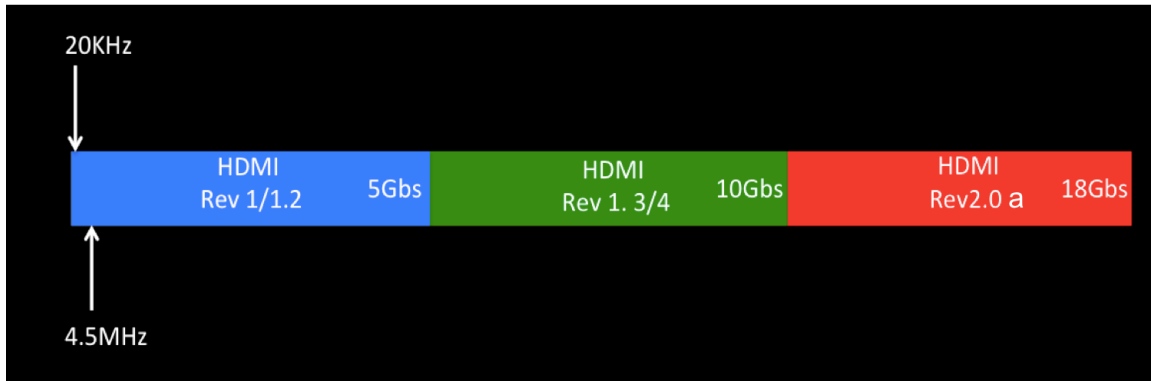
HDMI high speed digital signaling has been supplying both audio and video to the consumer electronics industry for over 10 years. Since its introduction in 2002 a substantial increase in performance has been introduced by way of technological advancements and upgrades both in electronics (silicon) and the transmission line itself. From its inception, a common revision management practice was implemented beginning with HDMI Rev 1.0. to document any changes taking place from its original design and deployment. Most of these advancements were specific to the frequency bandwidth and not the supporting attributes typically found inside an HDMI transmission line. The below diagram depicts each attribute for reference.



This paper will focus on just the low impedance HDMI High Speed Digital Signaling channels D0, D1, and D2, using TMDS (Transition Minimized Differential Signaling). By utilizing a true differential balance line topology, both bandwidth and signal to noise is optimized to carry all the audio and video throughout the system. This is where most of the advancements took place since HDMI Rev 1.0.

The illustration below shows each Revision, their features and time lines associated with each Revision.

Noticeably the bandwidth has almost quadrupled since HDMI was first released in order to support the additional features that consumer demand expressed. As this bandwidth increased so did the requirement for higher performance transmission lines.



Even during the early days of HDMI, the bandwidth requirements were astronomical when compared to the mere 20KHz for audio and 4.5MHz for video that we had been accustomed to for so many years.

Our signals now operate in the RF (Radio Frequency) portion of the frequency spectrum. The rules have changed substantially and every single cable manufacturer has had to adapt to a transmission line that very few had little understanding of, let alone designing and manufacturing it.

The flood gates opened with countless claims from companies that could only mimic what their off shore partners were professing as specifications. There was little, if any, research and development, engineering and manufacturing being implemented in the USA. HDMI brought in a completely new transmission method and because very few US companies had the resources to do anything about it, it was typically contracted out to off shore firms, which made things even worse because of poor Quality Assurance and specifications.

Now, over 10 years later, HDMI Rev2.0a reaches out even further to support 4K UHD, major audio improvements, and improved aspect ratios, which force the bandwidth to just about quadruple in size while many in the industry are still playing the guessing game of design with off shore manufactures.

Nordost Brings it Home

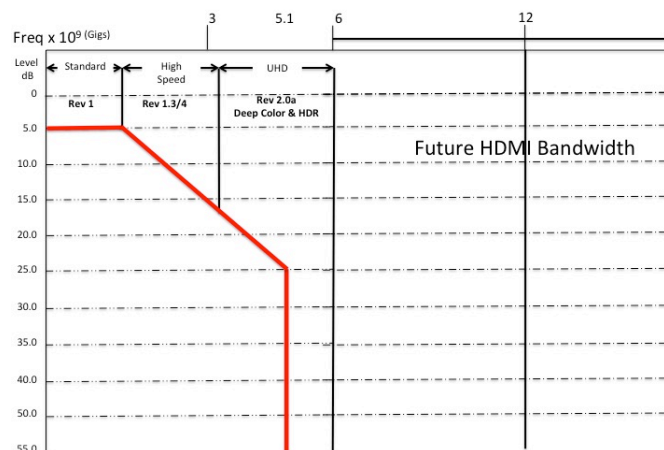
For the first time in HDMI history, Nordost broke the overseas barrier and started to build HDMI cables in the USA both in engineering and manufacturing. Based in Massachusetts, Nordost has the ability to design each function of the HDMI interface, manufacture the entire assembly and has the capability to test each product's performance by way of sophisticated test and measurement equipment.

Back to Science and Basic Principles

There is a huge assortment of raw materials that can be used to construct an RF transmission line. Whether it be balanced or unbalanced in makeup, there are some basic fundamentals that are generally followed when designing any cable or transmission line. The first and most important one is to determine what the cable is intended for and the stated specifications needed to support its function. In HDMI's case, the specification is tight and extends the operating frequency response much further than we had ever practiced in our ancient low bandwidth analog days. The rules of engagement increased 100 fold; there is no room for any invented claims or misleading narratives when offering these types of products. Let's cut to the chase and run through the major requirements and define each purpose.

Bandwidth

This defines the fundamental characteristics of the frequency response required to support HDMI data transported through any transmission line. There is a certain amount of insertion loss that occurs over the cable as the frequency or cable length increases. This can be improved by increasing the gauge of the cable, changing the material used in the cable, changing the topology of the individual components of cable or all of the above. The chart below defines the HDMI frequency response and required cable insertion loss limits from revision Rev 1 and



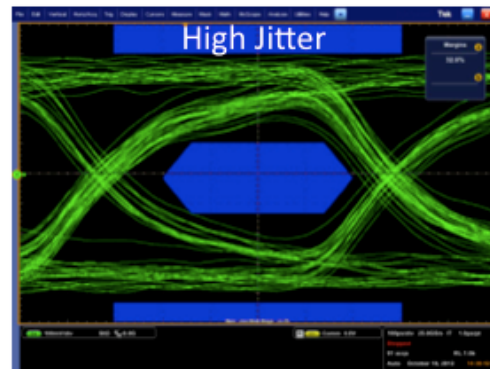
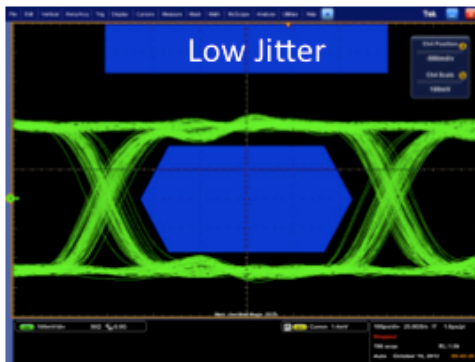
extends out to the most recent Rev.2.0a bandwidth of 6GHz.

There are two types of HDMI cables, Category 1 (Standard Speed) and Category 2 (High Speed). However many believe there should be a third Category for Rev 2.0 since the CEA has now labeled these new features as UHD. The interface has long surpassed standard speed, so we will focus our attention on just the high-speed cable specification including UHD.

The red line denotes the roll off limits that HDMI expects over any transmission line. This is called the cables “Sufficient Condition”. This roll off is then matched with an internal correction equalizer (blue line) in the destination component of the cable. In most cases this is an input to an amplifier or input to a television display. This equalization is used to correct for high frequency losses. What this means is that as long as the signal losses do not drop **below** the red line of the roll off curve the internal equalization, which is specific to HDMI Rev 2.0, should be able to recover the signal.

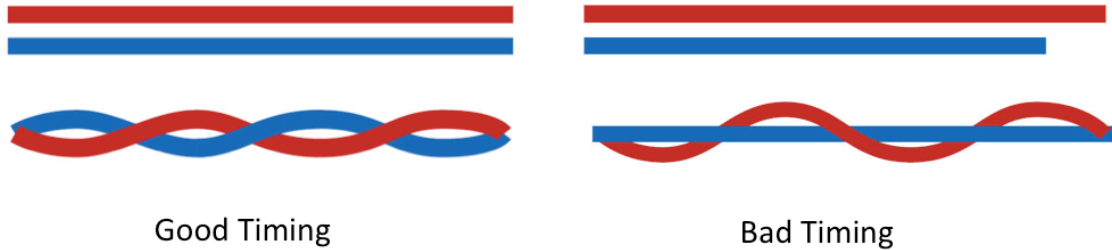
Rev 2.0 has introduced additional 4K feature sets with increased frame rates and Deep Color. These feature sets operate at different bandwidths.

It also should be understood that just recovering the signal is only half the work necessary to transport perfect HDMI data packets. We still have to contend with the notorious jitter normally found in any high-speed digital transmission line. Below find two waveforms called Eye Patterns. Assuming the signal losses make it over the attenuation limits shown earlier, the Eye Pattern’s waveform becomes a mechanism to inspect the signal’s integrity for jitter, noise, and distortions. The left hand waveform below shows a well-uniformed Eye with no noise but the right hand waveform depicts a far greater amount of jitter and noise.



Timing

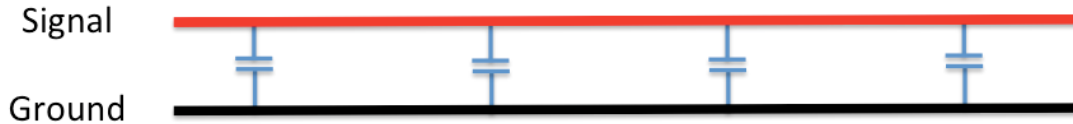
Due to the incredible high-speed operation of HDMI, timing is crucial when it comes to signal integrity. There are three video channels denoted as D0, D1, and D2. All three use a balanced line topology, which requires two signal carrying wires and a ground. These wires have to be as close to the same length as possible otherwise the data packets will lose their symmetry and errors will take place. The specification for this is in the Pico-seconds range. That is expressed as 10^{12} or .000 000 000 001 seconds. Pretty small, so the cable has to be perfectly cut and soldered to achieve this level of accuracy.



The illustration above offers a good example for this timing requirement. The key to any good timing is to have the wires as close to the same length as possible. It becomes somewhat obvious that a twisted wire pair configuration can induce more timing errors than a non-twisted wire pair or twin-axe design.

Capacitive Loading

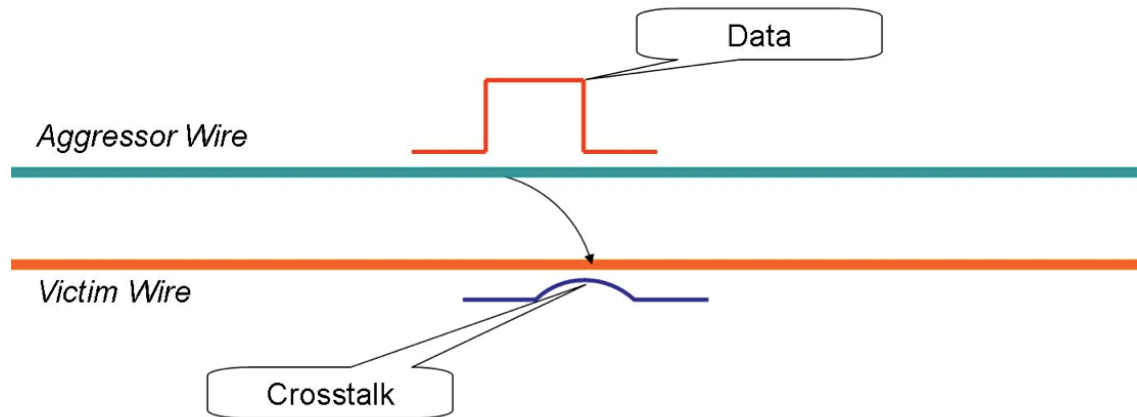
The effects due to capacitive loading can be found in almost any type of transmission line made from the beginning of time. This phenomenon takes place when high frequency AC signals gets close to a ground. High frequency signals tend to gravitate toward ground by way of capacitive loading, reducing the signals amplitude inevitably causing data bit errors.



This signal attenuation becomes more threatened as the frequency increases. Using a higher-grade dielectric insulator can minimize signal attenuation. The better the dielectric the less capacitive loading.

Cross-Talk

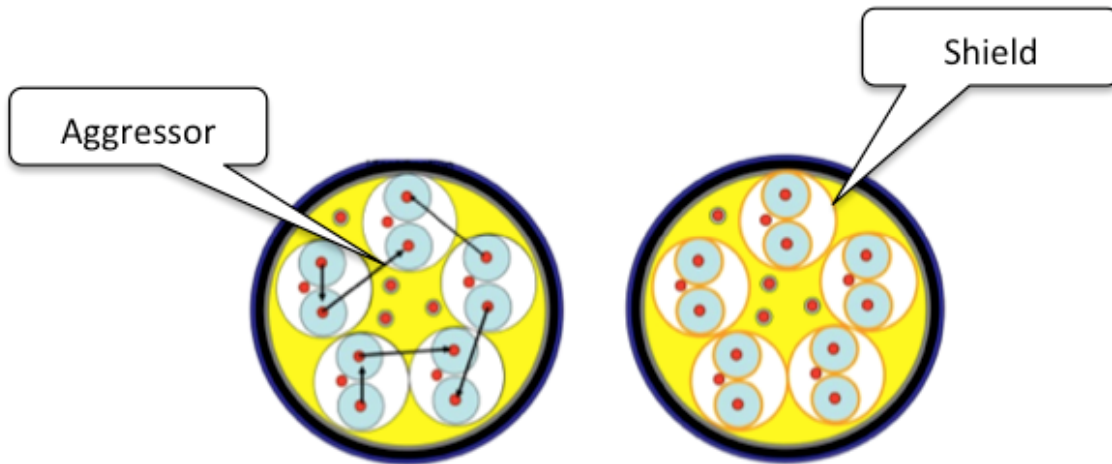
Crosstalk is nothing more than a form of interference between two channels over some conductive medium. Crosstalk is a form of electrical coupling between a fundamental channel and an affected channel. It also can be induced in reverse. There are a wide variety of techniques used to reduce this effect such as Frequency Channeling Deviation, Code Structure, polarization, segregation, and even purposely-shifting signals in time.



Segregation seems to be the biggest offender when it comes to HDMI crosstalk issues. If a pair of wires are bundled with other pairs of wires transporting different signals, the close proximity of these conductors can induce crosstalk on the other wires by emitting electromagnetic radiation to any or possibly all of the other modulated channels. This particular type of radiation is linear in response and has little to do with actual signal amplitude. From the illustration, you can see that the signal data on the “Aggressor” wire inductively “leaks” onto the “Victim” wire. The longer the wire, the better the odds are that the crosstalk will get worse. This interference is frequency dependent and generally is worse at the upper extremities of the spectrum. Crosstalk also may induce *Timing Jitter*, a definite evil to HDMI signaling. The timing should be rock solid and never vary so it does not influence the relationship between the clock and data signaling.

There are several methods to reduce crosstalk. Using the twisted pair topology shown earlier has been the predominant rule when it comes to reducing crosstalk. However, as we mentioned earlier, twisted pairs will allow for each wire's length to be longer and less accurate in time thus inducing a timing problem. Using a twin-axe design reduces wire length issues but may cause more crosstalk. A well-defined balance must be designed and configured within each cable.

Shielding is yet another way to reduce crosstalk. It is like putting a steel wall between the two conductors. If the high-frequency data pairs are not shielded, the

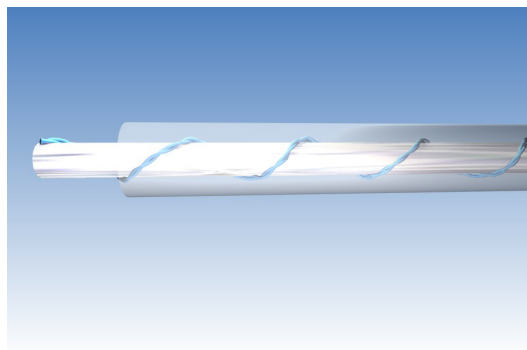


aggressor, shown with black arrows, can leak its signal onto each victim. However, with a shield wrapped around each set of wires, shown in orange, the crosstalk is greatly minimized.

Nordost's Micro Mono-Filament

Nordost combats all of these losses by employing a "**Micro Mono-Filament**" dielectric alternative. This technique allows wire to increase its VP (Velocity Propagation) as much as 20%. The Mono-Filament is an extruded fluoropolymer string-type material, helically wound around each signal wire at a predetermined pitch.

Its purpose is to produce a space around the wire that allows air to be part of the dielectric. To insure the best VP, two filaments are first twisted together. Then the twisted mono-filament pair is helically wound around a silver-plated solid core



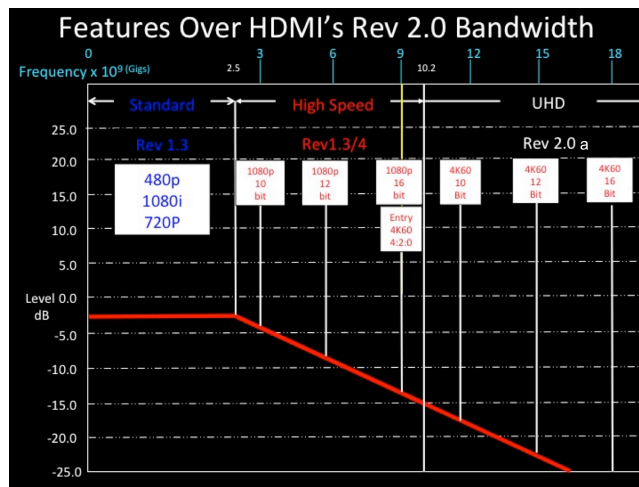
center conductor. Silver is used to compensate for electrical current losses due to skin effect associated with any wire conductor.

The term “Skin Effect” is used to describe the natural tendency of higher frequencies to move more to the outer circumference of conductor rather than the inside. Since silver is a better conductor than copper, Nordost plates each conductor with silver to increase the conductor’s current flow at the ultra high frequency used to carry HDMI TMDS data.

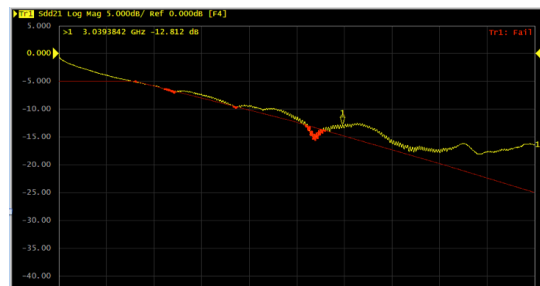
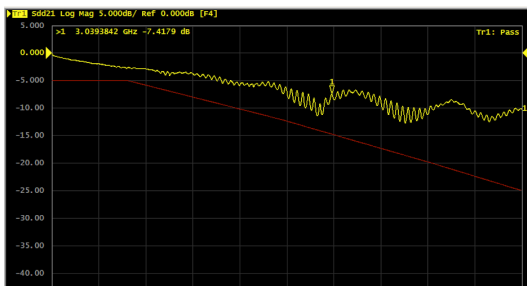
Nordost chose to use a twin-axe topology over twisted pair to reduce the wire length by as much as 10%. In addition, twin-ax construction increases wire length accuracy to minimize errors. An effective shield wraps each pair to overcome any crosstalk issues.

Summary “The Acid Test”

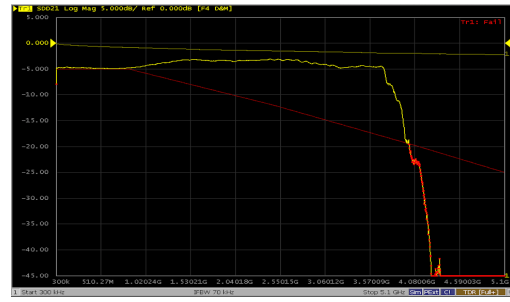
As mentioned earlier, an increase in features will proportionately increase bandwidth. The illustration below details where these new Rev 2.0 features are positioned within the bandwidth requirements. Notice that the first entry feature of Rev 2.0’s 4K features are positioned under 10.2GHz. This area is in fact still part of the older HDMI Rev 1.4 specification. However in order to achieve the full advantage of 4K Deep Color, HDR (*High Dynamic Range*) and audio advancements it requires the data to be transmitted beyond 10.2GHz ending at 18GHz. This is the most crucial area that must be supported. Unless the signal has enough integrity over 10.2GHz, the user will not be able to operate at these higher performance levels.



By running comparisons between multitudes of HDMI cable products one can recognize the huge differences between low and high performance products. Below are two response curves, a one-meter cable and a 5-meter cable respectively.

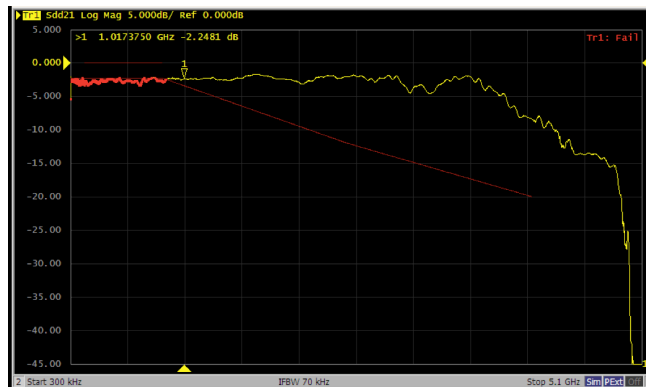


Noticeably, there is a definite loss in the higher frequency response with the 5-meter. This is typical with most HDMI cables. Over the course of the last few years more and more companies are gravitating to active cables to achieve these longer distances. However, these products were design limited to Rev 1.4, only half the bandwidth required for HDMI Rev 2.0. Below are two more waveforms taken using active HDMI cables. The one on the right uses the same electronics as the one on the left, but with a better wire design allowing for better bandwidth. But still, it rolls off



at about 2GHz. Nordost breaks the 5-meter bearer by using a newly designed set of electronics to extend the bandwidth of these products way beyond the HDMI bandwidth window. Below is an example of a Nordost Heimdall 2 8 meter 4K UHD cable. The electronics are custom programmed for each cable, allowing for longer lengths with a better response curve than the 5 meter passive cable seen earlier.

Nordost's approach for high performance 4K UHD cables will allow users to



have the power to expand for future bandwidths with their 4K system for years to come. It's these engineering breakthroughs that will drive the market for increase performance.