Cabling to Support 4K UHD HDBaseT Applications

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Introduction

HDBaseT™* networking technology enables HDMI signals to be transmitted over balanced twisted-pair cabling. This allows AV system designers to combine the benefits of HDBaseT and category cabling by transmitting uncompressed high-definition video, audio, Ethernet, control, USB and remote power over a single network cable, extending reach up to 100 m from the AV source to the display.

Types of Convergence

Convergence can be discussed in two ways:

Technology | **Infrastructure**

Technology convergence combines several autonomous networks onto a single network, working from the same system switch and backbone. VoIP phones, IP surveillance cameras, lighting systems and building controls are all connecting to networks to transfer data, receive data and adjust performance in real-time.

Infrastructure convergence uses category cabling to support different applications, such as Class 2 circuits for remote signaling, audio and video, including HDBaseT.

IT and AV Standards

Because there is no convergence of standards for IT and AV networks, both must be consulted individually.

IT networking standards rely on ANSI/TIA-568-C.2 and ISO/IEC 11801 cabling standards. Both specify that general-purpose category cabling is suitable for a wide range of applications for balanced twisted-pair copper cabling and fiber optic cabling.

The HDBaseT Alliance created its own standard for the transmission of uncompressed high-definition video, audio, Ethernet, control, USB and remote power; it is different than the IEEE 802.3 network standard that transmits Ethernet and power. Currently, the HDBaseT Alliance intends its Spec 2.0 to become a publicly available IEEE 1191 standard. This standard is now in working draft form and is not considered a standard at this time.

*HDBaseT is a trademark of HDBaseT Alliance.

White Paper Goals

Within HDBaseT Spec 2.0, the cabling system calls for category cabling. This white paper takes a closer look at HDBaseT transmission requirements and confirms whether category cabling is adequate for error-free transmission – or if a better option is possible.

“Error-free transmission” refers to the transfer quality of the cabling system; it can be defined in many ways. For the purpose of having a measurable definition of transfer quality, the “gold standard” for HDMI testing criteria is used here as the definition. This gold standard has passing criteria of no more than one pixel error per billion pixels received.

HDBaseT Signals

The highest resolution supported by the latest release of HDBaseT Spec 2.0 is 4K Ultra-High-Definition (UHD) and 4K Digital Cinema Initiatives (DCI). Each has a unique active pixel display, as shown in Table 1.

Resolution	Horizontal Pixels	Vertical Pixels
4K UHD	3840	2160
4K DCI	4096	2160

Table 1: 4K Resolutions

HDBaseT supports 4K UHD and 4K DCI with the video signal characteristics shown in Table 2.

Color Depth	Frame Rate	Chroma Subsampling	Pixel Clock	8-Bit Color Bandwidth
8 bit	30 Hz	4:4:4	297 MHz	8.91 Gbps
8 bit	60 Hz	4:2:0	297 MHz	8.91 Gbps

Table 2: Requirements for 4K Video Signals Supported by HDBaseT

Cabling Effects on Transfer Quality

Common questions often arise when it comes to cabling for HDBaseT technology and applications:

- What cable can be used to transmit 4K over HDBaseT?
- What distance can be run?
- What picture quality is acceptable?
- Do noise and/or bundling negatively impact cable performance or distance?

A digital signal is a string of bits in time. This digital signal in the time domain also has a corresponding response in the frequency domain, referred to as Power Spectral Density (PSD). PSD describes the power present in the signal as a function of frequency. The chosen cabling must have sufficient bandwidth to transmit the digital signal; cable bandwidth must be at or near the highest frequency of the PSD. Referencing the PSD of the HDBaseT signal, as given in HDBaseT Spec 2.0, a cumulative power of the HDBaseT signal as a function of frequency is shown in Figure 1.

A 10GBASE-T signal has a data rate of 10 Gbps and utilizes a PAM16 modulation scheme that requires cabling with a bandwidth of 500 MHz. Comparing this to an HDBaseT signal with an 8.91 Gbps data rate, and also with PAM16, the minimum required bandwidth of the cabling is about 425 MHz. The Cumulative Power over Frequency graph (Figure 1) confirms this requirement.

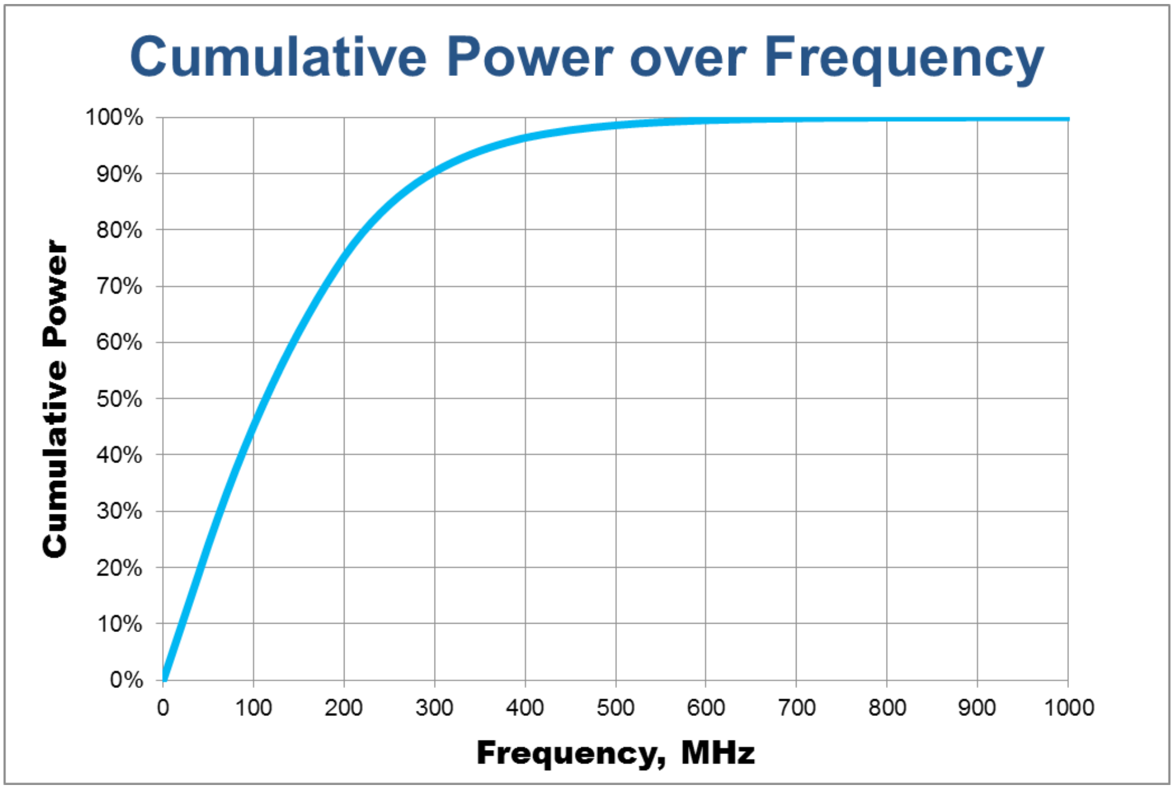

Figure 1: Cumulative Power of HDBaseT Signal vs. Frequency

Network performance (or, more specifically, cabling performance) has historically been measured in terms of information capacity. The junction of the signal power to the noise on the cabling determines cable bandwidth; information capacity is defined by the area bounded by these two curves as shown in Figure 2. A reduction in signal power, or an increase in noise, reduces bandwidth and, subsequently, information capacity.

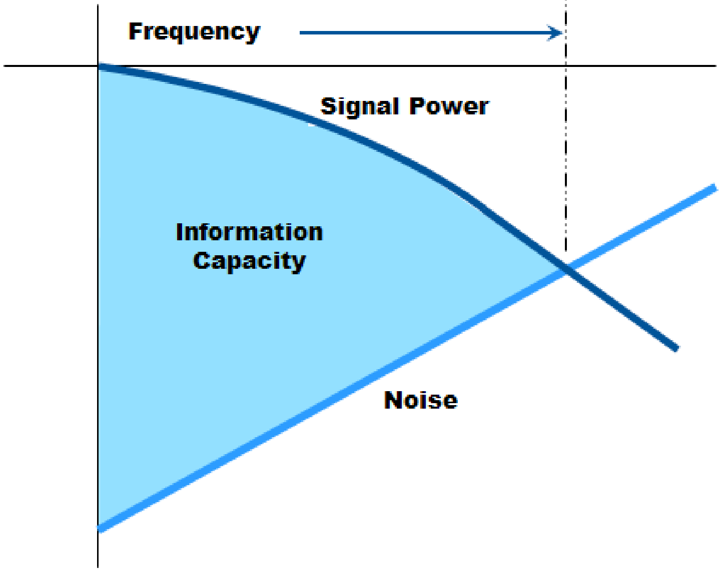

Figure 2: Cabling Bandwidth

Measuring Cable Transfer Quality

The information capacity of cabling varies from cable to cable because each has its own unique design and construction. To determine how cable performance affects the transmission of HDBaseT signals, a pixel error test was set up using an HDMI protocol analyzer in the test set-up shown in Figure 3 to evaluate the transfer quality of the HDBaseT system: the gold standard we referenced earlier.

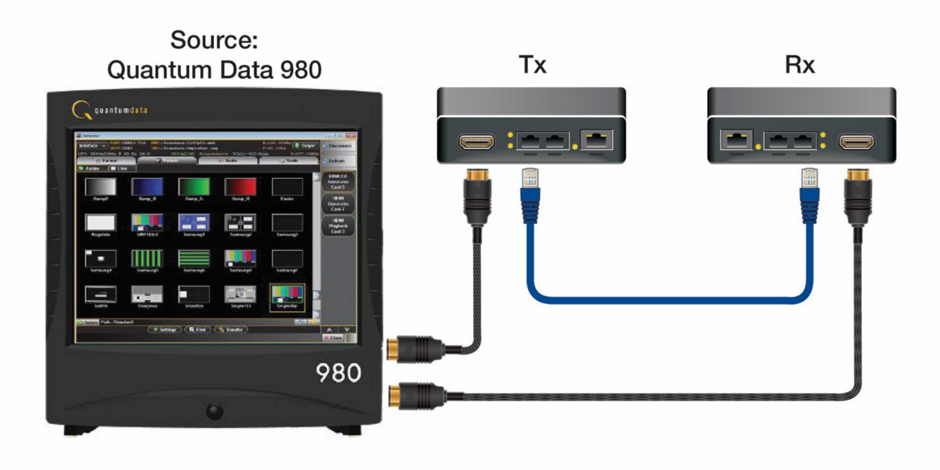

Figure 3: Transfer Quality Test Set-Up

The HDMI protocol analyzer was set to transmit HDMI 1.4 using the settings listed in Table 3.

Resolution	Aspect Ratio	Color Depth	Frame Rate	Chroma Subsampling
4K UHD	16:9	8 bit	30 Hz	4:4:4

Table 3: HDMI Protocol Analyzer Settings

Cable Type	Shield	AWG	Distance (meters)
Belden 2183	F/UTP	23	100
Category 7A	S/FTP	22	100
Category 7	S/FTP	22	100
Category 7	S/FTP	23	90
Category 6A	F/UTP	23	90
Category 6A	U/UTP	23	90
Category 6A	S/FTP	24	70
Category 6+	F/UTP	23	90
Category 5e	SF/UTP	24	90
Non-Ethernet	STP	22 (stranded)	10

Table 4: Cable Lengths Meeting the 1-Per-Billion Gold Standard

Cable Transfer Quality Results

Several different cables were measured using the test in Figure 3. All cables were assembled into 120 m direct connect links. The cable was inserted into the extenders; the resulting pixel error test was monitored on the HDMI protocol analyzer.

If the cable transmitted the HDBaseT signal, the number of errors seen in 1000 frames was recorded. This was repeated five times. To change the information capacity of the cabling, the cable was trimmed down by 10 m, a plug was reattached and the process was repeated. The results are summarized in Table 4.

Cable Transfer Quality Analysis

A few cable samples were further evaluated to determine the correlation between cable length and the number of received errors. Figure 4 is a summary of two Category 6A samples and a cable designed to optimize HDBaseT performance, labeled as Belden 2183.

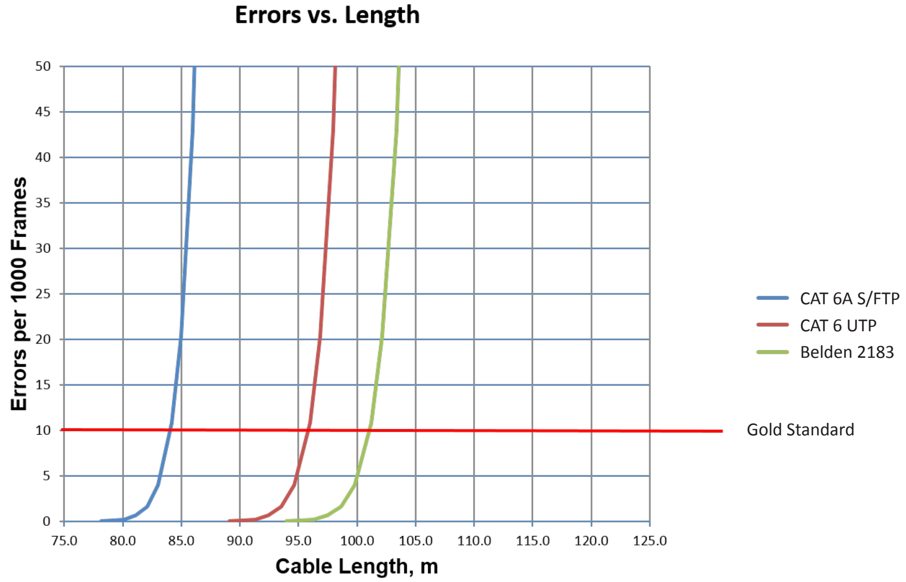

Figure 4: Insertion Loss of Some Samples

Each cable sample surpassed the gold standard at different lengths. A closer look at the cable parameters at the gold standard limit revealed that measured insertion losses were equivalent. The correlation of errors to insertion loss (or cabling length) is logarithmic; a small change increased error dramatically, until signal was lost altogether.

Because insertion loss and pixel errors are the same for these samples, a linear regression comparing the transfer coefficient to the number of pixel errors was performed. Transfer coefficient is the linear voltage used to calculate insertion loss.

If the Significance F is not less than 0.1 (10%), there exists no meaningful correlation. The result of the linear regression given in Table 5 showed that insertion loss was the most significant factor in predicting the number of errors.

Cable Characteristics	Significance F
Insertion Loss (IL)	0.08
Near-End Crosstalk (NEXT)	0.18
Return Loss (RL)	0.22

Table 5: Linear Regression Results

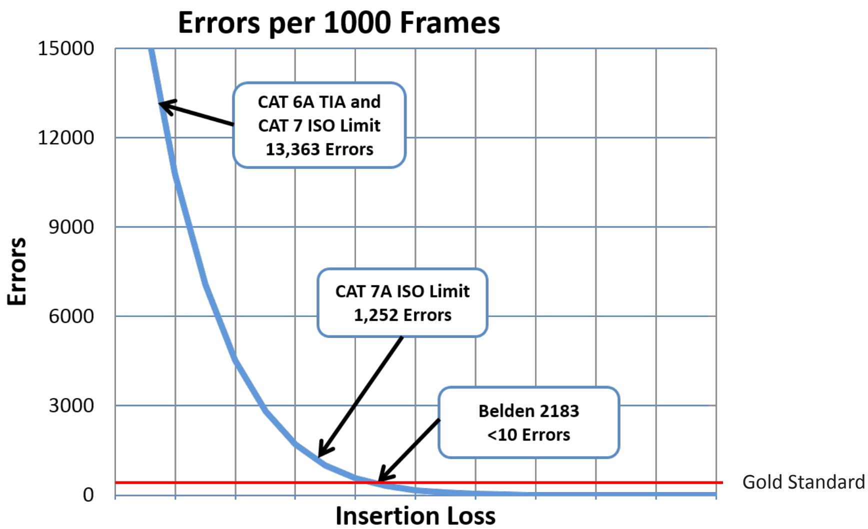

Figure 5: Number of Errors vs. Insertion Loss of 100 m Cable

Using a derived linear regression formula, a relationship of the insertion loss for 100 m of cable can be used to predict cable transfer quality. This relationship is shown in Figure 5. The insertion limit for category cabling, along with Belden 2183 cabling designed to optimize HDBaseT transmission, is noted on the graph. Note that cabling meeting the minimum requirements of ANSI/TIA Category 6A and ISO Category 7 and 7A is not sufficient to meet the gold standard of transfer quality.

External Effects on Transfer Quality

The ability of a cable to transmit data can be diminished by an increase in noise. Noise is any unwanted signal that is unable to be predicted and removed by the digital signal processors in the HDBaseT extenders. In cabling, a common source of this noise is a data signal from an adjacent cable or cables interfering with the data signal on another data cable. This type of noise is referred to as “alien crosstalk,” and is measured by bundling the cables as shown in the cross-sectional view in Figure 6.

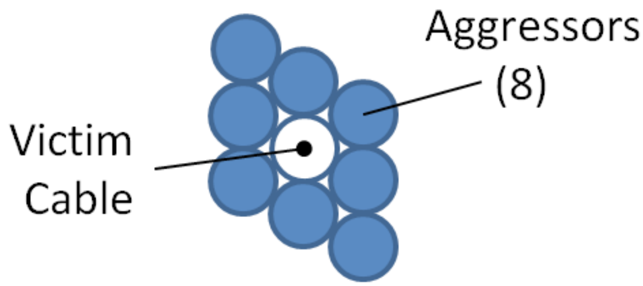

Figure 6: Cross Section of Cable Bundle Used to Measure Alien Crosstalk

This same bundle can determine how external noise affects the transfer quality of a cable. Using the set-up shown in Figure 7, a source signal from the quantumdata 980B platform is fed into a matrix switcher. The switch splits the signal nine ways, each to an installed HDBaseT extender card. The HDBaseT 4K signal travels on all nine cable channels simultaneously. The data on the victim channel, in the middle of the eight aggressor channels, is fed back to the quantumdata 980B platform to evaluate the number of errors received in the presence of adjacent aggressor channels.

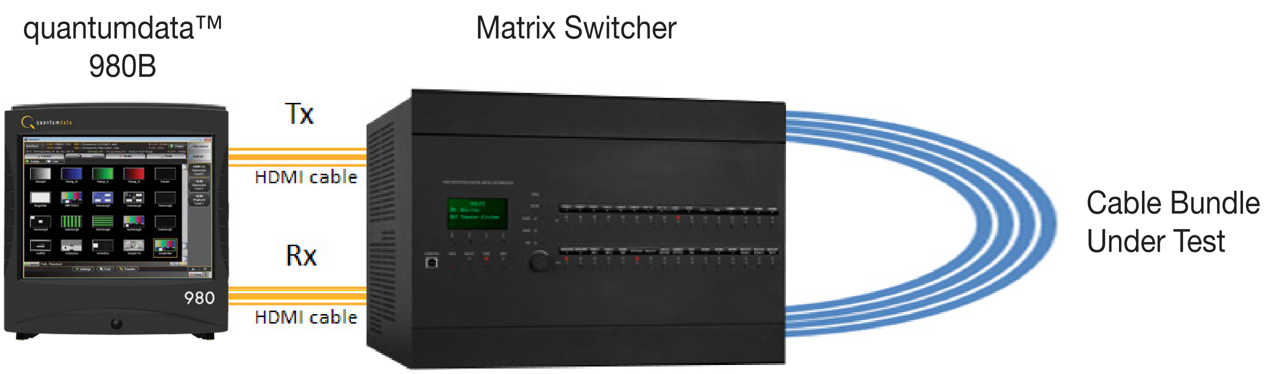

Figure 7: Test Set-Up to Measure External Noise Effects on Transfer Quality

To quantify the effect of external noise on a cable with HDBaseT 4K data, a comparative study was done on cables of varying category and construction. A single cable was measured to ensure transfer quality to the gold standard. Then, the single cable was surrounded by eight cables of the same type and length, also with the same HDBaseT 4K data. Table 6 summarizes the results.

Belden Cable	Cable Length	Effect of Bundling
Belden 2183 Cable F/UTP (single)	100 m	None
Belden 2183 Cable F/UTP (bundle)	100 m	
Category 6 F/UTP (single)	90 m	None
Category 6 F/UTP (bundle)	90 m	
Category 6A UTP (single)	90 m	None
Category 6A UTP (bundle)	90 m	
Category 5e UTP (single)	80 m	Length Reduced
Category 5e UTP (bundle)	unknown	

Table 6: Effect of External Noise on Transfer Quality

Cables that were shielded (F/UTP) were not affected by the cable bundling for any category of cable. Unshielded (UTP) Category 6A cable also was not affected by cable bundling. Unshielded cabling of a less-than-6A category cable was affected by the data in the aggressor cables in the bundle.

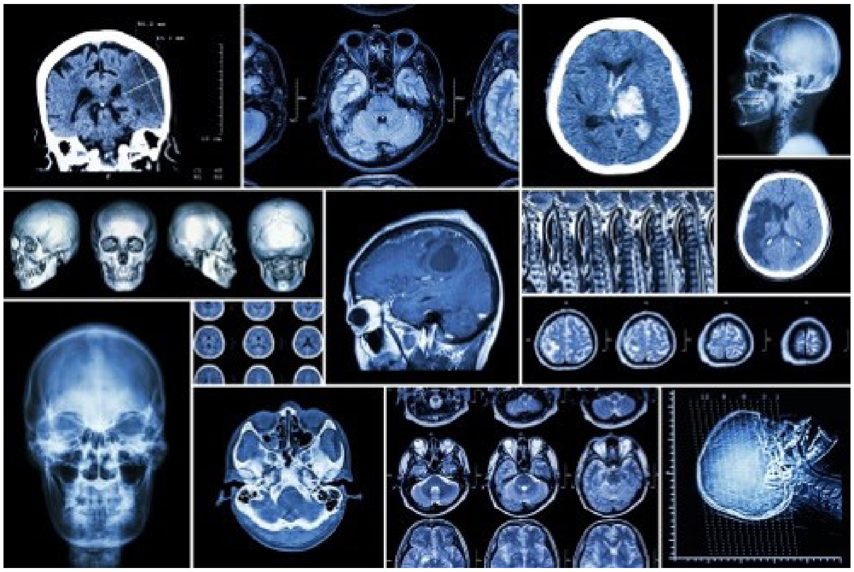

Figure 8: HDBaseT 4K Medical Image Display Meeting the Gold Standard

Visual Errors

Looking at visual errors (some call this "visual losslessness") is not sufficient because it is subjective and not repeatable or measurable. Factors, such as distance from the monitor, size of the monitor and randomness of errors, all impact what the human eye can see. What may appear to be "good" may actually display several thousand errors.

Because 4K is used to deliver sensitive information, testing to one pixel error per billion ensures the best image transmission possible, thereby maximizing the investment made in the HDBaseT 4K system. For example, visual errors – no matter how small they may be perceived – have no place in medical imaging or test results, as shown in Figure 8.

Field Testing

Since minimum limits of Category 6A or Class EA, Class F (Category 7 cabling) or Class FA (Category 7A cabling) channels will not guarantee error-free HDBaseT performance, the use of field testers and passing category limits may not be sufficient.

Replicating lab testing with the quantumdata 980B platform is not practical in the field. Recent releases of testers specific to HDBaseT are available, but they are company specific – validity of these testers is still undetermined.

New limits for HDBaseT channels need to be developed for field testers; correlation of testers specific for HDBaseT to a lab standard need to be established. Until this occurs, validity of field testing will need to be coordinated with cabling manufacturers.

Extender Variation

Extenders with Class A and Class C chipsets exist in the market, with Class C chipsets offering extended reach, among other advances. Our testing showed that extenders with the same class have a different reach using the same cabling type. This was not expected since these chipsets are procured primarily from the same source.

Consulting with an HDBaseT technology expert verified our observation. The use of different chipset classes is not enough to ensure maximum reach. The signal integrity of the circuit board inside is the key: the layout of the traces on the circuit board must be designed to be as lossless and noiseless as possible to maximize information capacity.

Channel Configurations

Often, HDBaseT installation is a direct connection between the source and the display; it is a good deployment strategy to maximize cabling efficiency.

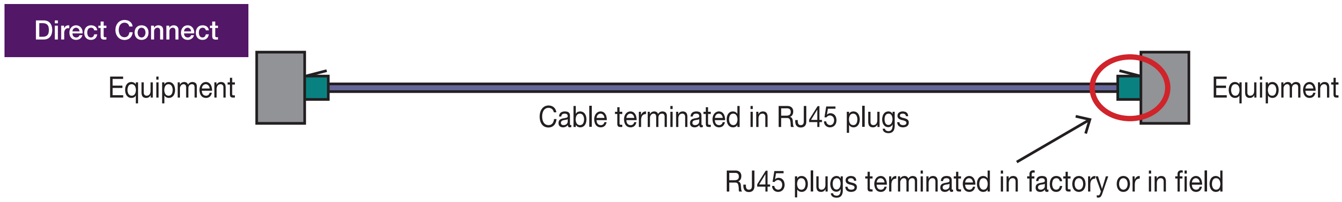

Figure 9: Direct-Connect Link

If you install a direct-connect plug in the field, it's important to select the correct plug type: crimp-on or PCB plug.

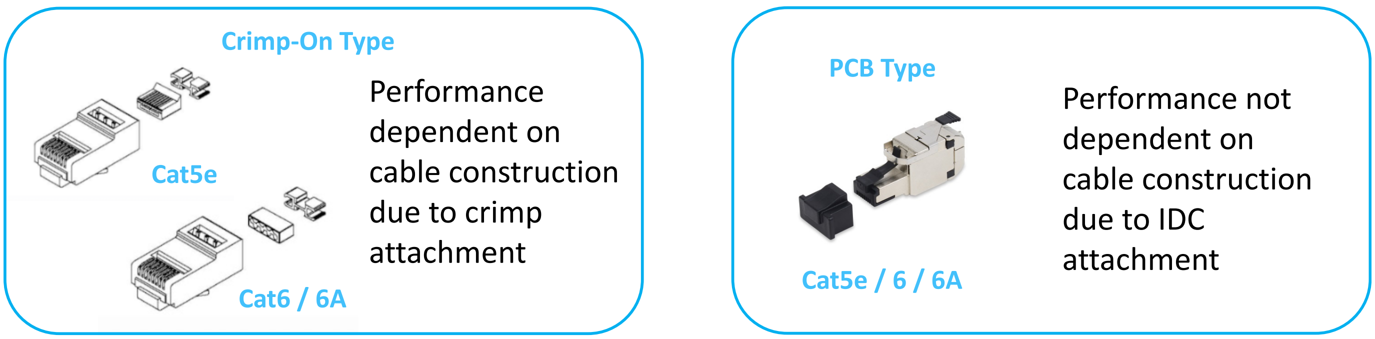

Figure 10: Plug Types

Crimp-on plugs require preciseness: cabling wires, contacts and plug components must line up correctly to achieve appropriate electrical performance. As a result, these types of plugs have more variation and a higher probability of being outside the plug range. The best way to reduce or eliminate this variation and ensure the best NEXT performance is by installing a Category 6A rated plug with PCB technology for field terminations.

If adding connectors into the channel, HDBaseT suggests the following configuration.

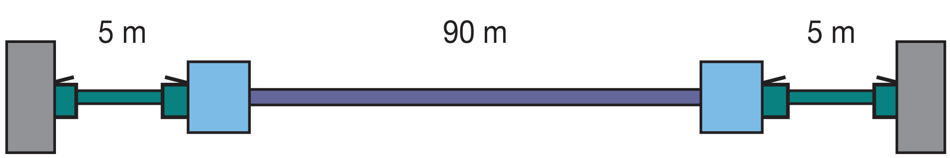

Figure 11: HDBaseT Recommended Channel

It is possible to have patch cords that are longer than 5 m, but the permanent link must be reduced to below 90 m to ensure that the channel insertion loss is sufficient to provide error-free transmission. Each connection adds potential for additional insertion loss. To maximize channel reach, patch cords must have same insertion loss (per foot) and other characteristics as the horizontal cable. If using a patch with lower electrical characteristics, such as stranded cable, horizontal length would need to be reduced even further.

Grounding of Cable Shielding (Screen)

The Authority Having Jurisdiction (AHJ) has first priority regarding the preferred method on grounding cables. In high-speed digital applications, a low-impedance connection between the shield and the equipment chassis at both ends is required so the shield can do its job.

Two conditions are necessary to ensure that shielding works at high frequencies:

1. The screen needs to be grounded at both ends.
2. The screen needs to be terminated with a low-impedance connection to ground. An impedance of 1 Ω or less is considered a low-impedance connection.

When grounding at both ends, ground loops can occur. Ground loop is a problem when a cable shield is terminated at both ends to a local ground and a remote ground. A ground potential difference between these ground points can cause stray currents to flow in the shield and couple noise into the signal conductors.

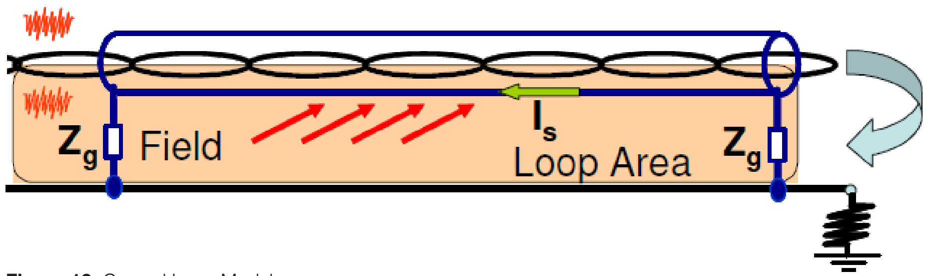

Figure 12: Ground Loop Model

To avoid ground loops, the potential difference of each grounding point must be less than 1 Vrms. Potential differences of grounding points above 1 Vrms can cause a current to flow on the outside of the cable shielding and cause interference to the HDBaseT signal. If the current is large enough, damage to the extender can occur when disconnecting the cabling. This is because the chassis ground and the digital circuitry ground in the extender are not connected.

When the potential difference between each shield termination point and earth ground is not less than 1 Vrms, or if the HDBaseT system uses an extender power supply that does not have a grounding connection, terminate the shield on the equipment end only.

Power over HDBaseT (POH)

The HDBaseT Alliance created the Power over HDBaseT (POH) standard, which can deliver power to extenders and displays within the HDBaseT system. The POH standard is based on the IEEE 802.3at power delivery standard, sometimes referred to as Power over Ethernet (PoE). POH has appropriate modifications to enable safe delivery of up to 100W over the four pairs of the Ethernet cable; it is fully backward compatible with the IEEE 802.3at-2009 PoE specification. The currently available PoE standard has a maximum power delivery of 30W, and is being updated to also deliver 100W. At this time, it is not known if POH will be backward compatible to this new PoE standard.

As power delivery increases, so does the power lost in the cable in the form of heat. A cable by itself will not experience negative effects of this added heat, but a bundle of cables delivering higher power will. A large bundle of cable may cause the innermost cable to rise high enough to reduce insertion loss to an unacceptable limit and inhibit data transmission.

The HDBaseT Alliance specifies the maximum bundle size to keep temperature rise to an acceptable limit and ensure proper performance. The latest National Electrical Code (NEC 2017) from the National Fire Protection Association (NFPA) has addressed power delivery over data cables and also limits bundle sizes for power over 60W. The NEC gives an exemption to bundle-size limits to cables with Limited Power (LP) certification.

If higher temperatures are introduced into the cable, the cable's reach is negatively impacted due to insertion loss. Heating effect is proportional to the square of the current flowing in the conductors. For example, a 50% increase in the source current results in a 125% increase in the power dissipated as heat within the cable. This is true for all cabling types, including those that are LP certified.

Conclusion

To achieve HDBaseT 4K transmission that meets the gold standard (no more than one pixel error per billion pixels received), a cable must have adequate information capacity. This information capacity is bounded by the insertion loss of the cabling and the noise external to the cabling up to a certain frequency.

The cumulative power of the HDBaseT 4K signal has very little power past 425 MHz. Testing has proven that the insertion loss required to meet the gold standard is better than the limits of Category 6A, 7 and 7A cabling. External noise must be kept to a minimum through cable design that meets alien crosstalk limits.

This white paper provides data that supports these facts. Based upon this information, using just a Category 6A, 7 or 7A cable may not be sufficient; the cable must have low enough insertion loss to transmit an HDBaseT 4K signal to the gold standard. Also proven: The higher bandwidth of Category 7 (600 MHz) and Category 7A (1000 MHz) cable does nothing to improve the transmission of HDBaseT 4K signal. Using just a category cable is not sufficient for error-free transmission; there are other factors to be considered in order to have a cable optimized for HDBaseT 4K.

As a result of this testing, Belden designed its 4K UHD Media Cable, 2183P (plenum) and 2183R (riser), to properly and reliably support 4K UHD and DCI HDBaseT applications. Bonded-Pairs are used to provide stable electricals that are resistant to the stresses of installation. With a single, durable foil shield, alien crosstalk is minimized, while making the cable easier to terminate compared to a Category 7A design. Belden 4K UHD Media cables are also up to 25% smaller than Category 7A cables, thereby improving ease of installation. They can be reliably terminated with standard, PCB-type, field-mount plugs or with Belden's REVConnect connectivity system, which reduces installation time even more and eliminates the need to separate Bonded-Pairs.

To learn more, or request a sample, visit
info.belden.com/HDBaseT